90TH CONGRESS
1st Session

SENATE

DOCUMENT
No. 19

557.78
M69
Ser.2
v.43
c.3

MINERAL AND WATER RESOURCES OF MISSOURI

REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

AND THE

MISSOURI DIVISION OF GEOLOGICAL SURVEY AND WATER RESOURCES

WITH THE COLLABORATION OF THE

UNITED STATES BUREAU OF MINES
UNITED STATES SOIL CONSERVATION SERVICE
MISSOURI STATE PARK BOARD
MISSOURI WATER RESOURCES BOARD
MISSOURI WATER POLLUTION BOARD

AND THE

UNIVERSITY OF MISSOURI

AND WITH A SUPPLEMENT ON

WATER RESOURCE DEVELOPMENT PROJECTS IN MISSOURI

BY THE

DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS

PREPARED AT THE REQUEST OF

Senator STUART SYMINGTON and Senator EDWARD V. LONG of Missouri

APRIL 6, 1967.—Ordered to be printed with illustrations

U.S. GOVERNMENT PRINTING OFFICE

77-278 O

WASHINGTON : 1967

SENATE RESOLUTION 95

Submitted by Messrs. Symington and Long of Missouri

IN THE SENATE OF THE UNITED STATES,
Agreed to April 6, 1967.

Resolved, That the report entitled "Mineral and Water Resources of Missouri", prepared by the United States Geological Survey and the Missouri Division of Geological Survey and Water Resources, in collaboration with other Federal and State agencies, and a supplement on "Water Resources Development Projects in Missouri", prepared by the Department of the Army, Corps of Engineers, shall be printed with illustrations as a Senate document.

SEC. 2. There shall be printed one thousand three hundred additional copies of such document, of which one thousand two hundred shall be for the use of the Members of the Senate from the State of Missouri and one hundred shall be for the use of the Committee on Interior and Insular Affairs.

Attest:

FRANCIS R. VALEO,
Secretary.

LETTER OF TRANSMITTAL

U.S. DEPARTMENT OF THE INTERIOR,
OFFICE OF THE SECRETARY,
Washington, D.C., March 11, 1967.

Hon. STUART SYMINGTON,
U.S. Senate, Washington, D.C.

Hon. EDWARD V. LONG,
U.S. Senate, Washington, D.C.

DEAR SENATORS SYMINGTON AND LONG: We are pleased to transmit the manuscript of a summary report, "Mineral and Water Resources of Missouri," which has been prepared in response to your joint request of June 1, 1965. The U.S. Geological Survey and the Missouri Division of Geological Survey and Water Resources have prepared the report, with contributions from a number of other State and Federal agencies.

Mineral commodities known to occur in Missouri are described in the report, together with information on their manner of occurrence, distribution, and relative importance to the present and future mineral industry of the State. The quality and quantity of surface and ground water supplies are described, and information is given on springs, water usage, and waterpower. The narrative discussions are supplemented by maps and other illustrations.

Parts of the section on water, prepared by State organizations not under the Missouri Division of Geological Survey and Water Resources and by Federal agencies not in the Department of the Interior, contain information other than on water resources. These parts are included, however, because of widespread public interest in water.

It is hoped that the report will supply the needed information and in a form that meets with your approval.

Sincerely yours,

STEWART L. UDALL,
Secretary of the Interior.

FOREWORD

This report was prepared at our request by the U.S. Geological Survey, Department of the Interior, with the cooperation of the Missouri Division of Geological Survey and Water Resources, with contributions from a number of other State and Federal agencies. In addition, the report contains a supplement on "Water Resources Development Projects in Missouri" by the Department of the Army, Corps of Engineers.

In her fields and streams, mines and forests, Missouri possesses great natural wealth and beauty. It is our hope that this material, presented here for the first time under one cover, will be of value to government, civic, and industrial leaders and other citizens interested in the proper development of the State's mineral and water resources.

STUART SYMINGTON,
U.S. Senator.
EDWARD V. LONG,
U.S. Senator.

MINERAL AND WATER RESOURCES OF MISSOURI

REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

AND THE

MISSOURI DIVISION OF GEOLOGICAL SURVEY
AND WATER RESOURCES

WITH THE COLLABORATION OF THE

UNITED STATES BUREAU OF MINES
UNITED STATES CONSERVATION SERVICE
MISSOURI STATE PARK BOARD
MISSOURI WATER RESOURCES BOARD
MISSOURI WATER POLLUTION BOARD

AND THE

UNIVERSITY OF MISSOURI

AT THE REQUEST OF

SENATOR STUART SYMINGTON AND
SENATOR EDWARD V. LONG OF MISSOURI

CONTENTS

	Page.
Introduction	11
Geology	13
Physiography	13
Precambrian rocks	15
Paleozoic rocks	16
Cretaceous and Tertiary rocks	18
Quaternary (Pleistocene) deposits	19
Structure	20
Geophysical studies	22
Magnetic	22
Gravity	23
Seismic	24
Electrical	25
Topographic and geologic mapping	26
Selected references	30
The mineral industry of Missouri	33
Selected references	39
Metallic mineral resources	41
Lead and zinc	41
Introduction	41
History and production	43
Mining districts	45
Southeastern Missouri	45
Geology	45
Ore deposits	49
Resources and outlook	55
Southwestern Missouri	56
History and production	56
Geology	58
Ore deposits	59
Resources and outlook	61
Central Missouri	61
Geology	62
Ore deposits	62
Copper	63
Cobalt and nickel	68
Silver	70
Minor metals associated with zinc-lead ores	73
Iron	74
Introduction	74
History and production	76
Ore deposits	78
Precambrian deposits	79
Filled-sink deposits	84
Brown ores	86
Outlook	87
Manganese	88
Tungsten	91
Uranium	93
Selected references	95

Page

Nonmetallic mineral resources 99
Barite 99
Clay and shale 106
Fire clay 107
Clay and shale resources for structural products 111
Bentonitic clays 116
Stoneware and pottery clays 117
Kaolin 117
Ball clay 118
Lightweight aggregate 119
Stone 125
Limestone and dolomite 126
Crushed and broken stone 134
Resources 141
Outlook 144
Dimension stone 144
Marble 147
Metallurgical limestone 149
Mineral wool 152
Sandstone 154
Dimension and broken 154
Asphaltic 155
Granite and felsite 157
Dimension 157
Roofing granules 160
Mine and mill tailing products 164
Cement and cement raw materials 172
Raw material resources 178
Limestone 178
Other raw materials 181
Lime 183
Refractory dolomite 192
Sand and gravel 196
Resources 201
Silica sand 203
Deposits 206
Sulfur 213
Pyrites 214
Sulfur in coal 217
Smelter gases 218
Phosphate 219
Tripoli 220
Gem stones 223
Selected references 229
Mineral fuel resources 235
Coal 235
Oil and gas 243
Selected references 251
Water resources 253
Introduction 253
Water resources investigations 258
Surface water 258
Introduction 258
Mississippi River main stem 260
Upper Mississippi River basin 263
Fox River basin 264
Wyaconda River basin 265
Fabius River basin 265
North River basin 265
Salt River basin 265
Cuivre River basin 265
Missouri River main stem 265

Water resources—Continued
Water resources investigations—Continued
Surface water—Continued
Page
Missouri River basin 267
Tarkio River basin 267
Nodaway River basin 268
Platte River basin 268
Blue River basin 269
Little Blue River basin 269
Grand River basin 269
Chariton River basin 270
Lamine River basin 271
Osage River basin 272
Gasconade River basin 274
Other Missouri River tributaries 275
Lower Mississippi River basin 275
Meramec River basin 275
St. Francis River basin 276
White River basin 277
Spring River basin 280
Ground water 281
Introduction 281
The Ozarks 286
Description of aquifers 287
Quality of water 291
Use of ground water 294
The saline ground-water province 295
Consolidated aquifers 295
Unconsolidated aquifers 297
Quality of water 298
Use of water 302
Province of southeast Missouri lowland and the alluvial valleys of the major streams 304
Alluvium 304
Wilcox Group 307
McNairy Formation 307
Quality of water 310
Use of water 313
Springs 313
Geographic distribution 314
Geologic distribution 315
Ebb and flow springs 315
Discharge 316
Quality of water 316
Use of springs and spring water 320
Summary 321
Summary of water use 322
Water resources for recreation 325
Caves 326
Water resources programs and projects of the Soil Conservation Service 327
Irrigation 328
Watersheds 329
River basins 330
Resource conservation and development 331
Waterpower 332
Distribution 333
State laws, policy, and programs pertaining to water and related land resources 338
Property rights in water 338
Policy 339
Programs 339
Pollution abatement 342
Selected references 345

SUPPLEMENT

	Page
Water resources development in Missouri	351
Introduction	351
Economic history of Missouri	351
Water resources development concepts	354
Agencies concerned with water resources	355
Existing and potential developments	357
Upper Mississippi River and tributaries	358
Upper Mississippi River	358
Des Moines River Basin	358
Fox River Basin	359
Wyaconda River Basin	359
Fabius River Basin	360
Bear Creek	361
Salt River Basin	361
Clarence Cannon Dam and Reservoir	362
Missouri River and tributaries	362
Missouri River	362
Missouri River stabilization and navigation project	364
Missouri River agricultural levees	365
Kansas Citys local protection project	365
New Haven local protection project	367
Gasconade River Basin	367
Osage River Basin	368
Pomme de Terre Dam and Reservoir	371
Bagnell Dam—Lake of the Ozarks	372
Kaysinger Bluff Dam and Reservoir	373
Stockton Dam and Reservoir	373
Hackleman Corner Dam and Reservoir	374
Bennett Spring State Park	374
Lamine-Blackwater River Basin	374
Chariton and Little Chariton River Basins	376
Thomas Hill Reservoir	377
Long Branch Reservoir	377
Grand River Basin	378
Pattonsburg Dam and Reservoir	379
Mercer Dam and Reservoir	379
Braymer Dam and Reservoir	379
Brookfield Dam and Reservoir	380
Trenton Dam and Reservoir	380
Other water resource developments	380
Fishing River Basin	381
East Fork and Dry Fork Reservoirs	381
Little Blue River Basin	382
Blue River Basin	383
Platte River Basin	384
Smithville Dam and Reservoir	385
Nodaway River Basin	385
Lower Mississippi River and tributaries	386
Lower Mississippi River	386
Lower Mississippi River channel improvement	386
St. Louis and vicinity local protection project	386
Perry County drainage district	386
Cape Girardeau local protection project	386
Mississippi River levees	386
New Madrid Floodway	387
Meramec River Basin	387
St. Francis River Basin	389
St. Francis River	389
Wappapello Dam and Reservoir	389
Other water resource developments	390
White River Basin	391
White River	391
Bull Shoals Dam and Reservoir	391
Table Rock Dam and Reservoir	393
Lake Taneycomo	394

Page
White River Basin—Continued
Black River 394
Clearwater Dam and Reservoir 394
Black River levee project 395
Poplar Bluff local protection project 396
Black River navigation project 396
Norfork Dam and Reservoir 397
Spring River Basin 398

ILLUSTRATIONS

Figure
1. Physiographic regions of Missouri 14
2. Geologic map of Missouri Facing 14
3. Major structural features of Missouri Facing 20
4. Major magnetic anomalies in Missouri 23
5. Aeromagnetic map coverage in Missouri 24
6. Index to topographic map coverage of Missouri at 1:250,000 (approximately 4 miles to the inch) 26
7. Areas of Missouri covered by topographic maps at 1:24,000 and 1:62,500 27
8. Areas of Missouri covered by published geologic maps at scales of 1:250,000 or larger 28
9. Areas of Missouri covered by unpublished geologic maps 29
10. Missouri mineral production through 1965 34
11. Annual value of mineral production of Missouri, 1905–65; and average value of major mineral groups; by decades, 1900–59; 1960–64, and 1965 35
12. Principal lead-zinc districts of Missouri 41
13. Percent of domestic lead and zinc production from Missouri, 1910–65 44
14. Value of lead and zinc production in Missouri, 1894–1965 45
15. Lead deposit areas and mines in southeastern Missouri 46
16. Missouri part of the Tri-State zinc-lead district 56
17. Copper, and copper-nickel-cobalt deposits of southeastern Missouri 65
18. Iron deposits of Missouri 79
19. Precambrian iron deposits of Missouri 80
20. Deposits known to have produced manganese, and silver and tungsten, in southeastern Missouri 90
21. Production and value of barite in Missouri, 1901–65 101
22. Barite-producing areas of Missouri 102
23. Barite-producing areas of the Washington County district, Missouri 105
24. Resources and utilization of clays and shales in Missouri 109
25. Missouri production and value of crushed limestone and dolomite, 1917–65 135
26. Counties in Missouri that produced crushed limestone and dolomite in 1965 136
27. Production for major uses, and total production and value of crushed and broken limestone and dolomite in Missouri, 1954–65 137
28. Consumption and value by major uses in Missouri of crushed and broken limestone and dolomite (1964) 138
29. Major carbonate rock areas in Missouri and approximate location of quarries active in 1965 141
30. Production and value of dimension limestone and dolomite in Missouri, 1920–64 145
31. Quarries in Missouri that produce dimension limestone, dolomite, and marble 146
32. Quarries in Missouri that produce dimension sandstone 156
33. Granite and felsite in Missouri 158
34. Production and value of dimension granite in Missouri, 1935–65 159
35. Principal centers of mine and mill tailings accumulations in Missouri, exclusive of coal mine and washer plant refuse 165
36. Use of mine and mill tailings in Missouri, 1915–65 169
37. Production and value of cement from Missouri plants, 1903–65 173
38. Portland cement shipments from Missouri plants by types of customers, 1965 174
39. Principal areas of limestone suitable for cement manufacture and location of cement plants in Missouri 175

Figure Page
40. Missouri production and value of quick and hydrated lime, 1900–65 184
41. Distribution of limestone suitable for the manufacture of lime and location of lime plants in Missouri 190
42. Generalized outcrop areas of dolomite in Missouri and location of refractory dolomite plant 194
43. Production and value of sand and gravel in Missouri, 1905–65 197
44. Missouri counties with reported sand and gravel production in 1965 198
45. Sand and gravel consumption in Missouri by use, 1965 199
46. Silica sand production in Missouri, 1930–65 207
47. Silica deposits in Missouri 208
48. Pyrites production in Missouri, 1900–65 215
49. General distribution of tripoli deposits in the southwestern Missouri area 223
50. Gem and mineral occurrences in Missouri 225
51. Distribution of the principal coal-bearing strata and coal fields of Missouri 235
52. Coal production in Missouri, 1840–1965 237
53. Stratigraphy of the principal coal-bearing rocks of Missouri 238
54. Oil and gas fields of Missouri 245
55. Stratigraphy of the Pennsylvanian oil- and gas-bearing rocks of Missouri 247
56. Areas of interest for potential production of oil and gas 249
57. Average annual runoff, in inches 254
58. Average annual precipitation, in inches 257
59. Annual discharge of the Gasconade River at Jerome, Mo. (Ozark region) 259
60. Annual discharge of the Grand River near Gallatin, Mo. (glaciated area) 260
61. Average discharge of the principal rivers 261
62. Representative ranges in hardness and dissolved solids in surface water 262
63a. Typical yield of wells in principal aquifers in the three ground water provinces 282
63b. Ground water provinces 283
64. Quality of ground water in the Paleozoic aquifers 284
65. Distribution of well logs per county 285
66. Specific capacities of typical wells in the Ozarks 287
67. Lithofacies map of the Gunter Sandstone member in southern Missouri 290
68. Map showing contours on the Precambrian surface in northern Missouri 296
69. Preglacial drainage pattern of northern Missouri 297
70. Isopachous map of clean sands in the glacial drift and alluvium in northern Missouri 298
71. Graphs relating depth to changes in chemical quality of ground water in Paleozoic aquifers in northern Missouri 299
72. Classification of ground water from glacial drift, the Wilcox Group, and the McNairy Formation for irrigation purposes 303
73. Isopachous map of the alluvial fill in the Southeast Lowland, Missouri 305
74. Water-table map for the alluvium in the Southeast Lowland, Missouri, October 1965 306
75. Contour map of the base of the Wilcox Group in southeastern Missouri 308
76. Contour map of the base of the McNairy Formation in southeastern Missouri 309
77. Springs of Missouri with average discharge more than 1 cubic foot per second (646,000 gallons per day) 318
78. Distribution of irrigated acreage in Missouri, 1965 324
79. Status of Public Law 566 watershed projects in Missouri, January 1, 1966 331
80. Waterpower sites in Missouri 335
81. Civil works projects of the U.S. Army, Corps of Engineers and other water-resource developments in Missouri, March 1966 357

TABLES

Table		Page
1.	Principal Paleozoic stratigraphic units in Missouri	Facing 16
2.	Upper Cretaceous and Tertiary rocks of southeastern Missouri	18
3.	Pleistocene deposits of Missouri	19
4.	Mine production of lead and zinc in 1965, from leading countries of the world, in short tons	42
5.	Production and value of lead and zinc mined in southeast Missouri	50
6.	Copper production in Missouri, 1838–1965	64
7.	Annual production and value of silver in Missouri, 1905–65	71
8.	Production and value of iron in Missouri, 1815–1925	77
9.	Production and value of iron ore in Missouri, by major geologic type, 1815–1965	78
10.	Estimated production and approximate value of ore and concentrates containing more than 35 percent manganese, 1872–1965	88
11.	Stratigraphy of the Washington County barite district	103
12.	Clay and shale production in Missouri, 1946–65	109
13.	Companies producing brick and tile in Missouri	113
14.	Clays and shales in Missouri suitable for lightweight aggregate	122
15.	Principal carbonate rock units in Missouri	127
16.	Summary of dimension limestone quarrying in Missouri	147
17.	Production and value of dimension and crushed marble sold or used by producers in Missouri during representative years from 1920–64	148
18.	Summary of marble quarrying in Missouri	149
19.	Specifications of limestone for use as a flux by the principal types of consuming plants	151
20.	Sales of fluxing limestone in the United States	152
21.	Roofing granules sold or used in the United States, 1959–63	163
22.	Main characteristics and uses of mine and mill tailings now being exploited in Missouri	166
23.	Characteristics and potential uses for some major mine, mill, and furnace wastes in Missouri	170
24.	Salient features of cement plants in Missouri	176
25.	Salient features of high-calcium lime plants in Missouri	186
26.	Uses of lime	189
27.	Specifications of dolomite raw material for refractory uses	193
28.	Chemical character of the major Cambrian and Ordovician dolomite formations in Missouri	195
29.	Particle size classification	200
30.	Specifications for silica sand by uses	205
31.	Current producers of silica sand from the St. Peter Sandstone in Missouri	210
32.	Favorable quarry locations in the St. Peter Sandstone in Missouri	212
33.	Representative analyses of tripoli and so-called "soft" silica from various areas in the United States	221
34.	Estimated production and value of tripoli mined and (or) processed in Missouri for selected years	222
35.	Estimated original coal resources of Missouri	243
36.	Production of oil and gas from Missouri	246
37.	Source and significance of dissolved mineral constituents and properties of water	255
38.	Chemical analyses of water from wells in Paleozoic aquifers in the Ozarks of central and southern Missouri	293
39.	Chemical analyses of water from Paleozoic aquifers and the glacial drift in northern Missouri	300
40.	Chemical analyses of water from wells in the McNairy Formation, Wilcox Group, and the alluvium in the Southeast Lowland, and the alluvial fill of the major streams	311
41.	Discharges of large springs in Missouri	317
42.	Yields of representative springs used by the fish-rearing industry of Missouri	321
43.	Developed and undeveloped waterpower in Missouri December 31 1965	334
44.	Developed waterpower sites in Missouri	335
45.	Undeveloped waterpower sites in Missouri	336

MINERAL AND WATER RESOURCES OF MISSOURI

INTRODUCTION

(By P. W. Guild, U.S. Geological Survey, Washington, D.C.)

The minerals and water of an area are fundamental to its economy and the well-being of its people; their resources must be appraised carefully to guide decisions that will affect their availability when needed. Furthermore, the increasing population and rising standards of living will impose ever more stringent demands upon the minerals and water of the world, requiring that a larger and larger share be either utilized immediately or identified and preserved safely for future generations.

This report summarizes our present knowledge of the mineral and water resources of Missouri. It has been prepared by more than two dozen individuals employed by various Federal and State agencies having responsibility for different segments of the natural resource fields discussed. The authors, their organizations, and headquarters are identified at appropriate places in the text.

In assembling the material, the authors have drawn on the best available sources, both published or in the files of their respective organizations, and, in some cases, upon the results of their own investigations. Treatment of the individual subjects is necessarily brief, but much additional information can be obtained by interested readers from the publications cited in the selected references. Sources of statistical data, whether presented in tabular or graphic form, are usually cited; if not otherwise identified, they are from the Minerals Yearbooks or other publications, including advance summaries, of the U.S. Bureau of Mines. However, particular acknowledgment is due Robert H. Arndt and his coworkers of the U.S. Bureau of Mines Mineral Resource office, Area IV, Bartlesville, Okla., for assembling and summarizing data on the mineral production of the State.

Geologic factors are responsible for the occurrence of mineral deposits and control their distribution; they also strongly influence the availability and especially the quality of water. The physiographic, stratigraphic, and structural features of Missouri are therefore described as an introduction to the more detailed discussion of individual commodities and water resources that follow. As topographic and geologic maps provide the basic data on which our knowledge rests, and geophysical methods afford powerful tools to extend it to the subsurface; the status of these studies are discussed and shown by appropriate maps.

An endeavor has been made to restrict the use of specialized terms (of which geology has very many, as do other areas of science and technology) that would not be familiar to the average reader. Some

77-278 O—67——2

are, however, unavoidable. Where differences exist between the usage of the U.S. Geological Survey and the Missouri Geological Survey and Water Resources, as, for example, in the form of words designating geologic time or rock series, the Missouri pattern has been followed.

A summary is given of Missouri's mineral industry—its history, size, composition, and the geologic and geographic distribution of the metals, nonmetallic minerals, and mineral fuels known to occur in economic or potentially economic quantities. Within the major commodity groups the order of discussion is basically by geologic association and importance; thus lead and zinc are described together and first, followed by copper and other metals associated with lead and zinc or occurring in the same general geologic environment. The space devoted to each is roughly proportional to its importance to Missouri.

The surface and ground water resources are described. In contrast to minerals, which are a "one-crop" resource that once extracted cannot be mined again, water is renewable; nevertheless constant monitoring of the quantity available and detailed studies of its quality are of the utmost importance. Data are presented on both these resource aspects of water, and measures taken to develop water resources for municipal and industrial use, irrigation, power, and recreation, and to protect them from pollution, are discussed. Major engineering projects undertaken or planned for flood control, navigation, or other purposes on the streams of Missouri are described in a special supplement.

The U.S. Geological Survey had the principal responsibility for preparation of the report. Many of the sections were written, however, by William C. Hayes, State Geologist and Director of the Missouri Division of Geological Survey and Water Resources and members of his staff. Douglas R. Stark, Chief Illustrator for the Missouri Survey, drafted many of the maps and charts. Anthony Homyk, Jr., of the Water Resources Division of the U.S. Geological Survey, arranged for contributions to and coordinated the sections on water resources and development, in addition to authoring part of it himself. The U.S. Soil Conservation Service and the Corps of Engineers, Department of the Army, furnished material on their respective activities in Missouri and related subjects. Members of the Missouri State Park Board, Water Resources Board, Water Pollution Board, and University of Missouri contributed to the report. P. W. Guild, U.S. Geological Survey, was general coordinator.

GEOLOGY

PHYSIOGRAPHY

(By Jerry D. Vineyard, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Missouri, bounded on the east by the Mississippi and bisected by the Missouri River, has a more varied geologic and physiographic character than might be expected from its position near the center of the country, far from the mountainous areas of the East and West. Rocks ranging in age from Precambrian to Recent are exposed; they include volcanic and intrusive rocks, marine and continental sedimentary rocks, glacial deposits, and windblown soils. The physiography reflects Missouri's geologic history through a remarkably long period and has, to a greater extent than in many areas, influenced the localization of its mineral resources. For example, hills that existed at least half a billion years ago still dominate the landscape in the St. Francois Mountains, though they were covered for much of the intervening time, and sink structures that may have formed more than 100 million years ago are widespread over much of the central part of the State. The former are, in some way, associated with large deposits of lead and other metals; many of the latter contain deposits of iron oxides and sulfides, clay, barite, coal, or other useful minerals. The search for still-buried hills and covered sink structures has been a principal method of prospecting in Missouri.

Maps of the physiography (fig. 1), geology (fig. 2), and structure (fig. 3) all show an imperfect but marked concentric pattern that is the result of intermittent, long-continued mild uplift of the Ozark region. Physiographically the Ozarks are an elongated dome that extends entirely across Missouri from the Mississippi River to northern Arkansas and northeastern Oklahoma. Remnants of a maturely dissected, rolling upland surface (the Salem Plateau) rise to altitudes of 1,500 to 1,700 feet along a south-southwest-trending divide between Iron County and Wright County. This surface is preserved largely on Cambrian and Ordovician rocks, though some rocks of later Paleozoic age remain, particularly on the north and northeast flank (fig. 2). Streams with a more or less radial drainage pattern have destroyed much of the Salem Plateau and cut valleys many hundreds of feet deep.

The St. Francois Mountains are on the "bullseye" of the domal uplift (fig. 3). Rugged hills of Precambrian volcanic rocks rise above the Salem Plateau to a maximum altitude of 1,772 feet in Taum Sauk Mountain, highest point in the State. They have been modified very little since they formed a group of steep islands in the Late Cambrian sea that were gradually covered with sediments. A few outlying hills of Precambrian rocks have also been exposed by erosion in Shannon County and elsewhere, and some still-buried ones are known from geophysical studies and drilling.

The Springfield Plateau, "that part of the Ozarks which is underlain by rocks of Mississippian age" (Fenneman, 1938, p. 652), rises slightly above the Salem Plateau along the inward-facing Eureka Springs Escarpment and descends gradually to the northwest. It is an area of low relief, and only a few remnants persist of the old surface, which has been variously interpreted as a structural plain (Marbut, 1896, pl. II) and a peneplain (Bretz, 1965, p. 95).

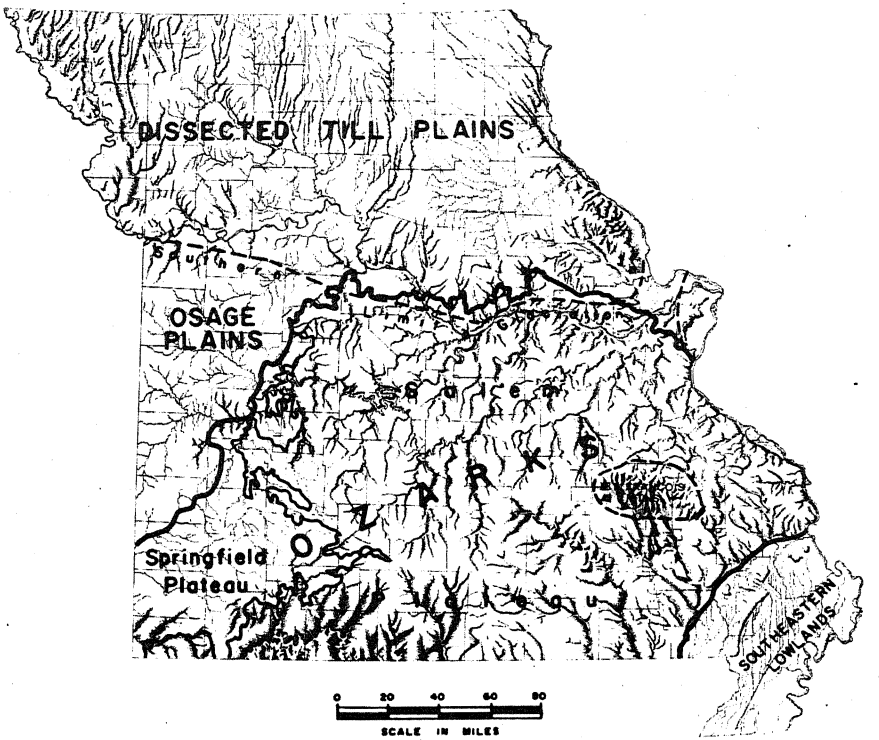
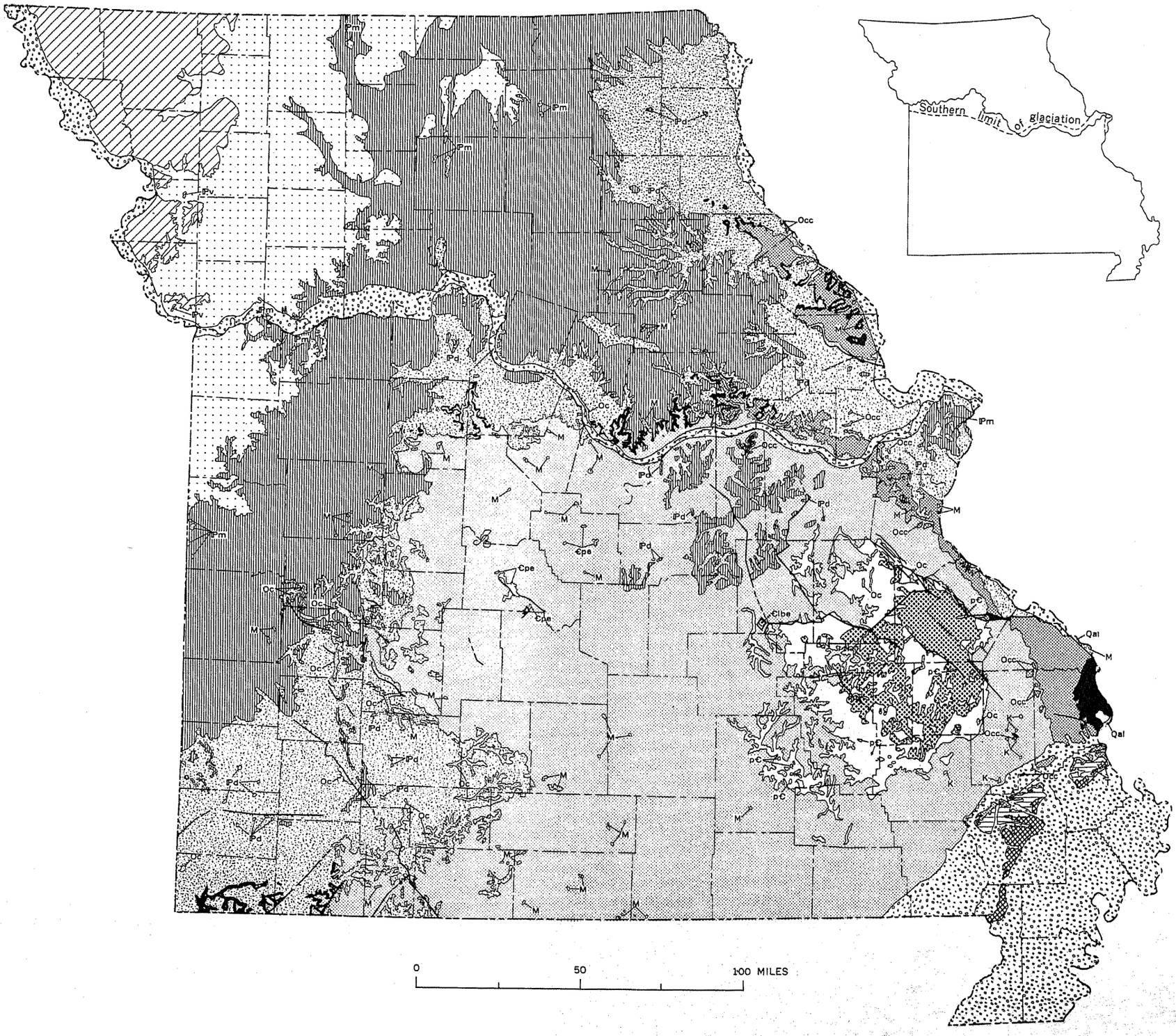


FIGURE 1.—Physiographic regions of Missouri.

The Osage Plains are rolling plains of low relief, carved on sedimentary rocks of Pennsylvanian age, that lie along the western border of the State south of the glaciated area.

Repeated glaciation in Pleistocene time (table 3, p. 19) covered the northern part of the State approximately to the Missouri River. Thick deposits of till (bouldery clay), sand, gravel, and loess (windblown silt) buried a surface of moderate relief and left a more or less featureless plain. Postglacial erosion has carved new streams, which in general have little relation to the preglacial drainage pattern, and given rise to the dissected till plains. The geologic map (fig. 2) does not show the glacial deposits, but actually the older rocks are exposed only in a few places where the till has been eroded away.

The southeastern lowlands of Missouri are part of the Mississippi lowlands, or embayment, and consist largely of alluvial deposits in the flood plain of the river. Paleozoic, Cretaceous, and Tertiary rocks are exposed in Crowley's Ridge, a line of low hills that rise above the flood



EXPLANATION

CENOZOIC

Qal — QUATERNARY — Alluvium only. See inset map for extent of glacial deposits

T — TERTIARY — Paleocene, Eocene, and Pliocene(?) Series; clay, sand, and gravel

MESOZOIC

K — CRETACEOUS — Late Cretaceous (Gulfian) Series; sand and clay

PALEOZOIC

PENNSYLVANIAN

IPv — Virgilian Series — Douglas, Shawnee and Wabaunsee Groups; shale, limestone, sandstone, and minor coal. Includes a little sandstone of Permian age

IPm — Missourian Series — Pleasanton, Kansas City, Lansing, and Pedee Groups; shaly limestone and sandtone, very minor coal

IPd — Desmoinesian Series — Cherokee and Marmaton Groups; includes some strata of the Morrowan and Atokan Series; shale, sandstone, limestone, coal, and clay

M — MISSISSIPPIAN — Kinderhookian, Osagean, Meramecian, and Chesterian Series; predominantly limestone, shale, and sandstone

DS — DEVONIAN AND SILURIAN — Limestone, dolomite, chert, and shale; too thin to subdivide at map scale

ORDOVICIAN

Occ — Cincinnatian and Champlainian Series — Chiefly limestone and dolomite; St. Peter Sandstone near base and Maquoketa Shale near top

Oc — Canadian Series — Cherty dolomite with minor sandstone of the Gasconade, Roubidoux, Jefferson City, Cotter, Powell, and Smithville Formations

CAMBRIAN

Cpe — Potosi and Eminence Dolomites; the former has abundant quartz druse

Clbe — Lamotte Sandstone; Bonneterre Formation, principally dolomite; and Elvins Group, shale and argillaceous dolomite

FIGURE 2.—Geologic Map of Missouri

plain in Scott, Stoddard, and Dunklin Counties. Little River leaves Missouri at an altitude of about 230 feet, lowest point in the State.

Where the Mississippi and Missouri Rivers cut through the till plains and the edge of the Ozarks north of the embayment, their narrow flood plains consist of alluvium.

PRECAMBRIAN ROCKS

(By William C. Hayes, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Although Paleozoic sedimentary rocks cover nearly all the area of Missouri (fig. 2), rocks of Precambrian age are exposed in the St. Francois Mountains and have been encountered at depths of as much as a few thousand feet in numerous test holes drilled in search of petroleum or ore deposits. Data are insufficient to give a detailed picture of the nature and distribution of the buried rocks, but the same general types of metamorphosed sediments, gneisses, and granitic to basic igneous rocks known on the exposed parts of the Canadian Shield are present. They may also be of the same general age, that is, early to middle Precambrian.

The Precambrian rocks exposed in the St. Francois Mountains and the isolated outlying knobs are of three types: felsitic volcanic rocks ranging from rhyolite to andesite, granites and granite porphyries, and basic intrusives of gabbroic composition.

The volcanic rocks are the oldest; most were extruded as overlapping, lenticular flows or tuff sheets, undoubtedly from a number of vents, and presumably on a surface of older rocks like those encountered in drill holes elsewhere in Missouri. Some small masses have intrusive relationships to the surrounding rocks. Two groups have been distinguished, an older one characterized by high ratios of potash to soda and a younger one with more normal ratios (Tolman and Robertson, unpublished report; Robertson, 1965). Anderson (1962, p. 15–51) shows that in part of the area, at least, many ash-fall (tuff) units can be mapped. Some of the tuffs show evidence of subaqueous deposition.

Granitic rocks ranging in texture from fine grained, slightly porphyritic to coarse grained and in color from red to gray intrude the volcanic rocks (Tarr, 1932) as a number of essentially concordant masses to which various names have been assigned. A slightly older group tends to be porphyritic and to occur as discontinuous, sill-like bodies; a younger group was somewhat differentiated in place, but forms larger, more homogeneous masses. In spite of compositional variations, the granites as a whole are considered to constitute the St. Francois batholith; uniformity of their trace elements (Kisvarsanyi, 1961) confirms their relationship to a single magmatic province.

Basaltic and diabasic dikes and sills intrude both the felsites and granites; though these basic rocks are obviously postbatholithic, Robertson (1965) believes, on the basis of chemical affinities, that they, together with at least some of the younger volcanic rock and the granites, comprise a single petrogenetic unit. Radioactive dating by various techniques indicates that this igneous activity may have taken place in a period from about 1,200 to 1,450 million years ago (Allen and others, 1959; G. W. Wetherill and G. R. Tilton, personal communication, 1958).

PALEOZOIC ROCKS

(By W. B. Howe, K. H. Anderson, and Mary H. McCracken, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Sedimentary rocks were deposited in Missouri throughout much of the Paleozoic era, when relatively shallow seas repeatedly covered part and at times all of the State. Mild vertical movements modified the environment from time to time; uplift with local or regional emergence resulted in discontinuous sedimentation (pinchouts) and unconformities; downwarping favored the continuity but not necessarily the thickness of sediments. The stratigraphic section, therefore, varies considerably from place to place in both thickness and character; though in aggregate it totals about 10,000 feet, less than half this thickness is present at any one locality (Howe and Koenig, 1961, p. 13). Only very minor igneous activity took place during the Paleozoic.

The succession of stratigraphic units of the Paleozoic era in Missouri is summarized in table 1. The geologic map (fig. 2) shows the general distribution of the rocks of the major time units. Intermittent uplift and long-continued post-Paleozoic erosion brought the older rocks to the surface near the center of the Ozark Dome, with progressively younger rocks cropping out around its flanks. Though dips are everywhere fairly gentle, they are generally steeper on the east and southeast so that the outcropping bands are narrow compared with those on the west and north where regional dips are very low. (See figs. 2 and 3.)

Upper Cambrian strata lie with profound unconformity on the Precambrian surface in Missouri, as in the St. Francois Mountains, where relief was locally as much as 2,000 feet around the Precambrian knobs when Paleozoic sedimentation began. The basal unit is the Lamotte Sandstone, which is conglomeratic and arkosic where it lies on the crystalline rocks. The sandstone grades upward through a zone of arenaceous dolomite to the Bonneterre Formation, typically a dolomite in its areas of outcrop but preserved as a limestone in some places. Rocks of the Elvins Group are shales, siltstones and fine-grained sandstone, and carbonates. Dolomite predominates in the upper part of the succession, whereas the lower part is typically shaly and glauconitic. The Potosi dolomite characteristically contains quartz druse and has a bituminous odor on freshly broken surfaces. It weathers to a deep red sticky clay. The Eminence dolomite is mostly coarse-crystalline and contains relatively abundant chert. These Upper Cambrian strata are present in the State throughout the subsurface except where not deposited around the knobs or where exposed by uplift and eroded. All, and especially the lower ones, have pinchout and overlap relationships to the Precambrian.

Much of Missouri remained submerged under a shallow sea at the end of the Cambrian, and sedimentation continued either unbroken or with only minor unconformity into Early Ordovician (Canadian) time. An overall cyclic depositional pattern is evidenced by the rhythmic repetition of cherty dolomite and sandstone beds; the latter occur most prominently in the Roubidoux Formation. Distribution of the Canadian Series is essentially statewide. Deposition apparently took place on a gently tilted surface, as isopachous maps (McCracken and McCracken, 1965) show a general thickening of the formations from

TABLE 1.—*Principal Paleozoic stratigraphic units in Missouri. (Typical thicknesses or range of thicknesses are shown for selected units; regional and local sequences shown for some units of less than statewide extent)*

System	Series	Groups and (or) Formations
Permian	Wolfcampian	Indian Cave Sandstone (only one isolated exposure known)
Pennsylvanian [1]	Virgilian	Wabaunsee Group—Severy, Howard, Scranton, Bern, Auburn, Emporia, Willard, Zeandale, Pillsbury, and Stolter Formations Shawnee Group—Oread, Kanwaka, Lecompton, Tecumseh, Deer Creek, Calhoun, and Topeka Formations Douglas Group—Stranger and Lawrence Formations
	Missourian	Pedee Group—Weston and Iatan Formations Lansing Group—Plattsburg, Vilas, and Stanton Formations Kansas City Group (Zarah Subgroup)—Lane, Wyandotte, and Bonner Springs Formations Kansas City Group (Linn Subgroup)—Cherryvale, Drum, Chanute, and Iola Formations Kansas City Group (Bronson Subgroup)—Hertha, Ladore, Swope, Galesburg, and Dennis Formations Pleasanton Group—three unnamed divisions of formation rank
	Desmoinesian	Marmaton Group (Appanoose Subgroup)—Labette, Pawnee, Bandera, Altamont, Nowata, Lenapah, and Holdenville Formations Marmaton Group (Fort Scott Subgroup)—Blackjack Creek, Little Osage, and Higginsville Formations Cherokee Group (Cabaniss Subgroup)—Weir, Tebo, Scammon, Mineral, Robinson Branch, Fleming, Croweburg, Verdigris, Bevier, Lagonda, Mulky, and Excello Formations Cherokee Group (Krebs Subgroup)—Hartshorne(?), Warner, Rowe, Drywood, Bluejacket, and Seville Formations
	Atokan	McLouth, Burgner, Riverton, and Cheltenham Formations
	Morrowan	Hale Sandstone of *Barry County*
		Major Unconformity
Mississippian	Chesterian	*Southwest Counties*: *Jasper-Newton*: Carterville Formation (200′ max.) *Southwest Counties*: *Stone-Barry*: Fayetteville Formation (20′); Batesville Formation (35′–40′), Hindsville Limestone (0–50′) *Southeast Counties*: *Ste. Genevieve-Perry*: Vienna Limestone (10′–15′), Tar Springs Sandstone (90′), Glen Dean Limestone (65–80′), Hardinsburg Formation (13′–20′), Golconda Formation (100′±); Cypress Formation (30′), Paint Creek Formation (80′–100′), Yankeetown Sandstone (60′), Renault Formation (46′–90′), Aux Vases Sandstone (40′–100′)
	Meramecian (Statewide)	Ste. Genevieve Formation (85′ *SE*, 0–5′ *NE*, 50′ *NW*) St. Louis Limestone (50′–150′) Salem Formation (10′–160′ *E*) Warsaw Formation (40′–100′)
	Osagean (Statewide except as noted).	Keokuk Limestone (50′–100′) Burlington Limestone (75′–100′) Reeds Spring Formation (100′) *SW* Pierson Formation (40′) *SW* Fern Glen Formation (20′–40′) *E*
	Kinderhookian	*Southwest and West-Central*: Chouteau Group: Northview Formation (5′–80′), Sedalia Formation (0–50′), Compton Formation (10′–50′) *East-Central*: Chouteau Group undifferentiated *Northeast*: Chouteau Group undifferentiated; Hannibal Formation (0–100′)
		Bachelor Sandstone (4″–10′) (Not recognized in *Northeast*)
		Major Unconformity
Devonian	Upper [2]	*Southwest*: Chattanooga Shale; Unconformity; (Absent) *Central and East-Central*: Bushberg Sandstone, Glen Park Limestone; Unconformity; Snyder Creek Formation *Southeast*: (Absent) *Northeast*: Louisiana Formation, Saverton Formation, Grassy Creek Shale; Unconformity; (Absent) *Northwest*: "Kinderhook" Shale (undiff. Devonian and Mississippian); Unconformity; ?
	Middle	Fortune Formation Callaway Formation St. Laurent Formation, Beauvais Sandstone (80′), Grand Tower Limestone (100′–250′), Clear Creek Chert (300′) Callaway Formation "Hunton" Group
	Lower	(Absent) (Absent) Little Saline Limestone (25′–100′), Bailey Limestone (300′) (Absent)
		Major Unconformity
Silurian	Niagaran	Bainbridge Limestone (30′–160′) *SE*
	Alexandrian	Sexton Creek Limestone (10′–60′ *SE*) Edgewood Formation (10′–60′ *NE*) Girardeau Limestone (0–40′) *SE* ? Major Unconformity
Ordovician	Cincinnatian	Orchard Creek Shale (50′) *SE* Thebes Sandstone (5′–25′) *SE* Maquoketa Shale (10′–100′ *NE*) Cape Limestone (15′) *SE*
	Champlainian	Kimmswick Formation (50′–250′ *NW*) Decorah Formation (10′–40′) Plattin Formation (100′–450′ *SE*) Rock Levee Formation (5′–270′ *SE*) Joachim Dolomite (50′–175′ *SE*) Dutchtown Formation (0–170′ *SE*) St. Peter Sandstone (10′–100′+) Everton Formation (0–400′ *SE*) Major Unconformity
	Canadian	Smithville Formation (150′ *SE*) Powell Dolomite (150′–175′ *SE*) Cotter Dolomite (250′–450′ *SE*) Jefferson City Dolomite (125′–350′ *SE*) Roubidoux Formation (150′–250′ *SE*) Gasconade Dolomite (300′–700′ *SE*)
Cambrian	Croixan (Upper)	Elvins Group: Eminence Dolomite (200′–300′), Potosi Dolomite (250′–400′), {Derby-Doerun Dolomite (110′), Davis Formation (160′)}, Bonneterre Formation (0–500′+), Lamotte Sandstone (0–400′) Profound Unconformity

[1] Formations within groups and subgroups named in ascending order. Most have subdivisions of member rank.

[2] Discontinuous formations unconformably overlying strata of Ordovician to Middle Devonian age. Stratigraphic successions and general geographic locations shown, but the formations are not necessarily correlative from one area to another.

northwest to southeast. Rocks of Canadian age are at or near the surface over much of the area of the Salem Plateau (fig. 1).

A strong unconformity, the result of uplift and erosion, separates the Canadian Series from the overlying rocks. Renewed deposition in Middle (Champlainian) and Late (Cincinnatian) Ordovician time was not as widespread as that of the earlier series, in general being restricted to the northern (now covered and known only from drill records) and eastern parts of the State. Local pinchouts and unconformities are common. The Everton and St. Peter are sandstones; most of the other formations are limestones that have been dolomitized in part. Shale and thin sandstone strata occur near the top of the Ordovician sequence. A narrow outcrop belt swings around the eastern and northeastern side of the Ozark Dome from the vicinity of Cape Girardeau to eastern Callaway County, and isolated areas (too small to show in figure 2) are present westward to Pettis County. Middle and Upper Ordovician rocks are also exposed in Lincoln, Pike, and Ralls Counties along the axis of the Lincoln Fold (fig. 3).

Deposits of Silurian and Devonian age in Missouri are relatively thin, restricted in their occurrence, and separated below, above, and internally by unconformities (table 1). They are shown by a single pattern on figure 2 as it is not practicable to separate them at the map scale. Limestones and cherty limestones predominate, some of them reef deposits laid down in shallow seas around the emergent Ozark Uplift, but sandstones and shales are also present. Widespread uplift at the end of Early Devonian time, accompanied by faulting, resulted in so much erosion and bevelling of beds that the original extent of sedimentation cannot be determined, though remnants in down-dropped blocks on the Ozark uplands indicate that it was greater than that now preserved. The largest outcrop area is in Cape Girardeau and Perry Counties, where rocks of Early and Middle Silurian and Early and Middle Devonian ages provide the most nearly complete section in the State. In northeast Missouri, Lower Silurian and Middle and Upper Devonian rocks are present, though they do not occur together in the same areas. In central Missouri, the Middle and Upper Devonian rocks rest unconformably on beds as old as Early Ordovician. To the northwest in the Forest City Basin, considerable thicknesses of both Silurian and Devonian rocks are known to be present in the subsurface.

Isolated thin deposits of limestone, sandstone, and shale assigned to the Upper Devonian occur in a number of places in Missouri (table 1). Data are insufficient to establish correlations from one area to another.

During Mississippian time, widespread shallow submergence of a stable platform resulted in deposition of more or less uniform and thick limestone beds, in part very cherty, with some shale and minor sandstone. Rocks of the Osagean and Meramecian Series, from the Burlington Limestone to the St. Louis Limestone, are present over large areas of the State, though they vary considerably in thickness from place to place. The older and younger Mississippian rocks are less uniform in their lithology; the successions differ and different names are applied in various parts of the State to strata that are of about the same age (table 1). Rocks of the Mississippian are shown by a single pattern in figure 2; they crop out on the flanks of the Ozark

Dome in the Springfield Plateau, as numerous isolated outliers on the Salem Plateau, and in the northeastern counties in the area of the Lincoln Fold. They are also known from drill holes in the northwestern part of the State.

At the close of Mississippian time, the Ozark region rose again; the resultant widespread erosion stripped nearly all the Mississippian rocks from the uplift and beveled them over much of the rest of the State. In Pennsylvanian time, deposition was renewed in shallow seas and contiguous swamps and deltas. About 2,000 feet of sand, silt, clay, and carbonates were laid down, and numerous coal seams formed from luxuriant forest growth. Deposition tended to be cyclical; conditions were so uniform that thin units can be traced over wide areas. Five series, nine groups, numerous subgroups, and more than 70 formations, many subdivided into three or more members, have been distinguished.

Three of the five series of Pennsylvanian rocks are shown by separate patterns on figure 2; together they cover about a third of the State. Desmoinesian, Missourian, and Virgilian rocks form successive bands of gently northwest-dipping beds; the lower two series are also present in the vicinity of St. Louis. Remnant outliers of Pennsylvanian limestone of Desmoinesian age and filled-sink deposits of Cheltenham clay on the north flank of the Ozark Uplift show that Pennsylvanian strata originally covered a greater area.

The Permian is represented in Missouri by the Indian Cave Sandstone of Early Permian age. It is known to be present only at a single locality in Atchison County and is too small to be shown separately on figure 2.

CRETACEOUS AND TERTIARY ROCKS

(By Mary H. McCracken, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Post-Pennsylvanian uplift again raised Missouri above sea level, and no marine deposition has taken place since then except in the area of the Mississippi Embayment. Here, rather sharp downwarping in Late Cretaceous time permitted the sea to advance from the Gulf Coast over a peneplaned surface of deeply weathered Paleozoic rocks, leaving a series of beds consisting predominantly of white, fine-grained, micaceous sand. Local patches of chert gravel, usually overlain by dark-gray plastic clay, occur at the base of the Cretaceous section, and plastic clay lenses also occur within the sands. A brown, calcareous, sandy clay with pyritized fossils and glauconite forms the top of the section. Formational designations are given in table 2.

TABLE 2.—*Upper Cretaceous and Tertiary rocks of southeastern Missouri (thickness figures are for outcrop; most units thicken in subsurface downdip to southeast)*

Tertiary System	Pliocene(?) Series	"Lafayette" Gravel (0–60′) —Major unconformity.
	Eocene Series	Wilcox Group:
	Paleocene Series	Midway Group: Porters Creek Clay (200′±). Clayton Formation (0–10′).
Cretaceous System	Gulfian Series	Owl Creek Formation (0–5′). McNairy Formation (0–100′). Tuscaloosa(?) Gravel (0–20′) —Major unconformity.

Cretaceous beds crop out principally in Scott and Stoddard Counties in Crowley's Ridge and the other low hills rising out of the alluvium of the flood plain; small outlying patches occur also on the southeastern flank of the Ozark Uplift in Butler, Wayne, and Bollinger Counties. Total thickness in outcrop ranges upward from a featheredge to about 100 feet, but in the subsurface to the south and east, the section thickens to more than 500 feet and becomes more marine in character.

Paleocene beds (Midway group) unconformably overlie the Cretaceous formations in Scott and Stoddard Counties. The Clayton Formation is a thin basal glauconitic bed with shell fragments, and the Porters Creek, a dark-gray clay that is in part bentonitic (derived from volcanic ash). These beds, deposited during an advance of marine waters, were succeeded by largely nonmarine sands, clays, lignitic material, and silt of the Eocene Wilcox Group as the sea withdrew again to the south. Both the Midway and Wilcox beds vary markedly in thickness in outcrop (table 2) and thicken rapidly down dip in the subsurface, the former to more than 650 feet and the latter to more than 1,300 feet in southeasternmost Missouri.

The term "Lafayette" is used to designate brown chert gravels, containing minor amounts of sand and red clay either as lenses or matrix, that are widely distributed in southeastern Missouri from the Embayment northward to St. Louis. They overlie all older rocks unconformably, at altitudes generally well above the present drainage system. As they seem to represent remnants of stream deposits formed prior to Pleistocene time, they are tentatively regarded as Pliocene.

TABLE 3.—*Pleistocene deposits of Missouri*

		Stage (age)	Deposits and soils.
Quaternary System (Period)	Pleistocene Series (Epoch)	Recent	Alluvium, landslide debris, soil.
		Wisconsinan (includes several divisions of substage rank in Missouri)	Bignell Loess; alluvium.
			Brady Soil.
			Peoria Loess (including Farmdale); alluvium.
		Sangamonian	Sangamon Soil.
		Illinoian	Loveland Loess; alluvium; unnamed till.
		Yarmouthian	Yarmouth Soil.
		Kansan	Alluvium; unnamed till(s); sand and gravel.
		Aftonian	Afton Soil.
		Nebraskan	Unnamed till(s); sand and gravel.

QUATERNARY (PLEISTOCENE) DEPOSITS

(By W. B. Howe, Missouri Geological Survey and Water Resources, Rolla, Mo.)

The essential features of the succession and classification of Pleistocene deposits of Missouri are given in table 3. The northern part of the State was glaciated during the Nebraskan and Kansan Stages, and glacial deposits, including till and outwash sand and gravel, are pres-

ent throughout northern Missouri with a maximum recorded thickness of nearly 400 feet. These deposits are associated with and overlie a pre-Pleistocene drainage system that is in part unrelated to the modern topography (see fig. 69, p. 297). Some glacial till of Illinoian age is present in the St. Louis area. The Peoria and other loesses (deposits of wind-blown silt) are prominent along the Missouri and Mississippi River bluffs, where these deposits reach maximum thickness of approximately 100 feet. The southern part of Missouri was not glaciated and did not receive any of the characteristic glacial deposits, but it was influenced by associated changes in regimen. The alluvial fill in the modern Missouri and Mississippi River Valleys is considered to be mostly of Wisconsinan age.

STRUCTURE

(By Mary H. McCracken, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Missouri, which lies within the stable Mid-Continent area, has as its dominant structural feature the Ozark uplift, locus of repeated mild uplift since Precambrian time. The times of major uplift shown by unconformities in the stratigraphic record, at least six in number since the igneous rocks of the St. Francois Mountains were emplaced, have been discussed in the previous sections and can be seen in tables 1 and 2.

Structure contours (fig. 3) drawn on the base of the Roubidoux Formation (and reconstructed by estimating its former position in areas where erosion has exposed older rocks) show that the arching of the Ozark uplift has totaled about 5,000 feet since Early Ordovician time. The uplift is assymmetric; dips on the southeast and east into the Mississippi Embayment and Illinois Basin, respectively, are much steeper than those in other directions. Though the major axis of the Ozarks now trends south-southwest, early uplifts had a greater northwest-southeast component, shown, for example, by the distribution of Lower Ordovician (Canadian) formations on the pre-St. Peter paleogeologic map (McCracken and McCracken, 1965, map No. 1) and still preserved in the northwest-projecting salient of Canadian and Mississippian rocks in north-central Missouri (fig. 2). Erosion on structural highs in the northwestern and southeastern corners of the State removed rocks down to and including the Roubidoux Formation (lightly shaded areas on fig. 3). The northwestern area began to sink in Middle Ordovician time, forming a minor basin (the Forest City Basin) which reached its greatest development in Pennsylvanian time. The area of the Pascola arch has had a complex, poorly understood tectonic history. It received thick sediments during early and middle Paleozoic time but was uplifted and beveled prior to Late Cretaceous time when it subsided as a part of the Mississippi Embayment.

In addition to the epeirogenic (warping) movements, there has been a rather considerable amount of faulting and folding that is believed to reflect structures in the basement rocks. The Precambrian structural grain is aligned predominantly in a northwest-southeast direction, with a subordinate northeast-southwest pattern plus some north-south and east-west fracturing (Graves, 1938). Repeated move-

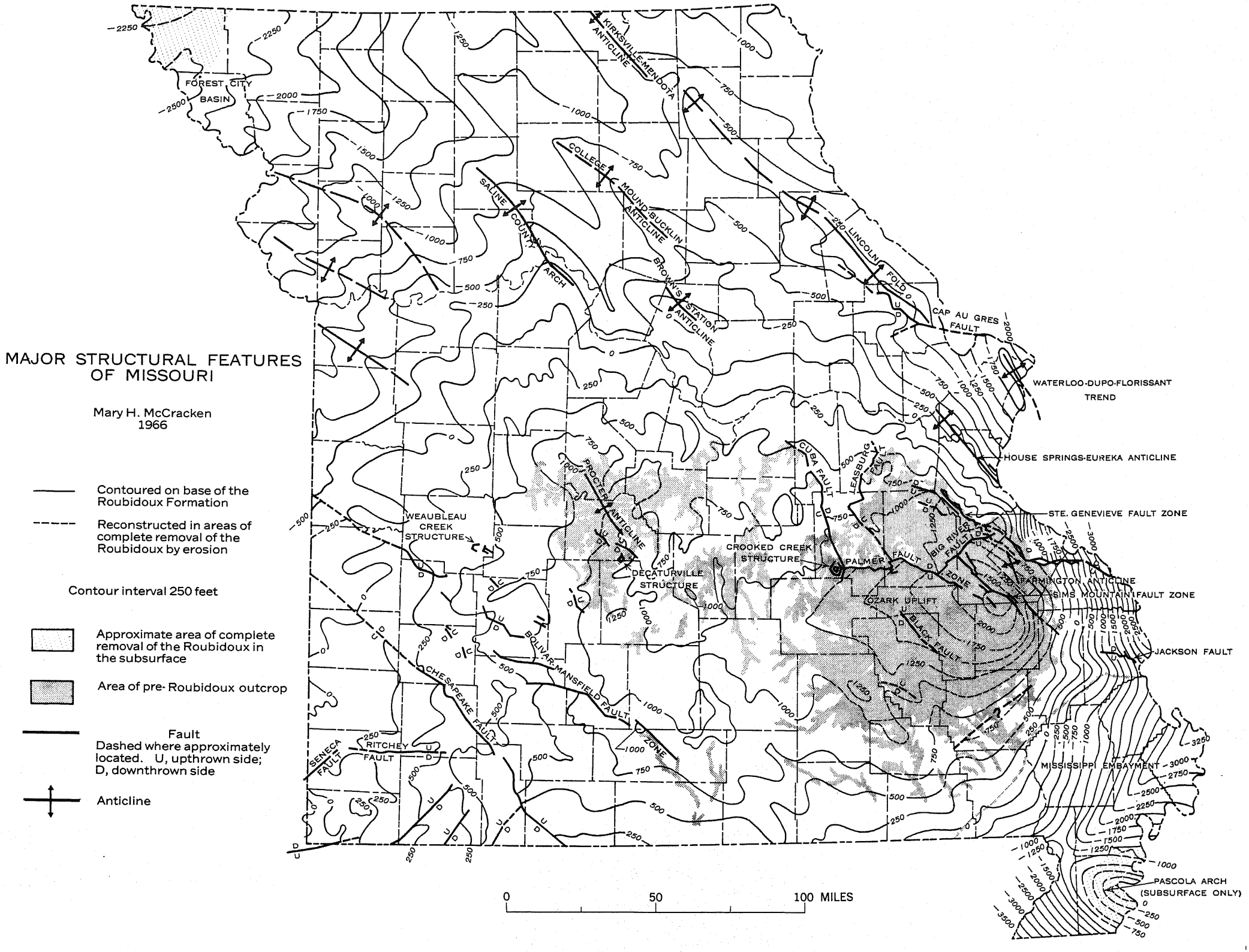


FIGURE 3.—Major Structural Features of Missouri

ment along at least some of these old structures has been reflected in the overlying rocks, and it is expected that, as detailed field mapping studies continue and drill data accumulate, stronger correlation of basement and cover rock structures will be established.

Faulting gives the Ozark area the pattern of a ruptured dome near the center of the structural high. The Sims Mountain, Big River, Palmer, and part of the Ste. Genevieve faults on the northern and northeastern sides, the Black on the southwest, and perhaps a fault on the southeast, rim the general area of the St. Francois Mountains. The outer sides were dropped. Vertical movement of about 1,500 feet on the east-trending part of the Ste. Genevieve fault zone (fig. 3) caused horizontal offset of the east-dipping belts of Ordovician rocks of up to 5 miles (fig. 2). In southwestern Missouri, the northwest-trending Bolivar-Mansfield and Chesapeake fault zones extend across many counties and into adjacent States. The northeast-trending faults in the extreme southwestern corner of the State are continuations of major fault trends in Oklahoma and Arkansas. Northeast-trending faults in the Mississippi Embayment, covered by the alluvium and not shown on the maps of this report, and the northwest-trending faults of southeastern Missouri have continued active to the present. Movement on them produces the earthquakes that shake the area from time to time.

Half a dozen areas of intense brecciation, some with minor intrusive or extrusive igneous rocks, are distributed along an east-west line that may mark a zone of deep fracturing. The Crooked Creek, Decaturville, and Weaubleau Creek structures (fig. 3) are more or less circular structures in which substantial vertical movement of rock units has taken place; at Decaturville a block of Precambrian granite pegmatite is exposed at the center of the structure at least 1,400 feet above its normal position in the basement. Volcanic materials in the Lamotte Sandstone at Hazelgreen, Laclede County, and Furnace Creek, Washington County, are known only from drilling (Snyder and Gerdemann, 1965); they are not shown on the maps in this report. Dikes and diatremes of mafic and ultramafic igneous rock near Avon occur in brecciated sediments of Cambrian age where faults cut the south end of the Farmington Anticline (Kidwell, 1947). Though each of these features (and others to the east in Illinois and to the west in Kansas) differs somewhat from the others in specific characteristics, and they have been attributed to various origins, Snyder and Gerdemann (1965) draw attention to their overall similarities and propose that they result from intermittent explosive igneous activity along a deep fracture in the crust of the earth.

Dips everywhere in Missouri are gentle except in the immediate vicinity of some of the faults. The most prominent structure north of the Ozark dome is the Lincoln fold. This, together with the other larger structures, such as the Procter anticline, Saline County arch, and Browns Station anticline (see fig. 3), trend northwesterly parallel to the principal direction of the Precambrian grain and to the early elongation of the Ozark uplift. It is believed that they originated in block-fault structures in the basement over which the Paleozoic sediments draped to produce the anticlinal and synclinal folds that persist to the surface (Hinds, 1912, p. 8).

GEOPHYSICAL STUDIES

(By William C. Hayes, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Geophysics is the study of the physical properties of the earth. Through interpretation of the results of meticulous surveys of magnetic, gravity, seismic, and electrical phenomena, our knowledge of geologic features not subject to direct observation has been greatly increased. Applications are both theoretical and practical. Geophysics has had striking success in finding mineral deposits in Missouri and elsewhere, and it will become of increasing importance in the future when we must explore more and more for resources not exposed at the surface.

MAGNETIC

Variations in the earth's magnetic field produced by different rock masses below the surface may be measured by a simple needle or the more precise magnetometer. The magnetic susceptibility of different rock masses varies widely and generally to a greater degree than many of the other physical properties. Easily portable magnetometers may be used for ground surveys, whereas airborne instruments are capable of surveying large areas at relatively low cost.

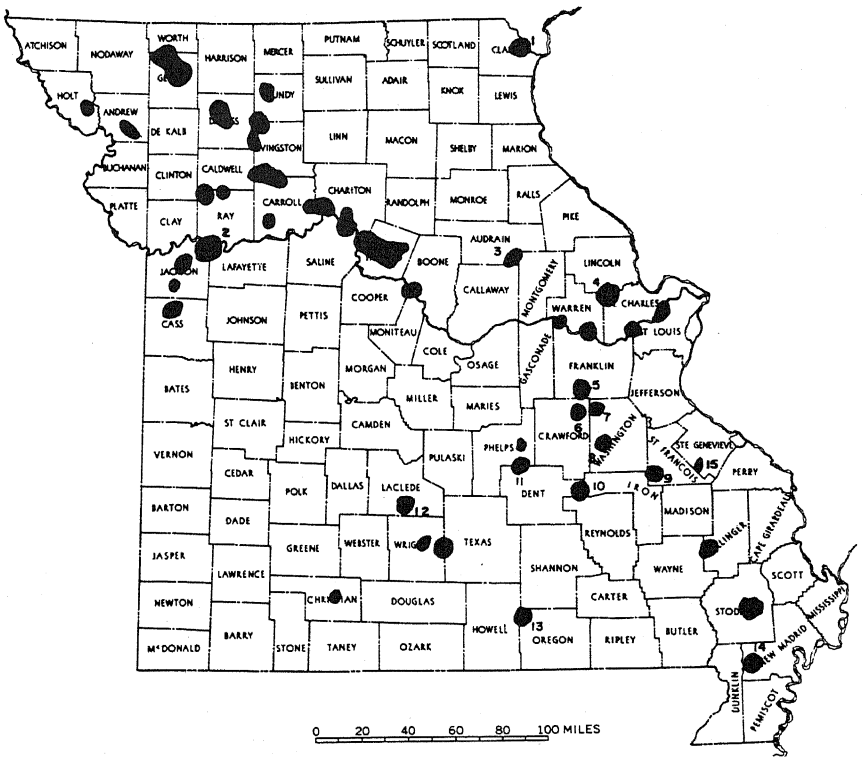
The first magnetic surveys in Missouri were magnetometer profiles made in 1929 across a variety of geologic structures (Muilenburg, Reinoehl, and Grohskopf, 1931). The profiles clearly indicated (1) location of buried igneous knobs; (2) outline of filled-sink iron deposits; (3) location of basic dikes; and (4) location of faults.

One of the most striking anomalies found in Missouri was at Bourbon, Crawford County, and this, as was suggested by Grohskopf and Reinoehl (1933), has more recently been proved to be caused by a concentration at depth of magnetic material.

A State magnetic map was published by the Missouri Geological Survey in 1943 as the result of ground magnetic readings taken at 1-mile intervals along roads. Locations of the major magnetic anomalies determined by this survey are shown in figure 4. Many detailed ground magnetic surveys of filled-sink hematite deposits are on file at the Misssouri Geological Survey.

In 1946 and 1948, approximately 3,500 square miles of aeromagnetic surveys were flown in Missouri as a cooperative project of the U.S. Geological Survey, the Missouri Geological Survey, and several interested mining companies. Additional areas were flown by the State of Missouri under the direction of the Missouri Geological Survey in 1961, 1962, 1963, and 1965. Data from these surveys are available to the public as contoured maps corresponding to the standard (U.S. Geological Survey) 15-minute quadrangle maps. To date, approximately 14,300 square miles of the State are covered by aeromagnetic maps (fig. 5). Aeromagnetic data compiled from the early flights showed a high-magnitude magnetic anomaly in Washington County that led to the discovery of the deeply buried magnetic iron ore of the Pea Ridge deposit now being mined by the Meramec Mining Co.

According to Allingham (1960), analyses of aeromagnetic surveys in the St. Francois Mountains allow determination of (1) separate



1. ST. FRANCISVILLE
2. LEVASY
3. BENTON CITY
4. WENTZVILLE
5. KRATZ SPRING
6. BOURBON
7. PEA RIDGE
8. FLOYD TOWER
9. IRON MOUNTAIN
10. BOSS
11. LAKE SPRING
12. ORLA
13. PEACE VALLEY
14. MALDEN
15. AVON

FIGURE 4.—Major magnetic anomalies in Missouri.

areas of granite and volcanic rock; (2) location of buried Precambrian hills and ridges; (3) extent and depth of shallow Paleozoic basins; (4) fault traces; and (5) areas of potential economic deposits of magnetite. Leney (1964) briefly summarized the magnetic characteristics of the Pea Ridge magnetite deposit. Paleomagnetic investigations of Precambrian rocks of the St. Francois Mountains (Hays and Scharon, 1966; and Scharon, Hays, and Anderson, 1961) suggest that the rocks are contemporaneous, representing a relatively short interval of Precambrian time, and are possibly related genetically.

GRAVITY

Gravity methods measure variations of the relative densities of rock lying below the surface. Gravity instruments must be used on the surface of the earth, and elevations of the occupied stations must be accurately determined. In 1940, gravity measurements were

taken at approximately 1,000 stations throughout the State, and in 1942, additional observations were made at points approximately 6 miles apart. The results of these surveys were published as a State gravity map in 1943, the first statewide gravity map to be published in the United States.

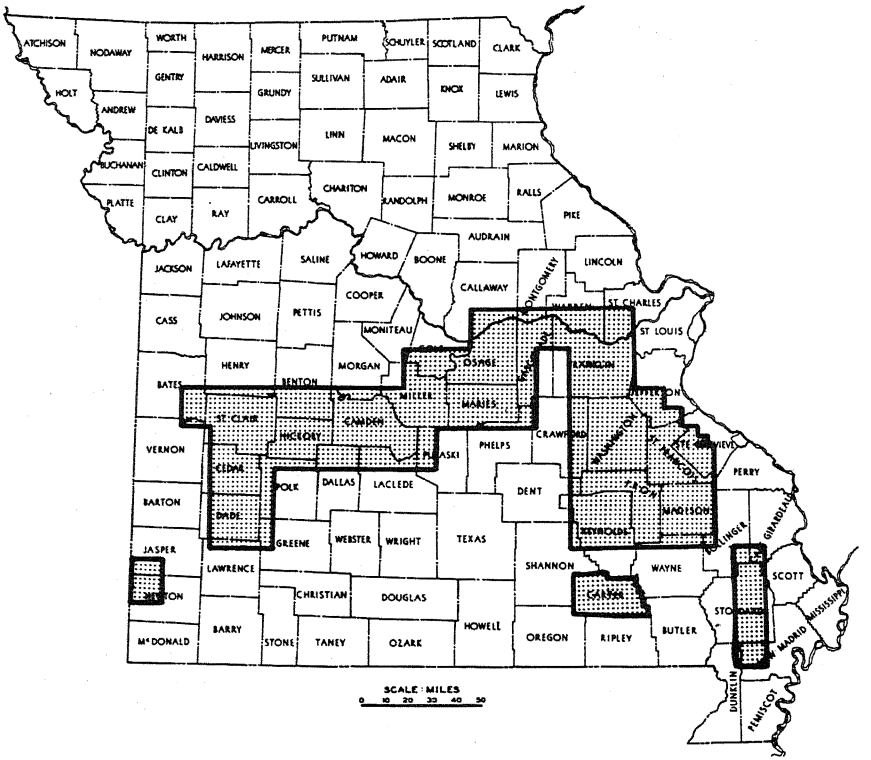


FIGURE 5.—Aeromagnetic map coverage in Missouri.

Because gravity methods have not proved as definitive as other methods for testing potential mineral deposits in Missouri, few detailed surveys have been made in the State.

Mateker (1959) describes several gravity problems in eastern Missouri, and Uhley and Scharon (1953) conclude from their investigation that large commercial bodies of barite in southeast Missouri can be outlined and tonnages computed within 35 percent. Leney (1964) describes the discovery of a part of the ore body at Iron Mountain that was masked in the magnetic survey.

SEISMIC

Variations in the elastic properties of rocks affect the speed of transmission of seismic waves so that measurements of travel time can reveal much about the nature of concealed rock masses. Study of

natural seismic waves generated by earthquakes provides information regarding the gross structure of the crust of the earth. The seismic history of Missouri has been explained by Heinrich (1938), and later work by Kisslinger (1949, 1950) and by Heinrich (1955) have added to the seismic data and interpretation of Missouri structure.

The New Madrid earthquake of 1811–12 was one of the most intense and widely felt seismic events ever recorded in the United States (Fuller, 1912). Earthquake epicenters in Missouri are concentrated along the Mississippi Valley in the New Madrid area, Charleston area, and along the Ste. Genevieve fault. The intensity of most of these midcontinent earthquakes is mild, but they are characteristically felt over wide areas. Transmission of seismic waves along northwest structural lineaments in Missouri appears to have taken place (Kisslinger and Nuttli, 1965).

Seismic prospecting, using manmade explosions, has been used less than other geophysical methods in the State because of the depth of weathering at the surface and the lack of definite reflection or refraction surfaces between rock masses in the subsurface throughout Missouri. The results of an investigation by Dayley (1962) indicate that seismic refraction profiling is a practical reconnaissance tool to locate sink structures and associated sink-type fire clay deposits. Meidav, Davis, and Jones (1960) compared the ability of seismic refraction and electrical resistivity methods to determine depth to bedrock. In over four-fifths of the tests made, the seismic measurements were in reasonable accord with test-hole data.

ELECTRICAL

The ability of rocks to conduct electric currents is based on their composition, texture, and moisture content. The resistance to current flow in a rock can be measured precisely with the proper instruments. By introducing a current into the crust through electrodes, the resistance (or voltage drop) may be measured between any two electrodes in the field of force. Quantitative determinations can be made of the character of the rock (or mineral) mass and its depth below the surface computed. The technique is most successful with sulfide and other deposits of abnormally high electrical conductivity.

Numerous detailed surveys of a variety of ore deposits have been made in the State, and the Missouri Geological Survey has on file more than 50 electrical resistivity surveys of ore deposits and prospects. Published reports describing the applicability of electrical resistivity to exploration in Missouri are tabulated below:

Authors and year:	*Type of deposit*
Algermissen (1955)	Flint fire clay.
Cook and Van Nostrand (1954)	Filled-sink type hematite.
Meidav, Hayes, and Heim (1958)	Surface limonite.
Meidav (1960)	Buried glacial channels.
Heinicke (1940)	Shoe-string oil sands.
Meidav, Davis, and Jones (1960)	Depth of overburden.

When certain ore deposits are so situated that different parts of the ore body are in contact with solutions of different chemical composition, chemical reaction produces a potential difference which causes a

current to flow between the two parts of the deposit. This commonly occurs in sulfide deposits such as pyrite situated partly above and partly below the water table. Oxidation in the upper part of the deposit yields acid solutions more readily than the lower part that is below the water table. This difference of potential causes a current flow between the upper and lower parts of the deposit. The self-potential method is especially effective in prospecting for shallow sulfide ore bodies.

Because of the relatively shallow water table and the blanket-like sulfide deposits of the Mississippi Valley type, the self-potential method has had limited application in the State.

TOPOGRAPHIC AND GEOLOGIC MAPPING

(By Jerry D. Vineyard, Missouri Geological Survey and Water Resources, Rolla, Mo.)

The U.S. Geological Survey, in cooperation with the Missouri Geological Survey, has published a topographic map of Missouri, a shaded relief map of Missouri, and a shaded relief topographic map of Missouri, all at the scale of 1:500,000, or approximately 8 miles to the inch. Larger scale maps of the United States series, produced by the Army Map Service and published for civilian use by the U.S. Geological Survey, are available for the entire State at a scale of about 4 miles to the inch (1:250,000) (fig. 6). Except for a small area in northern Missouri, all of the State is covered by modern

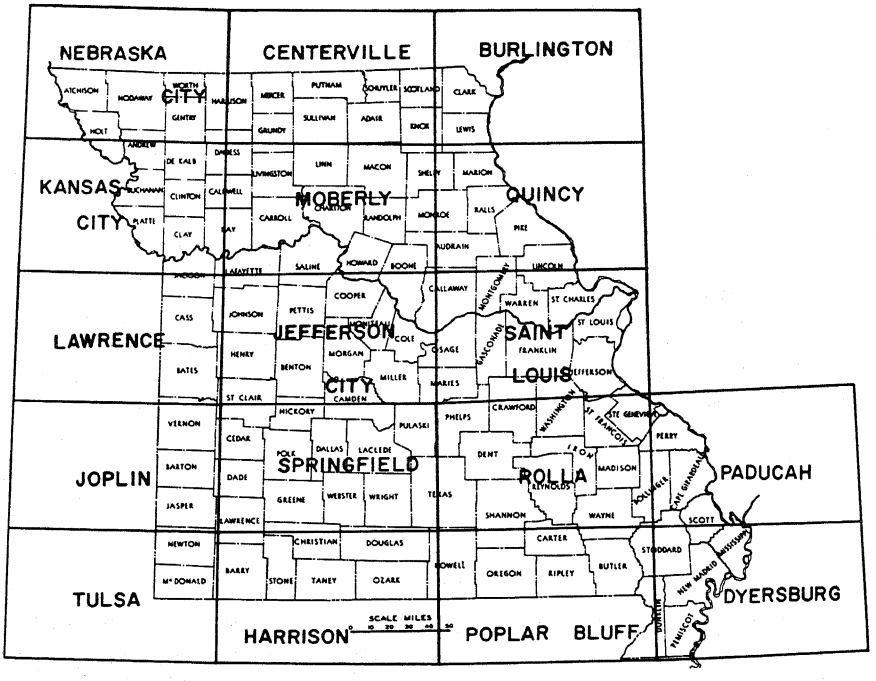


FIGURE 6.—Index to topographic map coverage of Missouri at 1:250,000 (approximately 4 miles to the inch).

topographic quadrangle maps at scales of 1:24,000 and/or 1:62,500, published by the U.S. Geological Survey in cooperation with the Missouri Geological Survey and other agencies (fig. 7). Topographic quadrangle maps may be obtained from either the U.S. Geological

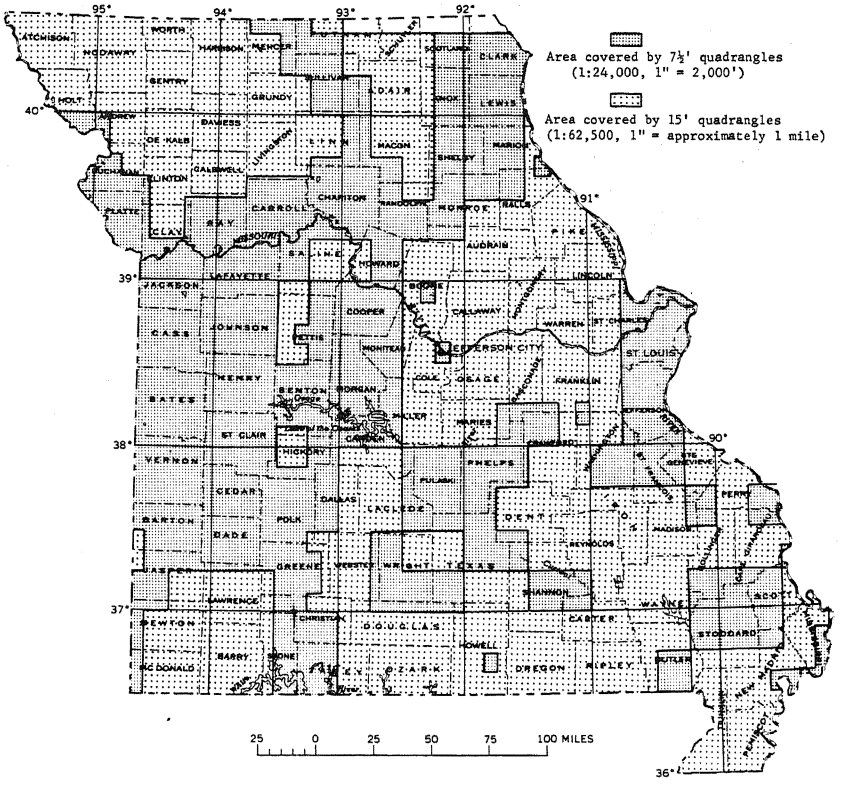
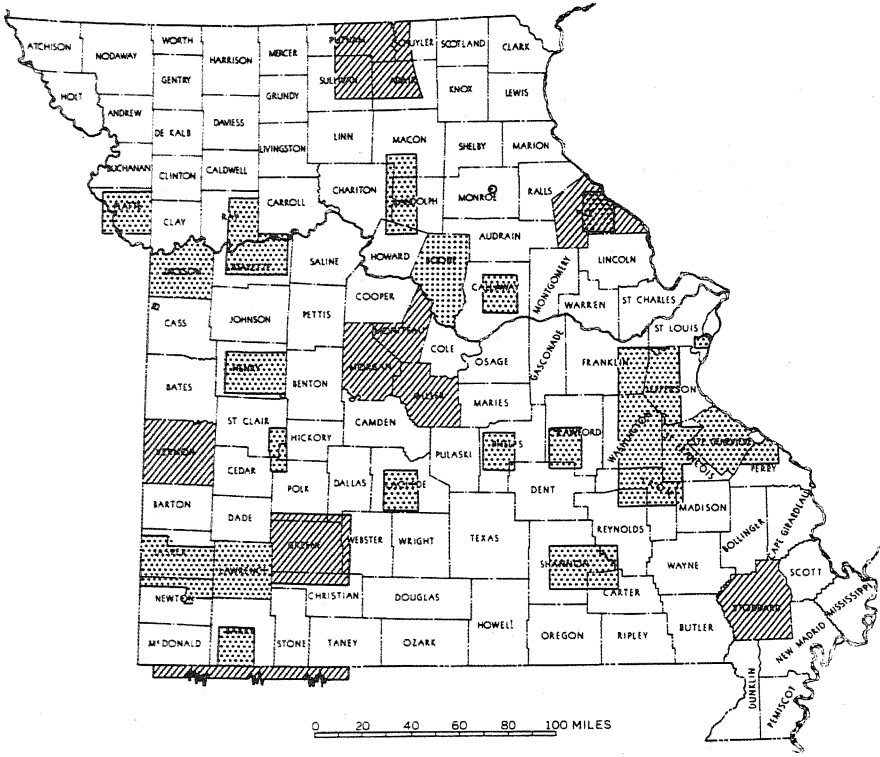


FIGURE 7.—Areas of Missouri covered by topographic maps at 1:24,000 and 1:62,500.

Survey or the Missouri Geological Survey. Index maps showing quadrangles by name and area covered, and frequently revised, are available free on request to either Survey. A continuous program of new mapping and revision of out-of-date maps is maintained.

A geologic map of Missouri at a scale of 1:500,000 was published in 1961 by the Missouri Geological Survey (McCracken, 1961). Areas within the State covered by published geologic maps at scales of from 1:63,360 to 1:250,000 are shown in figure 8. References to published geologic maps are found in bibliographies of the geology of Missouri which are published periodically by the Missouri Geological Survey, and in the "Index to Geologic Maps of Missouri" (Beveridge and Koenig, 1963), which is available at no charge from the Missouri Geological Survey.

77-278 O—67——3



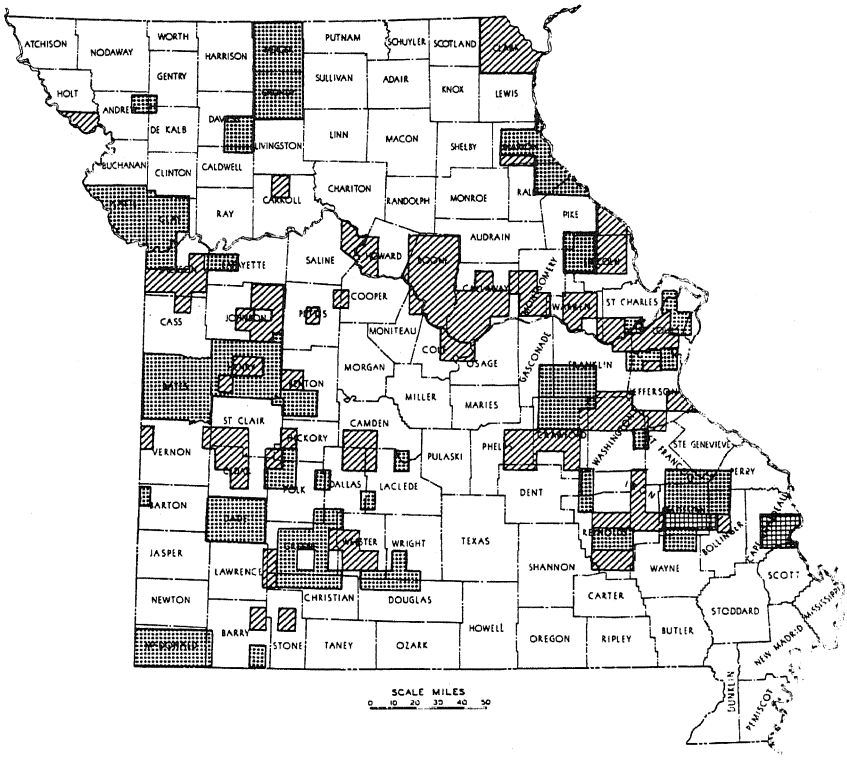
EXPLANATION

Areas covered by published geologic maps at scales 1:63,360 and larger. Incomplete maps are not included.

Areas covered by published geologic maps at scales smaller than 1:63,360 to and including 1:250,000. Incomplete maps are not included.

FIGURE 8.—Areas of Missouri covered by published geologic maps at scales of 1:250,000 or larger.

Many areas in Missouri are covered by geologic maps of good quality that have remained unpublished. Some of these were made by graduate students as part of their requirements for advanced degrees. Thesis maps are generally available through interlibrary loan from the degree-granting institutions. Figure 9 shows those areas of the State that are covered by unpublished geologic maps, and refer-



EXPLANATION

Areas covered by unpublished geologic thesis maps at scales of 1:63,360 and larger. Incomplete maps are not included.

Areas covered by unpublished geologic maps other than thesis maps, at scales 1:24,000 to and including 1:250,000. Incomplete maps not included.

Areas covered by both unpublished geologic thesis maps and other unpublished geologic maps meeting the conditions listed above.

FIGURE 9.—Areas of Missouri covered by unpublished geologic maps.

ences to the maps are given in the "Index to Geologic Maps of Missouri."

The Missouri Geological Survey serves as repository for geologic maps of all kinds, and in particular those maps made by its own employees, or by graduate students whose research is supported in part by Survey funds. Manuscript maps are stored in Survey archives and may be examined in the offices of the Geological Survey.

SELECTED REFERENCES

Algermissen, S. T., 1955, Resistivity measurements over flint clay deposits: Master's thesis, Washington Univ., St. Louis, Mo. (unpub.).

Allen, V. T., and others, 1959, Age of Precambrian igneous rocks of Missouri [abs.]: Geol. Soc. Am. Bull., v. 70, p. 1560–1561.

Allingham, J. W., 1960, Interpretation of aeromagnetic anomalies in southeast Missouri *in* Geol. Survey Research 1960: U. S. Geol. Survey Prof. Paper 400–B, p. B216–B219.

Anderson, R. E., 1962, Igneous petrology of the Taum Sauk area, Missouri: Ph. D. thesis, Washington Univ., St. Louis, Mo. (unpub.).

Beveridge, T. R., and Koenig, J. W., 1963. Index to geologic maps of Missouri (index map and references): Missouri Geol. Survey and Water Resources.

Bretz, J H., 1965, Geomorphic history of the Ozarks of Missouri: Missouri Div. Geol. Survey and Water Resources [Rept.], ser. 2, v. 41, 147 p.

Cook, K. L., and VanNostrand, R. C., 1954, Interpretation of resistivity data over filled sinks: Geophysics, v. 19, no. 4, p. 761–770.

Dayley, R. D., 1962, Seismic investigation of flint clay deposits in east-central Missouri: Master's thesis, Univ. Missouri School of Mines and Met., Rolla, Mo. (unpub.).

Fenneman, N. M., 1938, Physiography of eastern United States: New York, McGraw-Hill Pub. Co., 714 p.

Fuller, M. L., 1912, The New Madrid earthquake: U. S. Geol. Survey Bull. 494, 119 p.

Graves, H. B., 1938, The Precambrian structure of Missouri: St. Louis Acad. Sci. Trans. v. 29, p. 111–161.

Grohskopf, J. G., and Reinoehl, C. O., 1933, Magnetic surveys: Missouri Bur. Geology and Mines 57th Bienn. Rept., app. 4, 20 p.

Hays, W. W., and Scharon, LeRoy, 1966, A paleomagnetic investigation of some of the Precambrian igneous rocks of southeast Missouri: Jour. Geophys. Research, v. 71, no. 2, p. 553–560.

Heinicke, H. C., 1940, Some resistivity measurements over a gas-producing shoestring sand: Missouri Acad. Sci. Proc., v. 5, no. 4, p. 135.

Heinrich, R. R., 1938, A contribution to the seismic history of Missouri: Master's thesis, St. Louis Univ. St. Louis, Mo. (unpub.).

———, 1955, Earthquakes and structural trends in the central stable region of the North American Continent—Pt. 1 Regional consideration; Pt. 2, The New Madrid area: Earthquake Notes, v. 26, no. 1, p. 7–8; no. 2, p. 16–20.

Hinds, H. C., 1912, Coal deposits of Missouri: Missouri Bur. Geology and Mines, 2d Ser. v. 11, 503 p.

Howe, W. B., and Koenig, J. W., 1961, The stratigraphic succession in Missouri: Missouri Geol. Survey and Water Resources, v. 40, 185 p. (Report includes a comprehensive bibliography of Missouri stratigraphy.)

Kidwell, A. L., 1947, Post-Devonian igneous activity in southeastern Missouri: Missouri Geol. Survey and Water Resources Rept. Inv. no. 4, 83 p.

Kisslinger, Carl, 1949, The velocity of elastic waves in some Paleozoic formations in the vicinity of St. Louis, Missouri: Master's thesis, St. Louis Univ., St. Louis, Mo. (unpub.).

———, 1950, Velocity of longitudinal waves in some Paleozoic formations in the vicinity of St. Louis, Missouri: Am. Geophys. Union Trans., v. 31, no. 2, pt. 1, p. 169–173.

———, and Nuttli, O. W., 1965, The earthquake of October 21, 1965, and Precambrian structure in Missouri: Earthquake Notes, v. 36, p. 32–36.

Kisvarsanyi, E. B., 1961, Spectroscopic distribution of the trace elements in the Precambrian granites of southeastern Missouri *in* Guidebook to the geology of St. Francois Mountain area: Missouri Geol. Survey and Water Resources Rept. Inv. 26, p. 95–105.

Leney, G. W., 1964, Geophysical exploration for iron ore: Soc. Mining Engineers Trans., v. 229, No. 4 p. 355–372.
McCracken, Earl, and McCracken, M. H., 1965, Subsurface maps of the Lower Ordovician (Canadian series) of Missouri: Missouri Geol. Survey and Water Resources, ser. 6 maps (scale 1:1,000,000).
McCracken, M. H., Compiler, 1961, Geologic map of Missouri: Missouri Div. Geol. Survey and Water Resources (scale 1:500,000).
Marbut, C. F., 1896, Physical features of Missouri: Missouri Geol. Survey, v. 10, p. 14–109.
Mateker, E. J., Jr., 1959, Some gravity and magnetic interpretation problems in eastern Missouri: Master's thesis, St. Louis Univ., St. Louis, Mo. (unpub.).
Meidav, Tsvi, 1960, An electrical resistivity survey for ground water: Geophysics, v. 25, no. 3, p. 1077–1093.
Meidav, Tsvi, Davis, W. C., and Jones, W. G., 1960, The applicability of seismic refraction and electrical resistivity to cut classification in Missouri: Missouri State Highway Commission, Division of Materials, Geology and Soils Section.
Meidav, Tsvi, Hayes, W. C., and Heim, G. E., 1958, Resistivity surveys of Missouri limonite deposits: Missouri Geol. Survey and Water Resources Rept. Inv. no. 24, 27 p.
Muilenburg, G. A., Reinoehl, C. O., and Grohskopf, J. G., 1931, Geophysical prospecting: Missouri Bur. Geology and Mines 56th Bienn. Rept. app. 3, p. 146–151.
Robertson, Forbes, 1966, Petrology of the St. Francois Mountains batholith, Missouri [abs.]: Geol. Soc. America Spec. Paper 87, p. 138–139.
Scharon, H. L., Hays, Walter, and Anderson, R. E., 1961, Paleomagnetic investigations in the St. Francois Mountains *in* Guidebook to the geology of the St. Francois Mountain area: Missouri Geol. Survey and Water Resources Rept. Inv. no. 26, p. 106–114.
Snyder, F. G., and Gerdemann, P. E., 1965, Explosive igneous activity along an Illinois-Missouri-Kansas axis: Am. Jour. Sci., v. 263 p. 465–493.
Tarr, W. A., 1932, Intrusive relationship of the granite to the rhyolite of southeastern Missouri: Geol. Soc. America Bull., v. 43, no. 4, p. 965–992; Science, new ser., v. 75, p. 265.
Tolman, Carl, and Robertson, Forbes, Exposed Precambrian rocks in Missouri *in* Precambrian rocks of Missouri: Missouri Geol. Survey and Water Resources. (Report in preparation, with W. C. Hayes as Editor and contributor.)
Uhley, R. P., and Scharon, H. L., 1954, Gravity surveys for residual barite deposits in Missouri: [Am. Inst. Min. Eng.] Mining Eng., v. 6, no. 1, p. 52–56.

THE MINERAL INDUSTRY OF MISSOURI

(By P. W. Guild, U.S. Geological Survey, Washington, D.C.)

According to the Bureau of Mines (Kuklis and Hayes, 1967), value of Missouri's mineral production in 1965 was at an all-time high of $225,568,000. This constituted 1.05 percent of the U.S. total for that year and ranked Missouri 23d among the States. Missouri was the leading producer of lead and barite and an important supplier of stone, cement, and iron ore.

The mineral industry of the State is diversified. Compared to the national average it is stronger in the metals and nonmetallic minerals but much weaker in fuels. The values and percentages by major mineral groups of the 1965 production of Missouri, together with those for the United States as a whole, are given below:

Mineral group	Value (millions)		Percent by group		Missouri percentage of U.S. total
	Missouri	United States	Missouri	United States	
Metals	$70	$2,472	31	11	2.9
Nonmetallic minerals	141	4,916	63	23	2.9
Fuels	15	14,045	7	66	.1
Total	226	21,433	100	100	1.05

Missouri's mineral production totaled nearly $5.6 billion through 1965; the breakdown by class and principal commodities is shown graphically in figure 10. Nonmetallic minerals have provided 46 percent of the dollar value, metals 40 percent, and fuels 14 percent. (Changes in these relative proportions with time will be discussed below.) Lead has been by far the most valuable mineral commodity. Cement, a manufactured product in which limestone is the chief ingredient, is second; if the values of cement and limestone (which comprises 93 percent of the total stone) were added, limestone would be the top ranking commodity in Missouri even without considering lime, another product of limestone which, like cement, is valued for statistical purposes after processing has increased its prices many fold. Values of some mineral products have been assigned at different stages by various persons; thus Bishop (1949) included the value of clay products (brick, tile, etc.) in his summary of Missouri's mineral production, whereas the Bureau of Mines uses the raw-clay value. The latter practice is followed in this report. Such variations can obviously cause discrepancies and illustrate a danger in attempting too great precision in or reliance on statistical summaries.

Coal constitutes almost all of Missouri's mineral fuel output, in sharp contrast to the more usual situation in which petroleum and

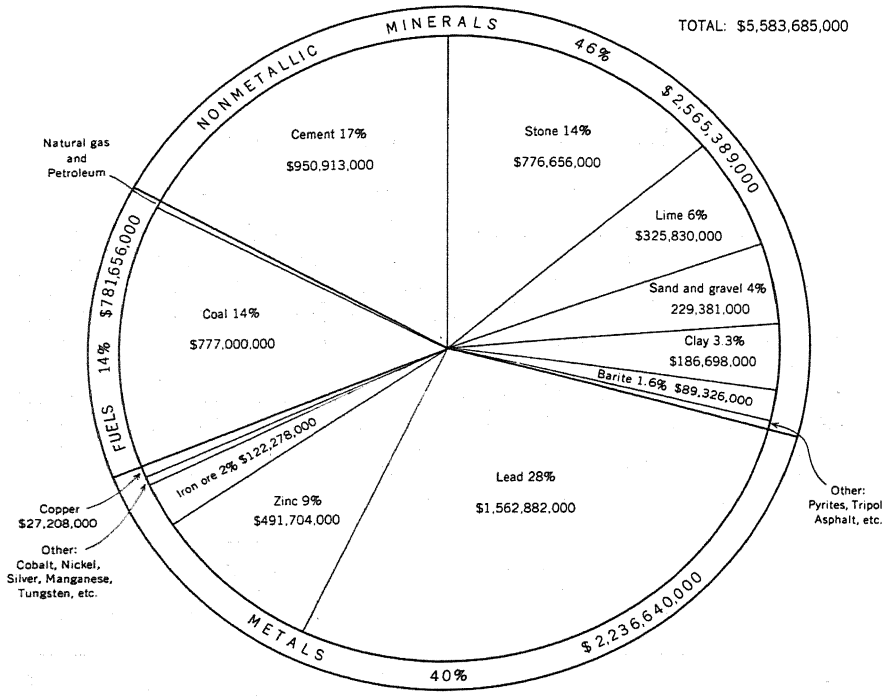


FIGURE 10.—Missouri mineral production through 1965. Sources: Bishop (1949); U.S. Bureau of Mines.

natural gas predominate and, indeed, account for one-half or more of the total value of all mineral production.

The mineral industry in Missouri began in the earliest days of settlement of the area. Lead was discovered about 1700 and mined intermittently by the French; more substantial production began about 1800 under American management and has continued to the present. Iron ores were smelted in primitive furnaces from about 1815 on; by 1845 the iron industry was well established. Small amounts of copper, cobalt, and nickel were being mined by about mid-century, and zinc assumed great prominence shortly after the Civil War.

Utilization of Missouri's clays also began very early; at first for construction brick and tile, and later for refractories also. The value of clay products (see comment above) surpassed that even of lead in the 19th Century; clay and stone together constituted most of the nonmetallic output until portland cement manufacture began in 1903.

Coal mining had begun at least by 1840 and has continued without interruption since then. It is interesting to note that coal had had the greatest cumulative value of any individual commodity at the end of the 19th century, having accounted for about 35 percent of Missouri's total mineral production.

Statistics of early production are incomplete and no doubt inaccurate, but those accepted by Bishop (1949) as most reliable show the following for the period through 1899, in round numbers:

	Value (millions)	Percent of total
Metals:		
Lead	$93	24
Zinc	84	22
Iron ore	30	8
Others (copper, cobalt, nickel, etc.)	2	1
Subtotal	209	55
Nonmetallic minerals:		
Barite	0.7	
Clays (raw value)	10	3
Lime	1	
Stone	25	7
Subtotal	37	10
Fuel (coal)	134	35
Total	380	100

Figure 11 shows how the product mix has varied since 1900. Metal output rose proportionately to its highest level in the second decade when the Missouri part of the Tri-State district was at its peak. Otherwise, metals remained fairly constant in overall value (except for the depression years) but dropped proportionately as nonmetallic minerals increased sharply, particularly when construction boomed after World War II. Coal output has been very steady in value but has dropped gradually to only 7 percent as the other sectors rose.

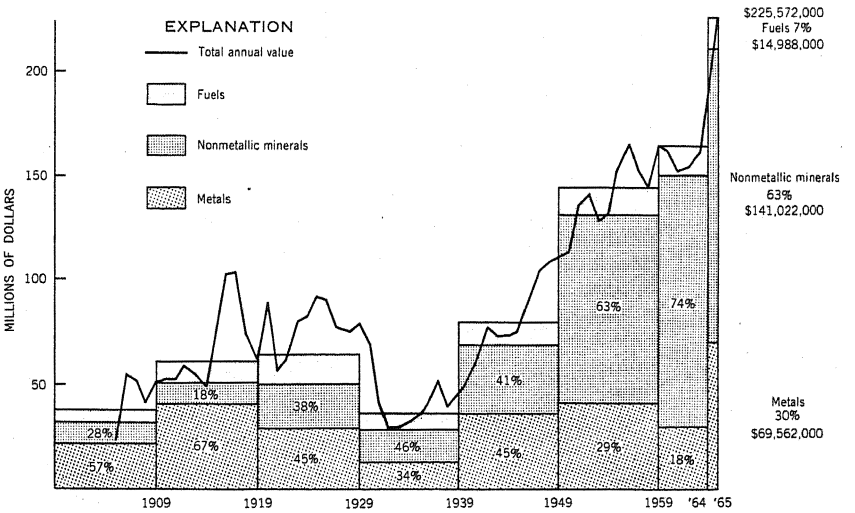


FIGURE 11.—Annual value of mineral production of Missouri, 1905–65; and average value of major mineral groups; by decades, 1900–59; 1960–64, and 1965.

The marked upturn in metals in 1965 is expected to continue; reasons for it will be discussed below and, in much more detail, in the pertinent commodity chapters.

The economic mineral deposits of Missouri occur in but one or at most a few geologic environments in the State, and the various segments of the mineral industry tend to cluster in well-defined areas. Except for the zinc-lead deposits of southwestern and central Missouri, the known metallic deposits are for the most part in the Precambrian rocks, and in the Upper Cambrian strata that overlie them. By far the greatest proportion of the iron ores are in Precambrian rocks; some are in Lower Ordovician rocks or on weathered zones above them. Most of the lead ores of southeastern Missouri, together with their greater or lesser amounts of zinc, copper, cobalt, nickel, silver, and cadmium, are in the dolomite of the Bonneterre Formation, usually near the contact with the underlying Upper Cambrian Lamotte Sandstone. Hence virtually all of the active metal mines are in or near the St. Francois Mountains and the surrounding area of the center of the Ozark Dome. The zinc-lead ores of the Tri-State district are in Mississippian rocks on the southwestern prolongation of the Ozark Dome; the lead and zinc deposits of the Central district, and some in the eastern extensions of the southwestern Missouri district, are largely in Ordovician strata and also on the Ozark Dome.

The coal deposits of the State, which are in the Pennsylvanian rocks, lie north and northwest of the Ozarks, as do most of the small oil pools that have been found in shallow basins that flanked the predominantly positive (rising) Ozark area.

Some of the nonmetallic minerals as, for example, stone, have the widest range in environment and distribution, but even these tend to be restricted if the general category is broken down to specific types. For example, most of the dolomite occurs in the Cambrian and Lower Ordovician rocks and hence is quarried nearer the center of the Ozark Dome than is the geologically younger limestone. Silica sandstone suitable for industrial use crops out in a single belt between Cape Girardeau and Callaway Counties. Clays occur widely, but specific types generally have restricted distribution. Other examples will be noted by the reader as he studies the text and maps.

The mineral industry has had a far larger impact on the development of Missouri's economy than might be thought from the numbers of people actually engaged in mining at any one time. In 1965 mining employment was slightly over 8,000, or 0.6 percent of the total nonagricultural work force of the State (Bureau of the Census, 1966, p. 225). Capital investment in transportation, among other things, has been stimulated by mining activity, which has thereby assisted in opening up isolated areas for other business activity. Thus the main line of the Missouri Pacific Railroad was first constructed to Ironton when the iron deposits in the vicinity were opened up in the 1840's. A 26-mile spur was constructed to the Pea Ridge iron mine in Washington County in 1960. The St. Louis and San Francisco (Frisco) Railroad will complete a 32-mile branch to Buick in Iron County to provide rail transportation for the new lead mines and a lead smelter along the recently discovered "Viburnum trend" of major mineral deposits.

The investment capital needed to find and develop new deposits to replace exhausted ones and to expand total capacity has been described recently by Weigel (1965), Hayes (1965), and Wharton (1967) among others. The figures below show the magnitude of the expenditures in southeastern Missouri for completed iron ore and lead projects that have already contributed to the recent increase in metals production (fig. 11) and for those under construction that will result in a sharp expansion in capacity in the next few years:

Commodity	Millions of dollars	
	Completed projects	Projects under construction
Exploration	75	
Iron ore	62	25
Lead:		
Mines and mills	+30	95
Smelters		37
Total	167	157

The above figures are approximate only, and items such as transport facilities designed expressly for mine products have been included. The exploration figure is not subject to verification; furthermore, plans have not yet been announced for development of all the deposits found, so the second column will almost surely be expanded.

Production increases due to completed facilities were, in 1965, more than 1½ million tons of iron pellets annually, gross value about $22 million; and 77,000 tons of lead, with byproduct zinc, copper, and silver, the total valued at about $26 million. Facilities under construction or planned in 1966 will, when completed over the course of the next few years, add from $80 to $100 million more to the annual value of metal output in Missouri, raising the total to perhaps $130 million. Uncertainties involve such things as demand, price, and possible exhaustion or closing of older facilities. Wharton (1966, 1967) has estimated that in a few years metals output could be as much as $165 million annually.

In addition, large investments have been made in nonmetallic minerals; for example, more than $100 million in cement plants, $5 million in a roofing granule plant, and large but unspecified amounts in refractories, silica sand, and other plants. As the raw material resources are large, the nonmetallic segment of the mineral industry will undoubtedly continue its steady growth, which had reached $141 million in 1965.

The fuel sector is also receiving attention; mine-mouth and other large-generating plants based on coal are being constructed to meet the rising power requirements, and mines are being opened as needed to supply them. We can anticipate that coal output will maintain a small but steady increase.

Exploration and construction contribute large sums to the local economies of the mining areas even before production begins. The permanent jobs created, estimated by Wharton (1967) at 4,300 in iron and lead alone, will provide $30 million annually in payrolls, much

of it in communities without other major sources of income. Taxes and royalties will greatly benefit local communities by providing educational, health, and other public services not otherwise feasible at an adequate scale. Processing of raw materials adds greatly to their value and provides many more jobs than does mining, milling, and smelting, so that the minerals industry has been aptly compared with the base of an inverted pyramid representing our industrialized economy. Value added in manufacture annually in Missouri is some $4 billion; not all of this involves mineral products directly, of course, but metals, nonmetallic minerals, and fuels do enter in greater or lesser amount into all manufacturing facilities and processing.

In the following commodity chapters the term "reserves" is used for known materials in the ground which can, whether completely explored or not, be estimated to a reasonably close degree both as to quantity and grade and which can be exploited under the economic and technologic conditions existing at the time the estimate was made. "Resources" includes reserves plus (1) materials known but not economically or technologically exploitable now, and (2) those materials whose existence is suspected on geologic grounds but which have not yet been found. Obviously, exploration aims at making resources into reserves, and it is faith in the existence of resources (in the second sense, above) that encourages the ever-increasing expenditures needed to find new ore deposits. Relatively few firm reserve figures are cited, as these are infrequently publicized by owners of mining properties, but from the long-range viewpoint of the State or Nation, it is the resources rather than the reserves that are of greater significance.

SELECTED REFERENCES

Bishop, O. M., 1949, The mineral industry of Missouri in 1946 and 1947, with total production summarized: Missouri Geol. Survey and Water Resources Inf. Circ. no. 4, 93 p.

Bureau of the Census, 1966, Statistical abstract of the United States—1966, Washington, D.C., 87th ann. ed.

Hayes, W. C., 1965, Recent mineral discoveries in Missouri—their economic impact: Missouri Mineral Industry News, v. 5, no. 4, p. 26–35.

Kuklis, Andrew, and Hayes, W. C., 1967, The mineral industry of Missouri, *in* U.S. Bur. Mines Minerals Yearbook 1965—V. 3, Area reports, domestic: Washington, D.C., p. 467–485.

Wharton, H. M., 1966, Summary of the economic impact of the expansion in lead mining in Missouri: Anticipated increases in Missouri's lead mining industry: Missouri Mineral Industry News, v. 6, no. 7, p. 79.

———, 1967, The impact of mining developments on the economy of southeast Missouri: Missouri Mineral Industry News, v. 7, no. 1, p. 3–6.

Weigel, W. W., 1965, The inside story of Missouri's exploration boom—pts. 1 and 2: Eng. and Mining Jour., v. 166, no. 11, p. 77–86, 170, and 172; no. 12, p. 81–83, 161–162.

METALLIC MINERAL RESOURCES

LEAD AND ZINC

(By T. H. Kiilsgaard, U.S. Geological Survey, Washington, D.C., W. C. Hayes, Missouri Geological Survey and Water Resources, Rolla, Mo., and A. V. Heyl, U.S. Geological Survey, Beltsville, Md.)

INTRODUCTION

Missouri has a long history as a leading producer of lead and zinc, which occur in numerous deposits in three large areas of the State (fig. 12) and as scattered occurrences elsewhere in the Ozarks. Two major regions—southeast Missouri, primarily a lead producer, and southwest Missouri, part of the world-famous Tri-State district, which is primarily a zinc producer—rank with the great mining districts of the world. Because new deposits recently found in southeast



FIGURE 12.—Principal lead-zinc districts of Missouri.

Missouri are the most important lead discoveries made in this country in the present century, Missouri also has a glowing future. These discoveries have led to the development of new mines and to the expansion of existing ore-processing facilities that will greatly increase our domestic production of lead. The future of lead-zinc mining in the State is further enhanced by widespread geological environments favorable for mineral deposits; hence there is every reason to believe that new deposits will continue to be discovered.

Lead and zinc are closely associated geologically, and most deposits that contain one of the metals also contain the other; therefore in this report the two are discussed together.

Lead was one of the first metals used by man. It has a low melting point and a high boiling point; it is resistant to corrosion, is soft and workable, is impenetrable to short-wave radiation, and has good alloying properties. These and other physical properties enable lead to be used for many purposes, including batteries, tetraethyl antiknocking compound for gasoline, cable covering, litharge, solder, ammunition, and many others.

Zinc is also an important metal and is used widely by industrialized nations. It is a good corrosion inhibitor, is chemically active, and alloys readily with other metals. It is used principally as zinc-based alloy for diecasting, for galvanized protective coatings on various iron and steel items, for brass products, as rolled, sheet, or plate zinc, as zinc oxides, and for many other uses.

The United States ranks as one of the leading lead- and zinc-producing countries of the world. Table 4 shows mine production of recoverable lead and zinc (content of ore) of the five leading producing countries of the world, which in 1965 produced 54 percent of the world's primary lead and 55 percent of the primary zinc. The United States, however, is the greatest consumer of lead in the world, using 1,241,482 tons in 1965. The deficiency between U.S. supply from domestic mines and total consumption is offset by recovered secondary lead and imports. The large deficit between the amount of lead used and the amount supplied from domestic mines emphasizes the importance of Missouri mine production, which, in 1965, amounted to 133,521 tons of lead, or 44 percent of our domestic mine output.

TABLE 4.—*Mine production of lead and zinc in 1965, from leading countries of the world, in short tons* [1]

Country	Lead	Zinc
United States	301,147	611,153
Canada	303,405	911,432
Australia	397,788	387,087
U.S.S.R.	410,000	454,000
Mexico	187,494	247,883
Other countries	1,375,166	2,138,445
Total World	2,975,000	4,750,000

[1] Data from Bureau of Mines.

Consumption of zinc in the United States amounted to 1,354,000 tons in 1965. Of this amount 45 percent came from domestic ores, and the remainder from imports and stocks. This supply position is in

notable contrast to the U.S. position prior to 1939, when domestic mine production provided a sufficient supply of primary zinc for our industrial needs and even an excess for export.

HISTORY AND PRODUCTION

According to Winslow (1894, p. 268) lead was discovered in southeastern Missouri by the French in 1701. Mine La Motte, in Madison County, was discovered in 1720 and immediately brought into production. Production of lead from the State has continued almost uninterruptedly to the present time. Continued exploration by the French led to the discovery of other lead deposits near Potosi, in Washington County. Late in the 18th Century lead deposits were found southeast of Potosi along Big River in St. Francois County. During the early 1800's other lead deposits were found and brought into production in St. Francois, Washington, Franklin, and Jefferson Counties. Small crude lead smelters were operated at several places and the lead was hauled in wagons to shipping points at Ste. Genevieve and Herculaneum. By 1818, a smelter had been established at Herculaneum. Zinc ores were recognized as early as 1810 in a number of deposits in Washington County.

Production of lead in Missouri increased during the period 1830 to 1850. New deposits were found in the central part of the State in Cole, Benton, Morgan, Cooper, and Moniteau Counties, but most of the production came from the southeastern part of the State. Winslow (1894, p. 281) reports that lead was discovered in the Joplin area in 1848; lead mining started near Granby in 1850 and at Oronogo in 1851. All zinc ore mined during this period was cast aside.

The demand for lead during the Civil War raised the price and following the war production increased. The first metallic zinc from the State was produced at Potosi in 1867. The first zinc ore from the Joplin area was shipped in 1873, and output rose rapidly in the following years. By 1880, lead and zinc mining was a major industry in Missouri.

Since 1907 Missouri has led all States in the production of lead except for 1962, when output was curtailed by a strike. The major role of Missouri in domestic lead production is illustrated in figure 13. The annual value of lead production is shown in figure 14, where four peaks of output are to be seen: the first came during World War I, the second during the prosperous 1920's, the third in World War II, and the latest one from recent discoveries in southeast Missouri.

Lead produced from Missouri in 1965 was valued at $41,658,552. Lead production from Missouri, from the beginning of mining through 1965, totaled 10,542,748 tons valued at $1,562,882,038. New mines being brought into production in southeastern Missouri and expansion of existing facilities should give the State a capacity to produce about 375,000 tons of lead annually by 1968. This will make southeastern Missouri the leading lead-producing district in the world.

According to Bishop (1949, p. 83), Missouri, except for 2 years, led all States in the production of zinc ores in the 43 years preceding 1918. Most of the ore came from southwestern Missouri. Peak out-

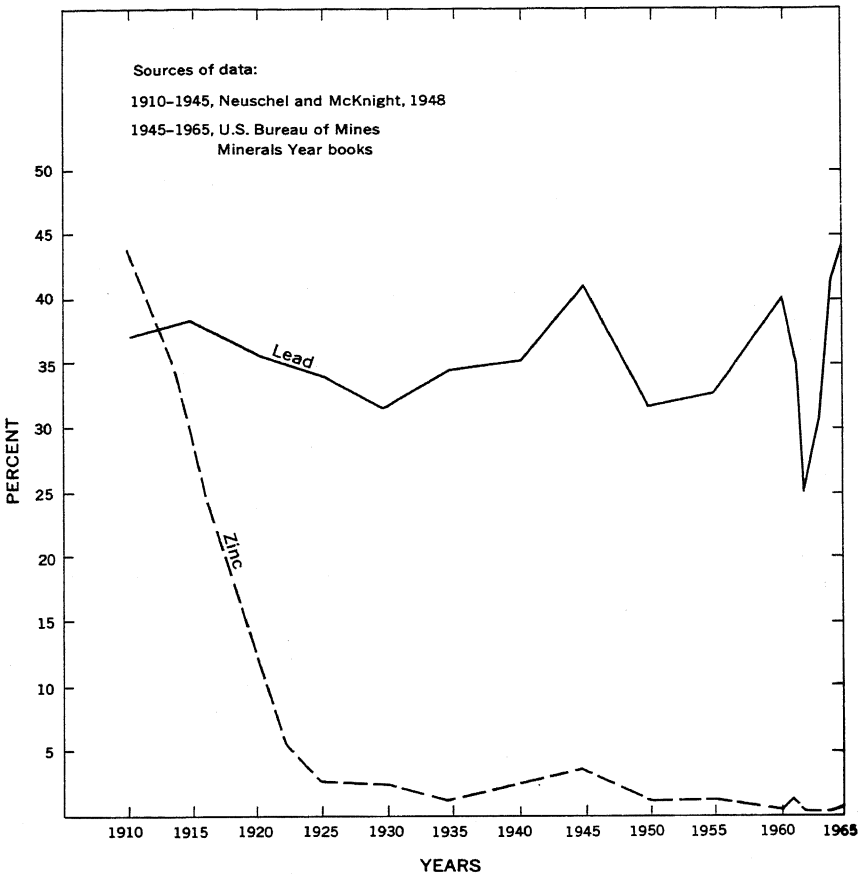


FIGURE 13.—Percent of domestic lead and zinc production from Missouri, 1910–65.

put was in 1916, when 155,527 tons of zinc was produced (fig. 14). Production then fell off sharply but increased somewhat during the 1920's, during World War II, and again during the Korean war. Figure 13 illustrates how zinc output from Missouri had declined since the early 1900's with respect to national output. In 1965, zinc production in Missouri totaled only 4,312 tons, valued at $1,259,104, all of which was byproduct from lead ores mined in southeastern Missouri. Through 1965, total production of zinc from Missouri, since mining began, has amounted to 3,703,211 tons valued at $491,690,457.

Although mining in the formerly productive southwest district has been inactive during recent years, the output of zinc from Missouri is expected to increase in the years ahead. Ores in the lead mines being developed in southeastern Missouri contain appreciable quantities of zinc and as the lead output increases from these developing

mines so will the output of zinc. Production of these ores alone, however, will not enable Missouri to return to the position once held as a leading zinc-producing State.

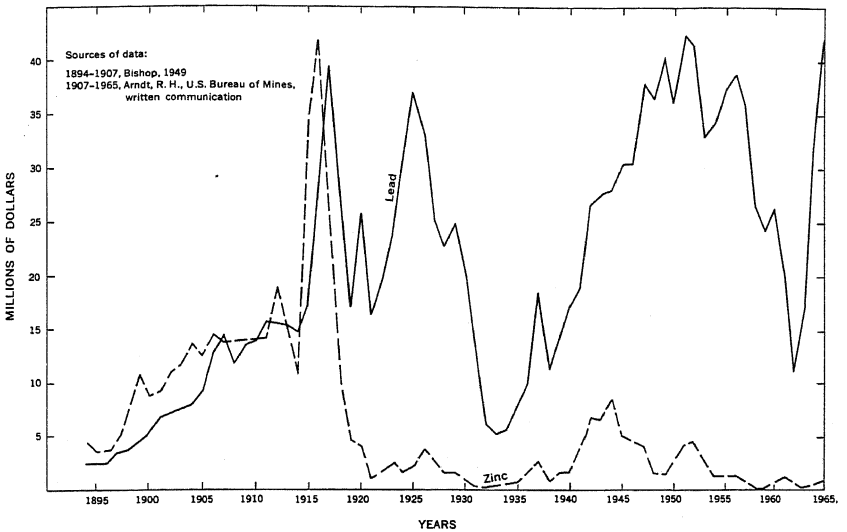


FIGURE 14.—Value of lead and zinc production in Missouri, 1894–1965.

MINING DISTRICTS

Most of the lead and zinc ores mined in Missouri have come from three districts: (1) the southeast district, (2) the southwest district (principally the Missouri part of the Tri-State), and (3) the central district (fig. 12). Of these, the southeast and southwest districts have been the most productive by far. Ores from the southeast district are mined chiefly for lead, although some zinc, copper, and silver are recovered as byproducts. By contrast, the southwest district has been mined primarily for zinc ore, with lead recovered as a byproduct. The ore deposits in all three districts occur, generally, as flat-lying replacement deposits in carbonate rocks. Because of their many similarities the deposits often have been referred to as deposits of the Mississippi Valley type. In the southeast and southwest districts the deposits commonly are extensive, both laterally and vertically, and lie within a few hundred feet of the surface. The large size of the deposits and the physical characteristics of the ores and the wallrocks permit them to be mined on a large-tonnage, low-cost basis, thereby making the deposits competitive with higher grade ores mined elsewhere in the United States.

Southeastern Missouri

Geology

Deposits of lead ore in southeastern Missouri extend in a roughly annular pattern around a dome of Precambrian rocks, which form

the St. Francois Mountains (fig. 15). Most of the sedimentary rocks of the region contain lead ore but the bulk of it, by far, occurs in the Cambrian Bonneterre Formation, which is the lowermost carbonate rock formation of the region and is, for the most part, a

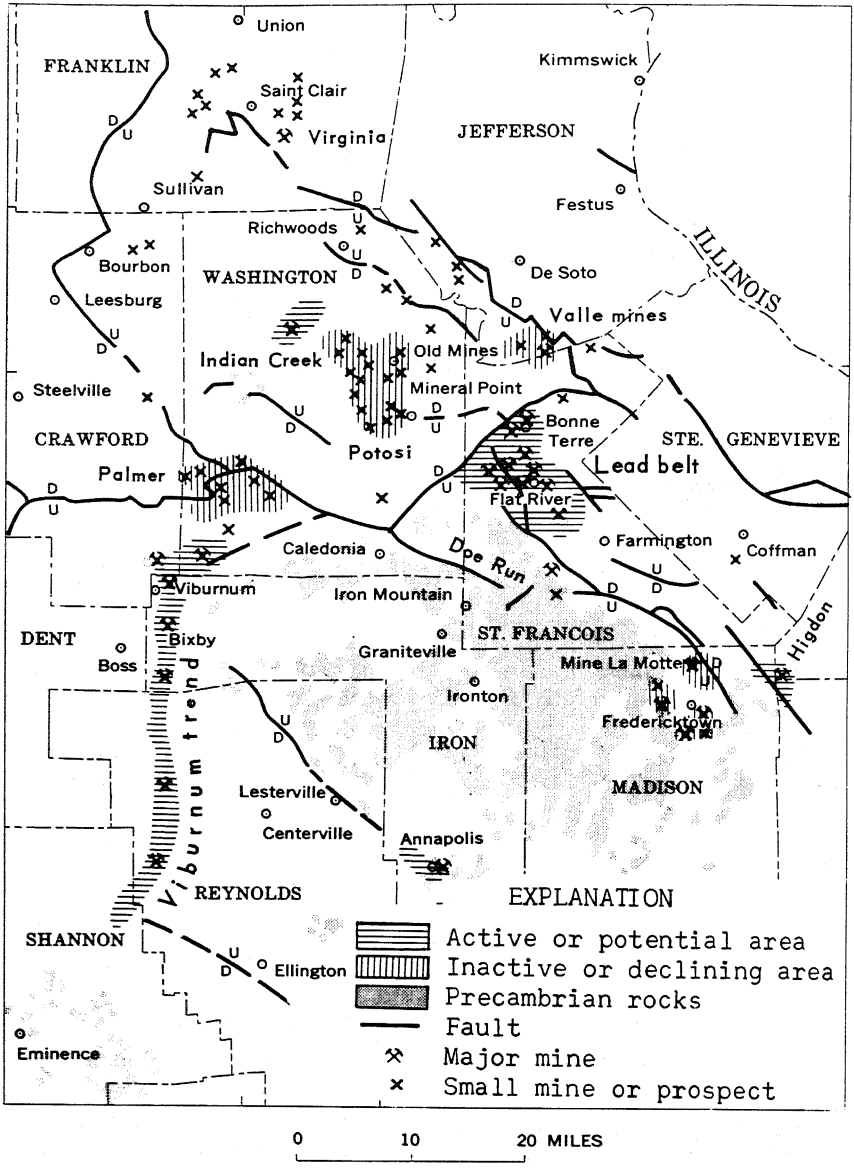


FIGURE 15.—Lead deposit areas and mines in southeastern Missouri.

dolomite, although locally it contains undolomitized masses of limestone. The formation is about 400 feet thick at Bonneterre, the type locality, but thins to the west and is about 275 feet thick at Viburnum (Weigel, 1965). The Bonneterre is underlain by the Lamotte Sandstone and overlain by the Davis Formation, a sandy, shaly dolomite or limestone that grades upward into a shale in the northern and western parts of the area.

Lead ore is disseminated throughout favorable rocks in the Bonneterre Formation, forming replacement ore bodies that spread laterally for hundreds of feet. Ore has extended vertically in some deposits for more than 200 feet. Galena is the principal ore mineral, although during the early days of mining some oxidized lead ores were mined from outcrop and near-outcrop areas, particularly in the Fredericktown and Mine La Motte areas. Zinc minerals occur only in minor quantities in ore from the Fredericktown area and Lead belt, although considerable zinc was produced to the northeast, at Valle Mines. A higher zinc content also occurs in ores from the Viburnum trend. Ore bodies in the Buick area, for example, contain from 4 to 6 percent lead and 1 percent zinc. Elsewhere in the Viburnum trend ores with an average lead content of 3 to 3.5 percent lead and about 0.6 percent zinc have been reported. Minor amounts of copper minerals, chiefly chalcopyrite, also occur in the ore of the Viburnum trend as well as in ores of the Fredericktown area. Copper concentrate is recovered in the St. Joseph Lead Co. mill at Viburnum and at the Federal mill at Flat River. The nickel-cobalt mineral siegenite also is common in ores of the Fredericktown area, some of which have been worked for their nickel and cobalt content (see p. 69).

As described in following paragraphs, understanding of the southeast Missouri lead deposits has been acquired over a long span of time. Geologic characteristics of individual deposits vary, but generally the deposits, their geologic environs, and the structures that control ore deposit localization may be summarized as follows:

(1) The deposits are peripheral to the Precambrian highland mass that forms the St. Francois Mountains (Heyl and others, 1965).

(2) Most of the mineralized areas in the northern and eastern parts of the area have a spatial relationship to major faults, along which ore minerals may have been introduced from underlying sources.

(3) The deposits occur chiefly in the Bonneterre Formation on the seaward flanks of buried or exposed Precambrian topographic highs, reasonably close to and above the line where the permeable underlying Lamotte Sandstone pinches out against Precambrian topographic highs.

(4) Locally, the deposits are within or near algal reefs that grew in shallow waters of the Bonneterre seas on the fringes of earlier sedimentary structures and Precambrian highs. Subsequent alteration of the reef rock and intertongued nonreef rock produced a porous dolomite that provided favorable loci for ore deposition.

(5) Locally, fractures and submarine slides in the Bonneterre resulting from differential compaction during sedimentation in the basins adjoining the topographic highs and solution thinning of the dolomite produced favorable loci for ore deposition.

(6) The overlying impermeable Davis shale, which, together with massive Precambrian igneous rocks on the landward side, has formed a stratigraphic trap in which ore minerals were deposited. Mineral exploration in parts of the area where other geologic features are favorable but where the Davis is a porous dolomite with little or no shale has been singularly unsuccessful in finding ore.

Geologic understanding of the ore bodies has evolved from more than 100 years of observations by miners, enginers, and geologists who have worked in the area. In one of the first reports published on southeast Missouri, Winslow (1894, p. 653) noted that lead ore mined at Mine La Motte in the early 1800's was from the lower part of a limestone and from the underlying Lamotte Sandstone. The galena occurred as a cementing material between sand grains and as replacement of dolomite that also cemented the sand grains. At Flat River, Buckley (1909, p. 175) described galena as disseminated through the dolomite and shale, as occurring in horizontal sheets along bedding planes, as filling vugs and cavities, and filling and lining the walls of joints. He stressed the occurrence of ore in the dark-colored dolomite and shale and noted that ore tended to occur chiefly at the base of the Bonneterre Formation, occasionally extending down into the underlying Lamotte Sandstone. Tarr (1936, p. 732) noted the preponderence of ore in disseminated and bedded deposits and that quantities of ore may be uniformly distributed through the rock, concentrated in masses within the bed, or aggregated along a structural feature, such as a joint or stylolite. He did not believe that ore was concentrated in what was thought to be dark shale. Instead, he considered the dark shaly material to be residual clay derived from solution of the dolomite by migrating ground water. The solution activity created stylolites and voids, which subsequently were filled with ore. Localization of an ore body by solution thinning of the dolomitic host rock is strongly suggested at the National Lead Co. mine at Fredericktown. The ore body mined there during the late 1950's was underlain by several feet of residual clay. The overlying unit of Bonneterre dolomite host rock was appreciably thinner than it was a few hundred feet from the ore body, and gave every indication of having been thinned by solution activity prior to mineral deposition. Tarr also believed joints in the host rock exerted a strong control on the ore deposits and directed attention to the tendency of Flat River—Leadwood ore deposits to trend northeast. more or less parallel to a major pattern of joints.

Wagner (1947, p. 366) also noted that ore bodies in the Lead belt area were elongated along the axes of fracture zones. He considered the fractures to have been formed by regional faults and joints that resulted from compaction of the sedimentary rocks.

Ore bodies in the Fredericktown area are structurally related to Precambrian topography, according to James (1949, p. 18). The ore bodies are in the lower 50 feet of the Bonneterre Formation along the flanks of buried or exposed Precambrian igneous rocks. His recognition of the nearness of ore bodies to the underlying Lamotte Sandstone and to the pinch-out line of the sandstone against Precambrian topographic highs provided a clue that since has guided much of the exploration for lead deposits in southeast Missouri. Ohle and Brown (1954a, p. 205) describe a subdivision of the Bonneterre Formation and note that in the Bonne Terre, Desloge, Leadwood, and Flat River

areas the bulk of ore has been produced from lower units of the formation. They call attention to the occurrence of much ore in "fingered rock," a type of rock they later (1954b, p. 935) believed to have resulted from algal growths of the genus *Collenia*. Northwest-trending pre-ore faults that cut the area are considered to have restricted or guided ore deposition in the area.

Geologic features of the Lead belt are described by Snyder and Emery (1957, p. 1218), who comment on the relation of ore deposits to sedimentary ridge structures that generally trend northeast. More than 90 percent of the ore mined in the district has come from within or along the flanks of these structures. They refer to reef ore bodies, which they define as ore bodies within or marginal to algal reefs that grew along topographic highs as the Bonneterre Formation was being deposited. Ore subsequently was deposited in these favorable rocks. They recognized specific types of ore structures related to the reefs, and to the intertonguing reef and nonreef rocks.

In a subsequent review of the Lead belt Snyder and Odell (1958, p. 921) conclude that masses of breccia in the Bonneterre Formation are host rocks for major ore deposits. They reason that at the time of Bonneterre deposition algal reefs were growing over topographic highs, whereas lime and argillaceous muds were being deposited in intervening basins and valleys. Successive layers of these muds became more compacted than did the adjacent reef rock. The gradation in compaction influenced the dip of unconsolidated sediments on the flanks of the highs, resulting in submarine slides of these sediments outward into the basins. The mass of brecciated material provided a permeable host rock for subsequent mineral deposition. Large tonnages of breccia ore have been mined from the Leadwood area.

The Viburnum trend consists of a belt of mineral deposits that extends almost due south from the initial discovery area near Viburnum for a distance of more than 30 miles (fig. 15). No mineral deposits crop out in this trend. The bulk of ore discovered to date has been in the upper part of the Bonneterre Formation, at depths ranging from about 600 to more than 1,200 feet. Most of the surface of the trend is underlain by residuum, which in places extends to depths of more than 200 feet. Where bedrock is exposed it has a rather flat attitude and is not contorted locally by folding or faulting. The straight alinement, continuity, and absence of surface structural trends in the belt suggest that its location is controlled by an underlying lineament of Precambrian hills. These hills were islands during Late Cambrian time, lying several miles west of a larger land mass that now is exposed as the St. Francois Mountains. Algal reefs grew on the fringes of these islands and in the lagoon on their eastern side, finally covering the islands as the region was inundated by transgressive seas. The coalescing reefs formed what Henshaw (1965, p. 29) describes as a barrier reef. Along this reef, particularly along the western or basin-facing side there subsequently developed a favorable rock environment for mineral deposition. Recent exploration activities and discoveries in the Viburnum trend are described by Weigel (1965).

Ore deposits

Lead ore has been mined from hundreds of deposits in southeast Missouri. Most of these are properties from which small quantities

of lead ore has been mined or searched for in shallow surface workings. These workings were dug during the early years of mining and most of them now are obscured by slumping and overgrown by trees and other vegetation. No attempt is made in the following paragraphs to describe these scattered workings. Instead, only the more productive mines, formerly productive localities, and potentially productive areas are described.

Total production and values of lead and zinc from southeast Missouri are shown in table 5. More than 90 percent of this output came from the Lead belt, which consequently has in the past been considered by many to be virtually coextensive with the Southeast district. However, discoveries in recent years have greatly enlarged the district both geographically and in total metal content. The major concentrations of deposits, each of which can properly be called a subdistrict, are described below.

TABLE 5.—*Production and value of lead and zinc mined in southeastern Missouri* [1]

Year	Lead		Zinc	
	Short tons	Value	Short tons	Value
Prior to 1948	7,627,669	$903,893,961	58,497	$7,059,062
1948	100,654	36,287,270	1,022	271,852
1949	126,269	39,901,004	749	185,752
1950	133,664	36,089,280	1,546	439,064
1951	122,318	42,322,028	2,277	828,828
1952	122,942	39,587,324	3,872	1,285,504
1953	125,273	32,821,526	3,180	731,400
1954	125,173	34,297,402	3,169	684,504
1955	125,357	37,356,386	3,934	967,764
1956	123,395	38,746,030	3,345	916,530
1957	126,323	36,128,378	2,866	664,912
1958	113,123	26,470,782	362	73,848
1959	105,165	24,187,950	92	21,160
1960	111,948	26,195,832	2,821	727,818
1961	98,785	20,349,710	5,847	1,344,810
1962	60,982	11,220,688	2,792	642,160
1963	79,844	17,246,304	321	73,820
1964	120,148	31,478,776	1,501	408,272
1965	133,521	41,658,552	4,312	1,259,104
Total	9,682,553	1,476,239,183	102,505	18,536,164

[1] Data prior to 1948 from Bishop (1949, pp. 42 and 81); from 1948 to present from Robert H. Arndt, U.S. Bureau of Mines (written communication), with corrections for central Missouri production.

Lead belt.—The Lead belt, an area encompassing mines in the vicinity of Bonne Terre, Leadwood, Desloge, and Flat River, has produced more than 90 percent of the lead and zinc ores mined in southeast Missouri. Nearly all the lead ore mined in the lead belt prior to 1869 was from scattered and shallow workings that explored areas above the water table (Buckley, 1909, p. 2). In 1864, however, the St. Joseph Lead Co. was organized and began operations at a property at Bonne Terre, at which ore was mined from a shallow trench. Subsequent exploration, by drilling, discovered disseminated lead ore in the underlying Bonneterre Formation, and this led to a rapid increase in underground mining that marked the beginning of substantial lead production from Missouri. Expansion of the St. Joseph Lead Co. centered in a triangular area embracing the towns of Bonne Terre, Leadwood, and Flat River, where eventually the company took over other mining companies and built up a complex of operating mines connected by more than 250 miles of underground railroad. The St. Joseph Lead Co., according to the company's 100th anniversary re-

port issued in 1963, mined at Bonne Terre from 1864 to 1961, at Doe Run from 1887 to 1914, at Deslodge from 1929 to 1958, and at Leadwood from 1915 to 1962. The company has operated a lead smelter at Herculaneum since 1891. In 1966 St. Joe operations in the triangular area were administered by the company's Federal Division, which was mining in the Flat River area, the site of principal output in the triangular area, from which slightly more than 110 million tons of ore were mined in the period 1923 to 1963 alone. Capacity of the Federal Division mill at Flat River enabled it to handle 12,000 tons of ore per day in 1966.

La Motte-Fredericktown.—Lead was discovered north of what is now Fredericktown in 1720. The deposit was worked under the direction of a Frenchman named La Motte and become known as Mine La Motte. The mine has been active intermittently since its discovery, although only a small production of lead was obtained from pits and near-surface workings prior to 1878. Winslow (1894, p. 649) notes that production from the mine, to 1894, amounted to 97,704 tons of lead. The mine was operated by several companies during the period 1902–28. It was closed for a few years in the early 1930's, but resumed production in 1937 and operated until 1959, when it was closed. Production from 1723 to 1947 is estimated by Hayes (1961, p. 24) to total more than 325,000 tons of lead.

There are a number of mines clustered about Fredericktown, all of which have been idle for a number of years. Northwest of Fredericktown are the Hickory Nut, Fleming, and Catherine mines. Mining started at the Catherine mine in the 1860's, but production from it appears to have been desultory. The Ruth mine is south of the town. The most productive deposits in the immediate Fredericktown vicinity are those about 1 mile southeast of the town, which were last worked by the St. Louis Smelting and Refining Division of the National Lead Co. These mineworkings as well as the surface plant were closed in 1961.

Ore deposits at Mine La Motte and near Fredericktown are similar geologically in that they are relatively shallow; most of them less than 400 feet from the surface. The ores occur in the lower 50 feet of the Bonneterre Formation and in places in the upper 15 feet of the Lamotte Sandstone. The ores are complex mineralogically and contain lead, zinc, copper, silver, nickel, and cobalt. Grade of the ore has varied somewhat during the long period of mining but during the mid 1950's an average ore from deposits near Fredericktown contained about 3 percent lead, 0.90 percent copper, 0.25 percent nickel, and 0.20 percent cobalt.

During the 1950's, the National Lead Co., in part assisted by an exploration contract with the Defense Minerals Exploration Administration, explored an area southeast and east of Fredericktown. Drilling in the Higdon area (fig. 15) discovered a significant deposit in the Bonneterre Formation, about 1,500 feet below the surface. The Bunker Hill and National Lead Companies undertook to develop the deposit jointly. Two shafts were sunk and work started on the surface plant and concentrator. Although originally scheduled for completion in 1968, further development was suspended in May 1967, pending a more favorable price outlook. The Higdon area has the deepest deposits known in southeast Missouri and reportedly contains about 10 million tons of reserves with favorable prospects for finding additional ore.

Viburnum trend.—The discovery of lead ore near Viburnum in 1955 by the St. Joseph Lead Co. extended the area of lead deposits to a part of southeastern Missouri not previously known to contain ore. The exploration program began in 1947 (Weigel, 1965) and was assisted in part by the Defense Minerals Exploration Administration. Following the initial discovery, intensive exploration by a number of companies has found numerous ore bodies along a zone that stretches for some 30 miles south of Viburnum. According to Weigel (1965, p. 77) this zone, or trend as it is called, ranges in width from a few hundred yards to more than 2 miles. It is not a continuous deposit, but rather a series of ore bodies that vary in thickness and width. The full extent of the trend may not yet be known. The discovery of large new deposits has led to development of a number of mines, mills, and smelters; these will be described briefly below.

The St. Joseph Lead Co. has developed three mines in the vicinity of Viburnum, all of which are operated through shafts. Shaft No. 27—the first one sunk—is near Czar Knob, in Crawford County. The shaft is 804 feet deep and about 2,000 tons of ore are produced from it per day. Production from the mine started in 1960. Shaft No. 28 is in the northwest corner of Iron County. This shaft is 910 feet deep and has a productive capacity of about 3,000 tons of ore per day. The St. Joseph Lead Co. concentrating plant is at the collar of the No. 28 shaft. Ore from all three mines is concentrated at this plant, which has a capacity of about 7,500 tons of ore per day. The third shaft sunk by the company, No. 29, is near Courtois, in Washington County. Production from this 595-foot shaft started in 1964. Although in different counties, the three mines are quite close spatially (fig. 15). Through 1965, the St. Joseph mines near Viburnum had produced 190,034 tons of recoverable lead.

South of Viburnum, near Bixby, the Magmont mine and mill were being developed jointly by Cominco American, Inc. and the Magnet Cove Barium Corp. in 1966. A 1,200-foot shaft is being sunk at the mine, which is estimated to have more than 15 million tons of reserves. Planned production from the mine is about 4,000 tons of ore per day, and output of pig lead from mill concentrates is estimated at 50,000 tons annually. The property is expected to be brought into production late in 1967 or in 1968.

Near Buick a mine, mill, and smelter complex is being developed jointly by the American Metal Climax, Inc. (Amax), and the Homestake Mining Co. The joint venture will be operated by a subsidiary organization, the Missouri Lead Operating Co. The Buick mine will have a productive capacity of 4,000 tons of ore per day and will be operated through two shafts, both slightly more than 1,350 feet in depth. The ore will be mined from flat-lying tabular ore bodies in the upper part of the Bonneterre Formation. According to the December 1965 issue of Missouri Mineral Industry News, the width of the ore bodies ranges up to several hundred feet, the thickness from a few to nearly 100 feet, and the lengths extend to well over a mile. Reserves are estimated at about 38 million tons, the grade of which ranges from

4 to 6 percent lead and about 1 percent zinc. A concentration plant is being built by the Missouri Lead Operating Co. at the mine site. Planned production rate of the mill is equivalent to 50,000 tons per year of refined lead and 10,000 to 15,000 tons per year of zinc concentrates. A smelter is being constructed 2.5 miles to the north which will have the capacity to produce 100,000 tons of pig lead and 50,000 to 70,000 tons of sulfuric acid annually. The smelter also will process the lead concentrates from the nearby Magmont mine. Cost of the complex is estimated at $35 million. Production from the mine and smelting plant is expected to start late in 1967.

The Frisco Railroad Co. is constructing a 32.3 mile spur line from Keysville to the Missouri Lead Operating Co. mine. This is the longest railroad built in the United States in recent years. The Missouri Highway Department also is building a highway from West Fork to the smelter.

The American Smelting and Refining Co. has delineated a lead deposit by diamond drilling about 8 miles south of Bixby, where the West Fork of the Black River crosses the Viburnum trend. The deposit is believed to be of substantial size but the company has not announced plans to develop it.

The St. Joseph Lead Co. is developing the Fletcher mine, about 1 mile south of the American Smelting and Refining Co. West Fork property. Construction of the mine plant began in 1963 and was completed and brought into production in 1967. It consists of 2 shafts about 300 feet apart. Ore will be mined at two levels, at 980 feet and at 1,116 feet. The concentration plant is located at the mine site and will have a capacity of 5,000 tons of ore per day. Concentrates will be trucked to the railroad at Buick and shipped to the company smelter at Herculaneum for processing. About 60,000 tons of pig lead are expected to be produced from the mill concentrates. The Herculaneum smelter had a capacity to produce 110,000 tons of refined lead per year in 1963; however, the smelter is being modernized and the capacity is being expanded to a rate of more than 200,000 tons of refined lead per year. A byproduct sulfuric acid plant capable of producing 100,000 tons of acid per year also is being constructed.

The Kennecott Copper Corp., through its exploration subsidiary, the Bear Creek Mining Co., has discovered extensive lead deposits near Logan Creek in the southern part of the Viburnum trend. An operating subsidiary of Kennecott, Ozark Lead Co., currently is developing a mine on Adair Creek, about 10 miles northwest of Ellington, to exploit the deposits. The mine will be operated through a shaft sunk to a depth of 1,430 feet. Development of the ore bodies will be on levels from 1,100 to 1,200 beneath the surface. About 6,000 tons of ore per day is expected to be extracted. A concentrating plant is being constructed at the mine site. The concentrates are expected to yield 60,000 tons of refined lead and 8,000 tons of zinc annually. The concentrates will be processed at an American Smelting and Refining Co. custom smelter, which will be constructed at Glover, about 10 miles south of Ironton, on the Missouri & Pacific Railroad. The smelter will have an initial capacity to produce 78,000 tons of refined lead annually. It is expected to be in operation by the end of 1967.

Indian Creek.—The Indian Creek mine in Washington County was the first major discovery in southeast Missouri away from the Lead belt. The mine was brought into production in 1953 by the St. Joseph Lead Co., following the discovery of lead deposits in 1947 by diamond drilling. From 1954 through 1963, the Indian Creek mine produced more than 4.5 million tons of ore (company report). The mine is operated through two shafts, No. 23, a 950-foot production shaft, and No. 24, a 729-foot auxiliary and ventilation shaft. Mill capacity at the mine is 2,500 tons of ore per day. An ore deposit on Goose Creek, about 1½ miles northeast of the Indian Creek mine, is being developed by the St. Joseph Lead Co. but is not scheduled to be brought into production before 1968. Ore from this mine will be trucked to the Indian Creek mill for concentrating.

Potosi-Palmer.—Lead mining started in Washington County at Mine Renault and Old Mines about 1725. Mine a Burton was discovered at Potosi in 1763 and the first reverbatory furnace was built at Potosi before 1802. The Fourche a Courtois deposits were discovered in the Palmer area in 1814 and the first furnace was built at Palmer in 1832. Peak production from the Palmer area appears to have been in 1873 when about 416 tons of lead was produced. A few carloads of zinc carbonate ore were shipped from the area in 1915 and 1916. Initial production from the Potosi and Palmer areas was residual ore from red clays, the product of previous solution of overlying dolomite and subsequent gravity concentration of the ore (Dake, 1920, p. 211). Lead ore also was mined from "runs" or solution channels, in which the ore had a greater horizontal than vertical extent. The mine workings were shallow and above the water table. Most of the ore was from the Potosi Dolomite, although some was mined from the Eminence Dolomite. Barite also was mined from residual clays in the Potosi and Palmer areas, and in recent years has accounted for a sizable part of Missouri's mineral output. Minor amounts of galena are recovered as a byproduct from the barite mines. Although some exploratory drilling has been done in these areas in recent years, there are no reports of lead discoveries. No lead mines have been productive in the Potosi-Palmer areas in recent decades.

Valle Mines.—Valle Mines area is largely in the southern part of Jefferson County (fig. 15). Mining started in the area about 1824 but was most active in the late 1800's and in the period 1909–17. Aside from some dump material shipped during World War II, the area has been idle since 1917. Ore was mined from a number of shallow workings, most of them less than 200 feet deep, and was similar to that mined in the Palmer and Potosi area except that it was higher in zinc content. The zinc carbonate, smithsonite, was the most common ore mineral. Barite also was common in the ores. The ore occurred in residual red clay and as cavity fillings. The deposits were relatively flat lying, extending over considerable horizontal area but with little thickness.

Annapolis.—Lead ore has been mined from a deposit about 1 mile east of the town of Annapolis. The ore was mined through a shaft, reported to be about 450 feet deep, which was sunk in the early 1920's. The mine was operated intermittently during the 1920's, and for a short period from 1938 to 1940. It has been idle since then. The ore

occurs in coarse-textured dolomite close to the contact with Precambrian rocks, which crop out throughout the area. Drilling northwest of Annapolis is reported to have encountered substantial quantities of lead-bearing material but the grade and extent of the deposit is not known to the writers.

Resources and outlook

Southeastern Missouri contains vast reserves of lead ore and enormous potential resources. Weigel (1965, p. 77) estimates that the Viburnum trend alone has a potential of 30 million tons of lead, with considerable copper and zinc. This would be more than three times as much lead as has been mined from the Lead belt. In addition to drilled reserves and potential resources in the Viburnum trend, there are substantial reserves in the Lead belt, where exploratory drilling for new deposits continues. The finding and current development of the Higdon deposit east of Fredericktown suggests that other deposits of this type remain to be found in the Lead belt-Fredericktown area. Most of the ore mined along the northern side of the St. Francois Mountains has been from residuum, from near-surface deposits, or from formations well above the Bonneterre. However, the discovery of the Indian Creek deposit in the Bonneterre Formation raises the possibility that deposits of similar type remain to be discovered in the general arclike region between the Palmer and Valle Mines areas. The southeastern side of the St. Francois Mountains also is a target for potential deposits, as are the western and southwestern and southern sides of Precambrian outcrops in the vicinity of Eminence.

The magnitude of lead discoveries made in southeastern Missouri during the 10-year period prior to 1966 is unprecedented in the history of lead mining in the United States. These discoveries have led directly to the boom in lead-mine development which Missouri currently is enjoying. According to information released by mining companies active in the area more than $140 million is being spent in mine and surface plant developments. The cost of exploration, property acquisition, future development, and supporting services such as roads, railroads, powerlines, etc. raise the total cost of bringing the area into production much higher. Output of metals from these developing mines will have a beneficial effect on the economy of Missouri and will significantly increase the domestic production of lead. For example, mine production of lead in the United States, during the period 1956 to 1966, averaged slightly more than 279,000 tons annually. However, by 1968 Missouri will have the capacity to produce approximately 375,000 tons of lead annually, or one and a third times the annual average National output during the past ten years. This increase should enable the Nation to meet its requirements for primary lead from domestic sources, a supply position we have not had for many years. Furthermore, the size, mining type, and geographic location of these deposits should make them competitive with deposits in other parts of the world in times of adverse economic conditions.

In summary, the outlook for lead mining in southeastern Missouri is bright, indeed. Far more lead remains to be mined than has been mined in the past and the possibilities for continued discoveries are encouraging.

Southwestern Missouri

The principal zinc and lead deposits of southwestern Missouri, together with those in adjacent parts of Kansas and Oklahoma, form the Tri-State district, one of the most productive mining districts of the world. The Missouri part of the Tri-State extends from the Kansas border eastward approximately 55 miles to the eastern part of Lawrence County and from Neosho, Newton County, northward about 30 miles to the North Fork of Spring River, some 12 miles north of Joplin (fig. 16). Lesser deposits are scattered as far east as Wright, Douglas, and Ozark Counties (fig. 12).

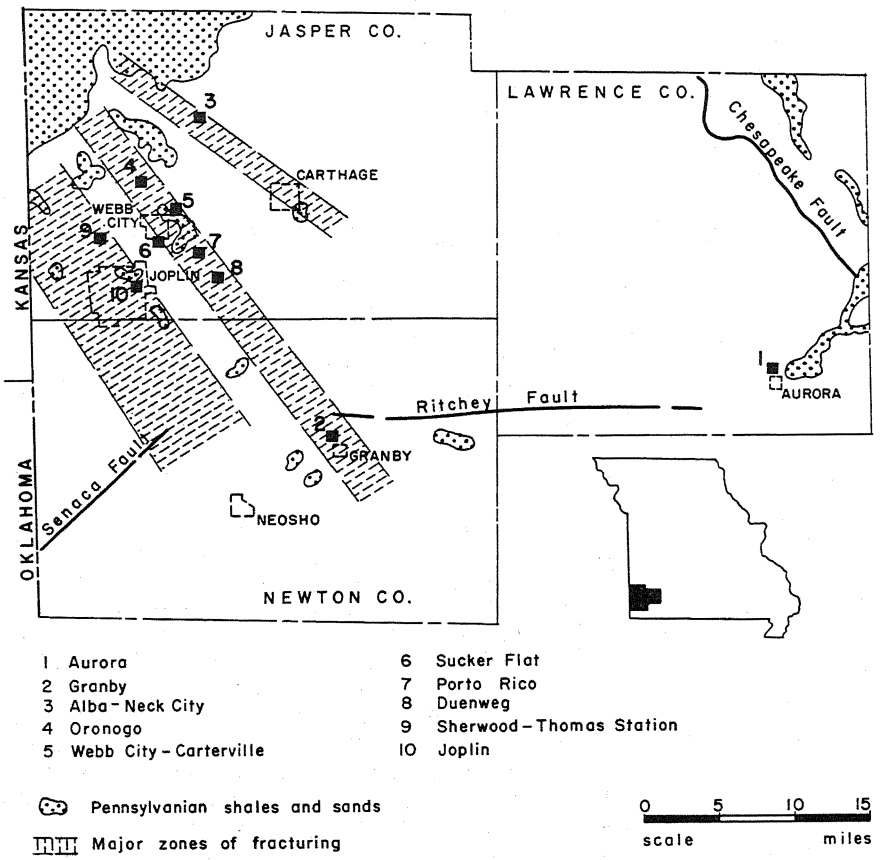


FIGURE 16.—Missouri part of the Tri-State zinc-lead district.

Most of the discussion to follow deals with the Missouri part of the Tri-State district; the outlying areas are described separately.

History and production

The first mining activity in southwestern Missouri, according to Winslow (1894, p. 281), was for lead ore about 2 miles east of Joplin,

Jasper County, in 1848. Mining activity soon expanded into surrounding areas and reached its greatest development at Granby in Newton County. Granby was the most important mining camp in the district during the two decades of 1850–59 and 1860–69. Records indicate that total ore production from southwestern Missouri in the former decade accounted for about 17,840 tons of contained lead valued at $1,926,720; from 1860 through 1869 production declined to 9,030 tons of contained lead worth about $1,535,100. Interruptions in mining activities had taken place during the Civil War years. Zinc ores were not mined or were discarded as waste in the initial 20 years of mining in this area.

The discovery of large quantities of lead ores in 1870 within what are now the Joplin city limits is generally considered to be the starting point in the district's growth to national prominence (Winslow, 1894, pp. 294–295). Mining was pursued actively, and a number of lead furnaces were operated continuously. Zinc mining began the same year at Granby upon completion of the St. Louis & San Francisco Railway westward to Pierce City in Lawrence County in 1870, which provided a means of transporting these ores to the smelting furnaces near St. Louis and in Illinois. The initial shipment of zinc ores from Joplin was made to the zinc works at LaSalle, Ill. in 1872. The first zinc works built in the tristate area was at Weir City, Kans., in 1873. Additional zinc works were built in Missouri at West Joplin and at Rich Hill in Bates County in 1881 and 1882 (Winslow, 1894, p. 302). By that time, the Missouri Pacific and the Kansas City, Fort Scott, and Gulf Railroads also had built branch lines to serve the new towns in the mining district.

By 1874, the population of Joplin had reached 5,000, and important new ore discoveries had been made nearby at Oronogo, Webb City, and Carterville. Missouri became the leading producer of zinc ore among the States in that year. The State maintained this position until 1918, a span of 43 years, except for 2 years (Bishop, 1949, pp. 83–87). Nonetheless, the value of lead production from southwestern Missouri was more than double that of zinc in the decade 1870–79; $11,063,400 for lead and $5,141,400 for zinc (Martin, 1946, p. 23).

The tempo in mining increased tremendously between 1880 and 1900, and the value of zinc production greatly exceeded that of lead. Mining became larger in scale and the center for major activities shifted from Granby to the Joplin region and Galena, Kans. During 1892, the Jasper County mines produced over 100,000 tons of zinc ore and about 11,000 tons of lead ore.

In southwestern Missouri, the practice of subleasing small tracts for mining had developed in the early days. In Jasper County these were often as little as 100 or 200 feet square. This led to numerous, small independent operations where mining and ore-dressing methods were usually crude and inefficient. Customary royalty payments were about 10 percent of the net smelter return, and pumping charges were another 5 percent. For larger tracts, the lease periods were as much as 10 years, and royalties usually 7½ to 10 percent (Winslow, 1894, preface to vol. 6). The system of subleasing of small tracts and the crude mining and milling methods persisted into the periods of large-scale production in the 1890's and even into the 1930's.

Mine production and value of zinc and lead continued to climb early in the 1900's. Larger and richer ore bodies were discovered in 1911 and 1912, near Picher, Okla, and mining activities began to shift to the new area (Bishop, 1949, pp. 85–87). Nevertheless, the alltime record mine production of recoverable zinc and lead for any year in southwestern Missouri was achieved during 1916. This amounted to 155,527 tons of zinc and 30,827 tons of lead with a total value of about $45,935,400. The production value declined to about $32 million in 1917 and to less than $12 million in 1918, when Oklahoma for the first time surpassed Missouri in mine production of zinc.

After 1917, annual production of recoverable zinc in Missouri never again approached 100,000 tons. In fact, during the final 40 years of production in the district from 1918 through 1957, average yield of recoverable zinc and lead was only about 16,800 tons per year. Since 1957, no zinc or lead production had been reported from southwestern Missouri until 1966 when one small operation a mile north of Duenweg, Jasper County, shipped ore to the Eagle-Picher mill at Cardin, Okla.

Geology

Surface rocks in the Tri-State district are mainly Mississippian limestones containing varying amounts of chert, but numerous small Pennsylvanian shale outliers have been preserved in sink structures southeast of the Pennsylvanian outcrop line (see fig. 2). The main Pennsylvanian outcrop area is in general limited to the area northwest of Spring River. The Mississippian rocks, in which the zinc and lead ores occur, range up to 400 feet in thickness. They are fine to coarse grained and medium to thick bedded. Chert nodules and bedded cherts are characteristic of the lower part, and in places, form massive chert masses.

The Devonian Chattanooga Shale underlies the Mississippian limestone to the south; its most northern subsurface occurrence is some 10 miles south of Joplin. From this east-west pinchout, it thickens southward to approximately 50 feet at the Arkansas State line. Ordovician cherty dolomites, with minor sandstone units, underlie the Chattanooga and attain an average thickness of approximately 800 feet. Cambrian dolomites, the host rock of valuable lead deposits in southeast Missouri, are thin and are encountered at depths of from 1,200 to 1,500 feet. Deep exploratory test holes have penetrated Precambrian granites in the Tri-State district, and data from these cores indicate the Paleozoic sedimentary rocks have been deposited on an uneven Precambrian surface.

The cherty Mississippian limestones are essentially flat lying with only a slight regional dip to the northwest. The Keokuk, Warsaw, and parts of the Reeds Spring and Grand Falls Formations are the host rocks for the lead and zinc mineralization. The Kinderhookian, Osagean, and Meramecian Series were formerly called the "Boone," and many early publications describing the ore deposits refer to the "Boone" formation.

Detailed underground studies by Fowler and Lyden (1932) established mappable units of the Osagean Series and Warsaw Formation that have proved valuable in structural studies and exploration for new or extended ore deposits within the Tri-State district.

Major faulting in the Missouri part of the Tri-State is limited to the Ritchey fault extending westward from south-central Lawrence County into Newton County and the Seneca fault that extends northeastward from near Seneca on the Missouri-Oklahoma line. Minor folds of relatively small magnitude are generally alined in a northwest-southeast trend and coincide with several major mineralized areas. The importance of fracture or shear zones as loci for ore deposition is illustrated by Fowler, Hernon, Conrow, and Stone (1955). Three major zones of fracturing are shown in figure 16.

Where mineralized, the cherty limestone country rock has been altered in varying amounts to dolomite and subjected to silicification that has resulted in the formation of massive chert and dark brown to black jasperoid.

Ore minerals of the district are chiefly sphalerite and galena, sphalerite being approximately four times as abundant as galena. Secondary oxidation minerals of lead and zinc are relatively sparse, although the lead and zinc carbonates (cerussite and smithsonite) and the zinc silicate (hemimorphite) have been mined in the past from shallow diggings.

The Joplin area is noted for exceptionally large crystals that lined open cavities, or vuglike openings, encountered in mining operations. Typically, the surfaces of many openings were lined with a druse of small dolomite rhombs, individual crystals of large calcite scalenohedrons, and small crystals of sphalerite, galena, pyrite, marcasite, and chalcopyrite. Bornite, enargite, barite, and wurtzite are associated with the ore, but only rarely. Greenockite (CdS) is closely associated with sphalerite as a thin yellow-green coating and was the source of part of the cadmium recovered during World War II as a byproduct of smelting.

Ore deposits

During the early mining phases in the Tri-State, shallow deposits in crevices and small openings in the bedrock, from the grass roots to a depth of some 75 feet, produced mainly oxidized ores. Major deposits in the "Boone" limestone are of three main types: circles, runs, and sheet ground.

Most circle deposits are relatively shallow and associated with sinkholes in the limestone in which Pennsylvanian shales were either deposited or slumped. The areas of Pennsylvanian outliers and small surface exposures of shale were recognized in the early stages of prospecting as guides to potential deposits. Some of the smaller circle deposits were mined by underground methods, but slumping of the shale always posed problems of roof support. In the 1930's and 1940's several of the larger circle deposits were mined by open-pit methods. Two of the most noteworthy were the Oronogo and Sucker Flat circles. A number of rather large circle deposits between Oronogo and Duenweg were mined to depths of 225 feet.

Most of the ore production from the Tri-State has been from deposits described as "runs." These are essentially linear deposits associated with fractures or shear zones that allow solutions to penetrate the limestone. Silicification in the form of chert has resulted in complete replacement of the limestone by chert in many areas. Brecciation of the limestone and chert was followed by deposition of the

77-278 O—67——5

lead and zinc ores. A very common ore type is a chert breccia cemented with jasperoid (a dark brown to black chert containing impurities of finely disseminated minerals), ore and gangue minerals.

Sheet ground deposits apparently are not controlled by major structures, but were formed by mineralizing solutions depositing lead and zinc minerals in horizontal or somewhat tabular form that are concentrated along bedding planes, stylolites, and other minor structures. Sheet ground deposits have been important throughout the Tri-State district, particularly in the Granby and Joplin areas.

Eastern part.—Lead and zinc were first mined in Greene, Webster, and Christian Counties near Springfield in the 1850's. Many small mines and prospects were developed prior to 1900 in this eastern outlying part of the southwestern Missouri district (fig. 12) in Greene, Christian, Webster, Taney, Ozark, Wright, and southeastern Dade Counties (Winslow, 1894, p. 623–644). Still further east a small quantity of lead and zinc was mined in Texas and Howell Counties (Neuschel and McKnight, 1948). Data are incomplete, but production of lead and zinc in these outlying areas was substantial, when compared to the rest of the district, in the years 1858 to 1893 (Winslow, 1894, p. 539), and again during the First World War (U.S. Geological Survey, 1914, 1915, 1916, 1917, 1918). The recorded production during these two periods is as follows: From 1858 through 1918 (not including the period 1894–1913 in which data are incomplete), 14,327 short tons of lead valued at $1,562,232 and 33,302 short tons of zinc valued at $5,217,088. If estimated production is included for the years 1894–1913 and after 1918, the total lead and zinc production for the outlying areas of the southwestern Missouri district probably approaches $10 million. Very little, however, has been produced since 1945. Commercially the most productive subdistricts were the Ash Grove-Everton area northwest of Springfield, the Springfield area, the Ozark area in northern Christian County, the Caulfield area in eastern Ozark County, and the Seymour-Mansfield area in Webster and Wright Counties.

The deposits are in the eastern part of the Springfield Plateau, in the dissected hills and valleys that lie north of the White River. The rocks range in age from Early Ordovician through Mississippian. Most of the deposits are very similar to, although smaller than, the deposits in the Tri-State district to the west. Runs occur along linear crevice zones in cherty limestones and limy shales near the base of the Mississippian limestone (Neuschel and McKnight, 1948). Small sheet-ground deposits, breccias, solution channels, and possibly circles occur in the cherty parts of the formation above these runs. Residual deposits of galena, smithsonite, and hemimorphite have been mined that consist of a mixture of weathered ore, chert fragments, and red tallow clays (Winslow, 1894; Heyl and Bozion, 1962). Some of the more eastern areas are in Ordovician dolomites such as the Jefferson City and Cotter Dolomites in the Lower Ordovician sequence. In such localities, as at Mansfield and Caulfield, ore deposits occur along faults (Winslow, 1894, p. 638), but most of them are runs along breccia zones and blanket veins in certain slightly deformed and shattered beds.

Mineralogically the deposits are identical with those in the Tri-State district and in the northern Arkansas district to the southeast

(McKnight, 1935, p. 106–122). Because of shallow depth and oxidation, most of the galena, sphalerite, and marcasite are oxidized or partly so, and the deposits contain large quantites of cerussite, smithsonite, hemimorphite, limonite, and traces of copper carbonates.

Resources and outlook

Following the shutdown of producing mines in the Missouri part of the Tri-State, most of the workings have become flooded. Although considerable tonnage of ore remained in place, economy dictated the gradual closing of the many small mines.

Studies by the U.S. Bureau of Mines (Ruhl, Allen, and Holt, 1949, p. 16) of ore reserves at the end of 1947 indicate a total of 5,249,700 tons of ore on a 2-percent cutoff capable of producing 273,661 tons of 60 percent zinc concentrate and 13,724 tons of 80 percent lead concentrate. These estimates were based on measured, indicated, and inferred ore. Although the tonnage figures are considerable, most deposits are small or flooded and in all probability could not be mined economically under present conditions.

Several deep test holes to the Precambrian have been drilled (mainly in the Picher field in northeast Oklahoma) in order to explore the possibilities of mineralization in Ordovician and Cambrian strata. To date, these tests have not been promising.

For the past few years several major mining companies have been active in exploration projects in northeast Oklahoma, northwest Arkansas, and southwest Missouri. Additional aeromagnetic surveying adjacent to the area surveyed by the U.S. Geological Survey in 1946 has been undertaken and exploration drilling is in progress in several areas.

The area flown by the U.S. Geological Survey covers an area approximately 14 miles from the Kansas State line eastward and from 2 miles south of the Newton-Jasper County line northward for 17 miles (see fig. 5, p. 24). A more recent aeromagnetic project—undertaken by private mining companies—was flown in the area south and west of Picher, Okla.

Most of the known deposits in the outlying eastern areas of the Southwest district are small and largely worked out. The market for the oxidized ores has largely vanished. No mining and little prospecting has been done in recent years, but the possibility exists that other deposits occur in the Ordovician rocks beneath the Springfield Plateau, similar to those mined in the easternmost areas and in northern Arkansas. As elsewhere in western Missouri, some possibility exists for the discovery of new deposits in the lowest Paleozoic carbonate rocks marginal to buried monadnocks, fault zones, and possible reef structures.

Because of similar stratigraphic and structural conditions to the south and west of the Picher field, exploration is anticipated in this direction. Exploration activity is expected to increase in northwestern Arkansas and southwestern Missouri in the near future.

Central Missouri

Morgan, Miller, Camden, Moniteau, Cooper, and Cole Counties in central Missouri comprise a mineralized district of about 2,000 square miles that includes many small deposits of barite, lead, and zinc

(Winslow, 1894). From 1830 to 1910, lead was the principal product of the district, but since then most of the mining has been for barite with galena as a minor byproduct. Lead production to 1947 had totaled 24,855 short tons, valued at $2,703,734 (Bishop, 1949, p. 42). Since 1950 no lead and very little barite (see p. 99) has been produced. Zinc output prior to 1945, the last year of production, totaled 7,032 short tons, valued at $715,127 (Bishop, 1949, p. 84).

Geology

The mineral deposits are on the northwest flank of the Ozark uplift in a gently flexed thin succession of strata that range in age from Late Cambrian through Pennsylvanian. Most of the exposed formations are limestone or cherty dolomite, but several sandstone units are present; also, coal and shale occur within the Pennsylvanian strata. All of the formations, including the Pennsylvanian sandstones and shales, are mineralized, but the most of the commercial deposits occur in dolomites of the Gasconade, Roubidoux, and Jefferson City formations of Ordovician age. Barite-rich deposits are principally restricted to the Roubidoux, Jefferson City, and Burlington formations.

The structure in the central Missouri district is relatively simple. The beds dip gently northwestward and are flexed into several gentle northwestward-trending anticlines and synclines. The most notable fold is the Proctor anticline that extends for at least 35 miles from Camdenton toward Sedalia (fig. 3). The Proctor anticline has an average dip of 4 degrees on its southwest flank and 1 degree on its northeast flank. Northeast of this fold a syncline extends northwestward through Versailles; on its northeast side a gentle anticline extends from the southeast part of Miller County northwestward for at least 75 miles to Marshall.

According to Mather (1947, p. 3), vertical and steeply dipping faults parallel the folds in the district. In addition, horizontal intraformational thrusts and bedding plane faults are common in cherty Ordovician rocks. A fault of fairly large vertical displacement extends northwestward from the Decaturville cryptoexplosion structure for at least 15 miles across the Osage River. Small mineralized faults, breccia zones, and sharp fractured flexures are found in the district, particularly near the crest of the Proctor anticline. Breccia zones along bedding-plane faults are found east of the Proctor anticline. Caves and solution channels are common throughout the district.

Many of the mineral deposits lie along the crests of the two major anticlines, in particular the central part of the Proctor anticline. Others lie on the gentle east flank of the Proctor anticline and many others on the gentle flanks of the other large anticlines.

Ore deposits

Barite, lead, zinc, and pyrite deposits occur in fissure veins, gash veins, breccia, solution channels, circles (cone-shaped breccia deposits with a barren core), filled-sinks (funnel-shaped mineralized sinkholes), solution channels, replacement bodies, and residual concentrations. These types of deposits have been described in detail by Winslow (1894), Marbut (1908), Mather (1946, 1947), and Grawe (1945). A relatively large, although low-grade, mineralized area is near the center of the Decaturville cryptoexplosion structure where brecciated

zinc-lead ores cement a dolomite breccia. Most of the lead and zinc was mined from veins, circles, breccias, and residual deposits.

The mineralogy of the ores is simple. The main minerals in their general sequence of deposition (according to Mather, 1946, p. 43) are quartz (including jasperoid), pyrite and marcasite, silver-lean galena, sphalerite, barite, and calcite. In a few places, a little chalcopyrite is deposited early and late in the sequence, and in places after renewed faulting, some late sphalerite and barite is deposited. Much of the pyrite has been altered to limonite and hematite near the surface. Galena is generally more abundant near the outer walls of the circle structures and barite is more abundant in the central parts. Sphalerite occurs sparsely throughout. The many colloform crusts, the sequence of deposition of the minerals, and crystal habits of the sulfides and barite are distinctive from the mineralogy in both the Southeast and Southwest districts. These facts in themselves suggest that the Central district is a distinct center of mineralization, probably deposited by warm fluids that tended to concentrate along the northwest-trending anticlines in the available faults, circles, and other openings.

Most of the known deposits in the central Missouri district are too small to be significant sources of lead and zinc. Although barite has been produced in substantial quantities, and small tonnages of byproduct galena concentrates were recovered from time to time, even the barite deposits have been largely exhausted. The lead-zinc breccia deposit at Decaturville possibly contains substantial tonnages of low-grade ore. Perhaps the best hope for the future in this district is to search at depth in the Bonneterre Formation for deeply buried deposits that might resemble those in southeastern Missouri.

COPPER

(By A. R. Kinkel, Jr., U.S. Geological Survey, Washington, D.C.)

The principal uses of copper derive from its physical properties, which include high electrical and thermal conductivity, ductility, malleability, strength, and corrosion resistance. The greatest consumption of copper is for electrical applications such as power generation and transmission, communications, industrial and home electrical equipment, electronics, and the electrical systems of transportation equipment (marine, air, and land). Other applications of copper and copper alloys include pipe and tubing for air conditioning, plumbing, and fluid and gas transmission lines.

Aluminum is the principal alternate or substitute for copper, especially in power transmission lines and equipment; radio, telegraph, and telephone equipment; engine electrical equipment; and metal stampings. Stainless steel, copper-clad steel, other copper-clad metals, plastics, and other materials compete with copper in a great variety of end products.

The United States is the world's leading copper producer; its output of newly mined copper in 1965 was 1.35 million tons, 23 percent of the world total of 5.6 million tons. Domestic production from the start of mining through 1965 has been 52.2 million tons. Leading States are Arizona, Utah, and Montana. Missouri's contribution has been small, only about one-tenth of 1 percent of the national total, but fairly continuous, amounting to about 60,000 tons valued at $28 million (table

6). Some early production was from deposits mined principally or entirely for copper, but most of the output has been byproduct from lead ore and a small amount has been a coproduct of lead-copper-nickel-cobalt ore.

Nearly all the copper mined in Missouri has come from lower Paleozoic rocks in the central part of the Ozark uplift; one copper-iron deposit has been found in the underlying Precambrian rocks but has not yet been mined. A very small amount of copper accompanied the zinc-lead ores in Mississippian rocks of southwest Missouri. The common primary mineral is chalcopyrite, $CuFeS_2$; secondary sulfides, oxides, and carbonates have formed in some shallow deposits.

TABLE 3.—*Copper production in Missouri, 1838–1965*

[No production recorded for years omitted]

Year(s)	Short tons	Value (thousands)	Year	Short tons	Value (thousands)
1838–40	[1] 300	[1] $120	1950	2,982	$1,241
1844–46	[1] 30	[1] 12	1951	2,422	1,172
1857–63	[1] 30	[1] 16	1952	2,576	1,247
1870	[1] 24	[1] 10	1953	2,374	1,363
1882–1906	[1] 735	[1] 220	1954	1,925	1,136
1907–10	[1] 1,575	[1] 401	1955	1,722	1,285
1911–30	4,834	1,659	1956	1,890	1,606
1934–37	517	110	1957	1,604	965
1940	685	155	1958	1,429	752
1941	1,400	330	1959	1,065	654
1942	1,300	315	1960	1,087	698
1943	1,340	348	1961	1,479	887
1944	3,302	892	1962	2,752	1,695
1945	3,399	918	1963	1,816	1,119
1946	1,857	602	1964	2,059	1,343
1947	1,760	739	1965	2,331	1,650
1948	2,370	1,029			
1949	3,670	1,446	Total	60,641	28,135

[1] Estimated.

Source: 1838–1947, Bishop, 1949, p. 29. 1948–65, U.S. Bureau of Mines.

Copper was known in the Eminence area, Shannon County, (fig. 17) about 1837 and some mining was done in the period 1838–40. Several deposits in this area were worked on a small scale at various times up to the late 1920's. Copper minerals occur along an unconformity between Precambrian rhyolite and tuff and the overlying Eminance Dolomite of Cambrian age. Ore occurs mainly as secondary copper minerals in a lenticular basal conglomerate as much as 12 feet thick composed of rhyolite pebbles in a calcareous matrix. The conglomerate appears to have been deposited in basins on a Precambrian surface of considerable relief. The ore minerals, including chalcopyrite, also fill in fractures in the underlying rhyolite and locally in the overlying dolomite. The principal deposit is the Slater mine, 1½ miles east of Eminence, but several nearby deposits have been explored (Bridge, 1930; Bain and Ulrich, 1905). The production records are fragmentary; Bishop (1949, p. 28–29) estimates an output of 300 tons for the initial mining period. The most recent activity was in 1924–27, when the Sutton mine, 4 miles southeast of Eminence, made two shipments of ore containing about 8½ tons of copper to a smelter in New Jersey (Bridge, 1930, p. 178). One car, of selected ore, averaged 27.29 percent copper.

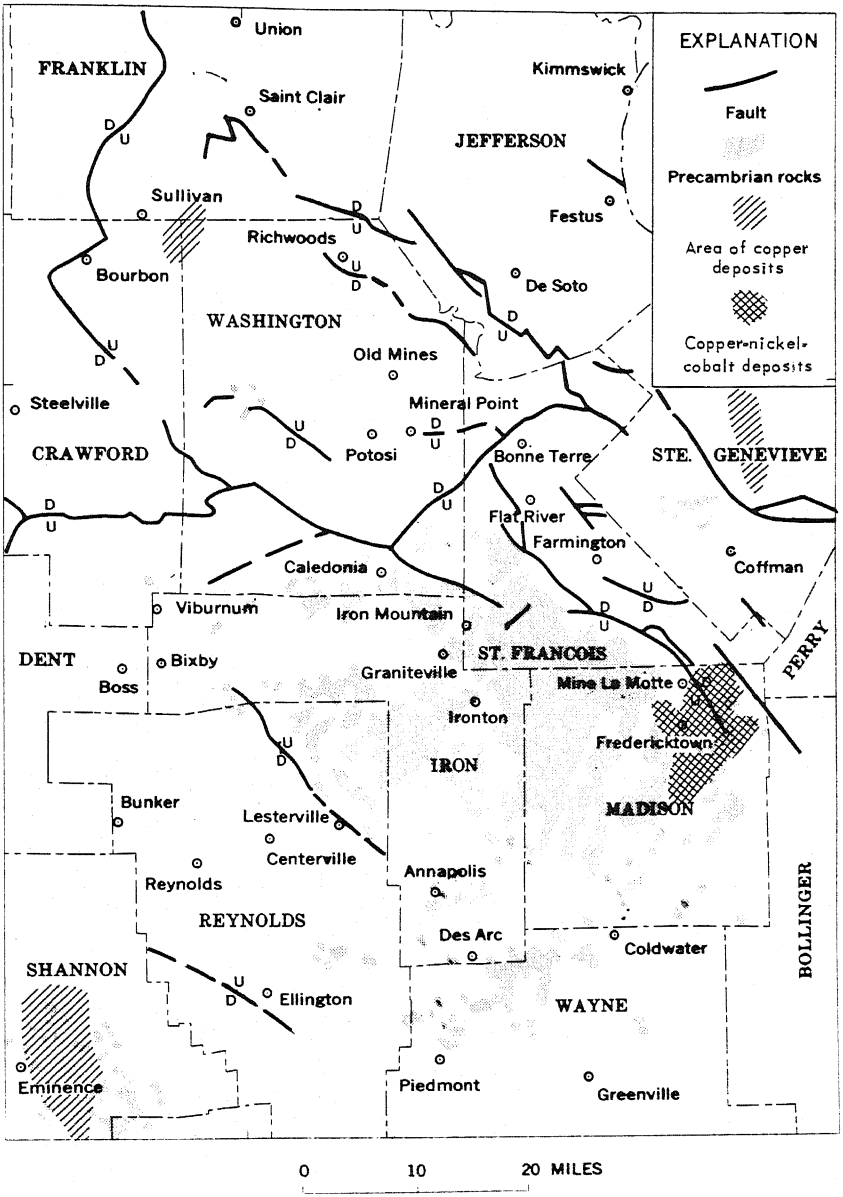


FIGURE 17.—Copper, and copper-nickel-cobalt deposits of southeastern Missouri.

Copper ore was discovered in Ste. Genevieve County (fig. 17) in 1863 and for the next 25 years sporadic operations produced a considerable tonnage of fairly high-grade ore (Weller and St. Clair,

1928; Bain and Ulrich, 1905). A 16-percent grade is said to have been commonly produced, but this was probably sorted ore. Ore occurs at several horizons marked by unconformities in the Powell Dolomite of Early Ordovician age. The country rock is coarse magnesian limestone with numerous flint nodules and bands of chert.

Weller and St. Clair (p. 332) state:

> The ore occurs as a replacement and impregnation of soft, porous chert beds, as a cement in sedimentary breccia, in small chimneys at vertical fractures, and irregularly filling erosion depressions in the dolomite. . . . Evidently chalcopyrite was the primary copper mineral and its alteration has produced some of the oxidized and enriched minerals.

Ore occurs principally at two horizons about 125 feet apart; a third horizon has also been explored. Churn drilling extending 1,800 feet from the workings showed that copper is present along the main ore horizon to this distance (Bain and Ulrich, 1905, p. 39). Nicholson (1882) describes the unoxidized ore as consisting of massive chalcopyrite concordant with bedding, but tending to be lenticular and in places pinching out completely. Breccia formed from broken layers of chert is cemented by chalcopyrite. He states that ore delivered to the smelter contained 18 percent copper and carefully cobbed ore contained 25 percent copper. The ore often contained as much as 50 percent silica.

Copper in minute amounts is found in many of the filled-sink pyrites deposits but only in the Sullivan area (fig. 17) has there been sufficient to encourage development. Bain and Ulrich (1905, p. 47–49) report that prior to 1905 a small amount of high-grade copper ore was mined from sinks in locally silicified limestone in Washington and Crawford Counties. Chalcopyrite and secondary copper minerals are in small irregular bodies in clay mixed with hematite and ocher near the bottom of filled sinks that were mined for iron oxide.

Copper has been a coproduct of the lead-copper-nickel-cobalt ores near Fredericktown, Madison County. Lead ores predominate in this area, but some deposits or parts of deposits have been mined mainly for their copper-nickel-cobalt content. Ore is chiefly in the lower part of the Bonneterre Formation and in the top of the Lamotte Sandstone, near their contact with projecting Precambrian knobs and ridges (Grawe, 1945, p. 361). Galena, siegenite $(NiCo)_3S_4$, chalcopyrite, and iron sulfides are disseminated through the sediments, mainly concordant with bedding; they also occupy fractures and cavities. Some of the ore was rich in copper, but the presence of nickel and cobalt made separation difficult. In the 1840's a small furnace produced a matte that was shipped to England for further refining (Bishop, 1949, p. 30). From 1870 to 1904 another furnace, at Mine La Motte, was in operation. The Buckeye mine at Fredericktown produced copper in the period 1907–10 and 1918–20. Bishop credits this property with about 3,000 tons of copper in these two periods. Grades of 10 percent, 4.0 percent, 2.5 percent, and 2.0 percent copper, cited by Grawe (1945, p. 357–363), illustrate the variable nature of the ore. Renewed activity, beginning in 1944, by the National Lead Co., resulted in additional copper production. Flotation was installed to produce lead, copper, and cobalt-nickel concentrates, each containing small amounts of the other metals because complete separation was not feasible. Kline and others (1961) describe some of the complex-

ities of the processing as practiced in 1956. Average grade of copper in the ore was 0.54 percent. The operation was apparently not profitable, for the mine closed in 1961, after termination of a Government stockpiling contract.

Exact production figures from the Fredericktown district cannot be published. However, it has apparently accounted for about one-third of the total Missouri output, for Kline and others (1961, p. 4) credit the Madison mine (formerly the Buckeye) with 19,000 tons of copper by the end of 1956. Deliveries under the stockpile contract from 1956 to 1959 were 1,420 tons (U.S. Congress, 1962, p. 2822); there could be some duplication in these figures.

More copper has been recovered as byproduct of lead ores in southeast Missouri (see fig. 15, p. 46) than from any other source, and since 1961 this has furnished the entire output. Copper circuits have been installed at the Federal and Viburnum mills of the St. Joseph Lead Co.; in 1965 they resulted in recovery of slightly less than 1 pound of copper per ton milled, or in other words, the ore contained an average of about 0.05 percent copper. Copper production was roughly 2 percent that of lead; it is known that the copper content varies, and that not all the mills have copper circuits now, but if this ratio holds even approximately, copper output may rise to well over 5,000 tons per year as lead output increases to the 375,000-ton level (see p. 43). Preliminary figures indicate that copper production did in fact increase to 3,660 tons in 1966, nearly 3 percent of the total lead output.

Copper occurs in small quantities in the Joplin zinc-lead district of southwest Missouri. The zinc-lead ores are in limestone, and to a lesser extent in chert and shale, of Mississippian age. Chalcopyrite and enargite occur most commonly in sphalerite-rich ore in preference to galena-rich ore, and mainly in areas that have been dolomitized.

One potentially exploitable copper deposit has been found in Precambrian rocks near Boss, Dent County, beneath flat-lying Cambrian rocks. An anomaly on the 1943 State magnetic map drew attention to the area. American Zinc, Lead & Smelting Co. (now American Zinc Co.) began drilling in 1955 and has continued, supported in part by the Defense Minerals Exploration Administration during the period 1958–60, to the present time. Surface and in-hole geophysical studies have aided the exploration. Chalcopyrite and bornite (Cu_5FeS_4) are the chief copper minerals; they occur with magnetite in an acid to intermediate igneous rock intrusive into rhyolite (G. Kisvarsanyi, 1966, p. 92). No tonnage or grade figures have been announced, but the grade is believed to be marginal for both copper and iron (Weigel, 1965, p. 82), and the deposit lies at such depths, about 1,000 to perhaps 3,000 feet, that considerable capital investment would be required to exploit it. The sustained interest on the part of the company suggests, however, that large amounts of copper must be present that could provide substantial output in the future. Similar deposits may well be present elsewhere in covered Precambrian rocks; should they occur without magnetite they would be extremely difficult to find.

Outlook.—Missouri's copper production as byproduct from lead ores should increase not only because the lead output, based on ample reserves (p. 55) is due to rise sharply but because the proportion of copper to lead may rise from 1 to 50 or less to something like 1 to 30 as the Viburnum trend assumes even greater importance. Copper may be

mined as a coproduct of iron at Boss, and here the proximity to the new railroad to Buick (p. 53) should encourage a decision to develop the deposit by providing transportation facilities at low cost. Some high-grade copper ores are known, with or without coproduct metals, in very similar geologic environments to those of the lead ores in the Cambrian strata flanking the St. Francois Mountains, so that there is a distinct possibility that additional deposits will be found in the course of exploration for lead. A continuing annual output of several thousand tons or more of copper can be anticipated; this would constitute perhaps 0.3 percent of the national output.

COBALT AND NICKEL

(By H. R. Cornwell, U.S. Geological Survey, Menlo Park, Calif., and J. S. Vhay, U.S. Geological Survey, Spokane, Wash.)

Cobalt and nickel are tough, lustrous, silver-white metals with similar melting points (close to 1,500° C.), densities, and other physical properties. They commonly occur together in nature associated with iron and copper as sulfides, arsenides, and sulfarsenides in or near mafic, ultramafic, and sedimentary rocks. Both metals are widely used to produce alloys of great strength and resistance to high temperatures and corrosion.

The major uses of cobalt are in high-temperature alloys, hardfacing alloys, tool steels, permanent-magnet alloys, driers for paints, and ground-coat frit for enameling (Bilbrey, 1962, p. 4). Cobalt is also used to color ceramics blue and to neutralize yellow tints caused by iron and other impurities.

Cobalt has been used by man as a coloring agent for 4,000 years, but it was not isolated as a metal until 1742 (Bilbrey, 1962, p. 1). Early in the 20th century, cobalt began to be used in alloys, and as the use of these alloys increased, world production rose from 400 tons in 1920 to 5,500 tons in 1940, and 17,100 tons in 1965. Domestic production, mostly by the Pyrites Co., Inc., Wilmington, Del., as a byproduct from Pennsylvania iron ore, amounted to 250 tons in 1964 (Lim, 1965, p. 156), and rose 12 percent in 1965 (Lynde, 1967).

Nickel has many varied and important military and peacetime uses, the chief of which are in stainless and structural steels, nonferrous alloys, high-temperature and electrical-resistance alloys, permanent-magnet alloys, coinage, and for electroplating.

Nickel was mined by medieval miners in Saxony, and an alloy of nickel, iron, sulfur, and arsenic was smelted which was called Kupfernickel. Nickel was first identified as a distinct metal in 1751 when Cronstedt discovered it in cobalt ores of Helsingland, Sweden (Bilbrey, 1960, pp. 549–550). Until about 1880 nickel was obtained from small mines scattered throughout the world, including the Gap mine in eastern Pennsylvania. Mining of nickel commenced from newly discovered large deposits in New Caledonia in 1874, and at Sudbury, Ontario, in 1886. As the use of nickel increased, especially in steel alloys, production likewise increased. World production has risen sharply in recent years; it was 472,000 tons in 1965, of which nearly three-fifths came from Canada. U.S. production of 13,510 tons in 1965 was largely from a single mine at Riddle, Oreg. A small amount is recovered as a byproduct from copper refining.

The average cobalt content of the earth's crust is estimated at about 0.002 percent, whereas that of nickel is 0.008 percent (Fleischer, 1953, p. 4). Cobalt occurs in a variety of deposits, for the most part as a minor constituent associated with other metals. Virtually all the cobalt being produced at present is recovered as a byproduct in the mining of copper, nickel, and iron ores, but it also occurs as a major constituent in certain sulfide veins, and in lead-zinc and in silver ores. The copper mines of the Congo and Zambia supply the greatest amount of cobalt and have the largest reserve, but significant amounts are also recovered from the nickel-copper ores of Canada and iron deposits in Pennsylvania.

There are two principal types of nickel deposits: (1) sulfide deposits closely associated with norite and peridotite; and (2) nickeliferous laterites, occurring as weathering mantles that overlie peridotite and serpentinite. The largest known nickel sulfide deposits are in the Sudbury and Thompson districts in Canada, and the largest nickeliferous laterites are in New Caledonia, Cuba, Guatemala, Indonesia, the Philippines, and Venezuela. The deposit in Oregon is of the latter type.

Nickel, cobalt, and copper, with or without silver, lead, and zinc, also occur as sulfides and arsenides in hydrothermal veins and as replacements of sedimentary rocks. Deposits of this type, most of which are rather small, are located in Canada, the United States, and elsewhere (Cornwall, 1966, p. 2). The most significant in the United States are in the Blackbird district, Idaho, and near Fredericktown, Mo.

The Fredericktown area (fig. 17) is part of the southeast Missouri lead district in which copper, nickel, and cobalt minerals occur in sufficient quantity to have potential value. The ore deposits are sinuous lenses, up to 40 feet thick, 50 to 250 feet wide, and several hundred feet long that lie in the upper part of the Lamotte Sandstone and dolomite of the overlying Bonneterre Formation near pinchouts against Precambrian knobs. They are fairly flat lying, at depths of 250 to 400 feet. Galena, chalcopyrite, marcasite, siegenite ($(Ni,Co)_3S_4$), and very minor sphalerite and bravoite ($(Fe,Ni)S_2$) are disseminated in the dolomite and locally in the sandstone. Distribution of the ore minerals is erratic, even within individual deposits, and a crude vertical zoning is apparent in some with copper, nickel, and cobalt more abundant in the lower parts. The total metal content and the relative quantity of each metal also tend to vary markedly within short distances laterally.

The lead-rich ores have been mined successfully, but the difficulties of separating the other metals, and particularly the cobalt and nickel, have defeated a number of attempts to achieve significant commercial production from the more complex ores. Bishop (1949, pp. 27, 55) describes intermittent small production of cobalt and nickel from 1844 on and states (p. 56) that Mine La Motte was the chief domestic source of nickel at various periods in the 19th century. Some output also came from the Buckeye mine just southeast of Fredericktown. Bishop estimates production of about 100 tons of cobalt and 200 tons of nickel to the early 1900's.

In the periods 1903–10, 1917–20, and 1944–61, efforts were made to separate and recover the lead, copper, cobalt, nickel, and sulfur of the

complex ores by various milling and metallurgical techniques. Considerable technical success was achieved, but at costs not compatible with the results. Production statistics have been concealed for most of the years, but output was at times considerably greater than in the preceding era. For example, during the latest period of activity, from 1954 to 1961, when the National Lead Co. operated the Madison mine under a U.S. Government defense contract, 2,885,789 pounds (1,443 tons) of cobalt was delivered to the General Services Administration (U.S. Congress, 1962, p. 2817). Nickel was not sold to the Government and the quantity is not a matter of public record, but as the ores generally contain somewhat more nickel than cobalt, it is reasonable to assume that total production of nickel has been a few thousand tons.

The irregular nature of the deposits make tonnage and grade estimates difficult. Grawe (1945, pp. 362–364) stated that ore mined in the 1918–20 period averaged 1.17 percent lead, 2 percent copper, 0.62 percent nickel, and 0.50 percent cobalt. Vhay (1952, p. 44) cited developed reserves as of 1943 at 1,770,000 tons averaging 2.29 percent lead, 1.43 percent copper, 0.46 percent nickel, and 0.28 percent cobalt. Reserves of the Madison mine as of January 1957 were reported (Kline and others, 1961) as: 1,500,000 tons proven, grading 2.30 percent lead, 0.60 percent copper, 0.24 percent nickel, and 0.18 percent cobalt; 3 million tons probable and possible, grading 1.75 percent lead, 0.40 percent copper, 0.20 percent nickel, and 0.16 percent cobalt. How much of this has been mined is not known, but Bilbrey (1962, p. 27) calls these deposits "one of the major U.S. cobalt reserves." It seems probable that technologic developments and a more favorable economic climate will eventually lead to renewed mining of these ores.

Additional minor amounts of cobalt are contained in lead ores in the southeast Missouri district. (See fig. 15.) It was estimated in 1949 that 600,000 pounds (300 tons) a year are not recovered from ores treated for their lead content (Vhay, 1952, p. 45). Trace amounts of cobalt and nickel are present in most of the ores, and the amounts fluctuate considerably, in general being greater in cupriferous areas (Davis, 1958). As the newly discovered ores of the Viburnum trend carry moderate amounts of copper, they may also have cobalt and nickel which could be recovered, probably at the copper refinery.

The manganese deposits of Missouri, and in particular those resulting from long-continued weathering of the Paleozoic rocks also carry small but significant amounts of cobalt. Contents range from a trace to more than 2.30 percent cobalt (Grawe, 1943, p. 30); an average of 11 analyses of manganiferous chert breccia gave 0.74 percent cobalt. However, as the average grade is too low (18.65 percent manganese) and the deposits too small to be mined commercially for their manganese, they seem to offer little hope as potential sources of cobalt.

SILVER

(By T. H. Kiilsgaard, U.S. Geological Survey, Washington, D.C.)

Silver has been mined since ancient times and long has been a basis of wealth and a monetary medium. In recent years, most of the world's silver production has been used in various industries and in the arts; however, substantial quantities continue to be used in dif-

ferent countries as coinage. Industrial usage of silver has increased steadily in recent years, and this increase, plus the very large amounts of silver used in domestic coinage, has led to a shortage of silver (Kiilsgaard, 1964). Merrill and others (1965) note that domestic mine production of silver during the interval 1955–64 averaged about 35.4 million ounces per year, whereas total domestic consumption requirements for the same period averaged about 192.4 million ounces annually. The domestic shortage has been met largely by withdrawals from U.S. Treasury stocks. It is expected to continue, even though domestic usage of silver in coinage has been reduced drastically through use of the new domestic "sandwich" coins.

Missouri produces only a slight portion of the silver mined in the United States, amounting to about 0.7 percent of domestic production in 1965. The total quantity and values recovered in the state, in the interval 1905–65, is shown in table 7. All of the silver is recovered as a byproduct from processing of lead and zinc ores. Silver is recovered in the process of purifying lead at the smelter. Silver residues also are recovered from smelting of zinc concentrates. These residues are further refined at the lead smelter. Bishop (1949, p. 70) notes that about 0.5 ounce of silver is recovered from each ton of refined pig lead. Bureau of Mines statistics during the 1950's indicate that about 2 ounces of silver were recovered for each ton of refined pig lead. A comparison of annual output of silver with that of lead suggests that in some years either considerable silver has been left in the lead, or that silver residues from zinc concentrates have been accumulated and then processed in batch lots.

TABLE 7.—*Annual production and value of silver in Missouri, 1905–65*

Year	Troy ounces	Value	Year	Troy ounces	Value
1905	12,900	$7,869	1937	179,700	$138,999
1906	31,268	20,950	1938	292,000	188,768
1907	25,300	16,700	1939	213,400	144,853
1908	49,400	26,400	1940	260,314	185,112
1909	15,200	7,900	1941	367,688	261,467
1910	32,200	17,100	1942	69,106	49,142
1911	49,867	26,129	1943	111,285	79,136
1912	35,438	21,794	1944	92,243	65,595
1913	35,620	21,514	1945	94,822	67,429
1914	61,168	33,826	1946	69,401	56,076
1915	57,756	29,282	1947	93,600	84,708
1916	129,450	85,178	1948	114,187	103,345
1917	61,586	50,747	1949	123,413	111,695
1918	46,939	46,939	1950	236,273	213,839
1919	90,401	101,249	1951	184,424	166,913
1920	111,128	121,130	1952	517,432	468,302
1921	69,902	69,902	1953	359,781	325,620
1922	212,656	212,656	1954	352,971	319,457
1923	177,270	145,361	1955	268,620	243,115
1924	103,694	69,475	1956	295,111	267,000
1925	83,340	57,838	1957	183,427	166,000
1926	105,242	65,671	1958	250,917	227,000
1927	233,931	132,638	1959	339,760	308,000
1928	176,840	103,451	1960	15,594	14,000
1929	181,638	96,813	1961	11,793	11,000
1930	170,210	65,531	1962	490,896	533,000
1931	40,000	11,600	1963	131,664	168,000
1932	1,128	318	1964		
1933			1965	299,522	387,282
1934	63,066	40,770			
1935	110,551	79,459		8,758,153	7,268,544
1936	163,720	126,801			

Sources of data: 1905–47, Bishop (1949, p. 71). 1948–65, U.S. Bureau of Mines.

Most of the silver produced in Missouri has come from the Southeast district. In that area silver occurs primarily as trace amounts in the galena and sphalerite mined from the Bonneterre Formation (see lead-zinc section of this report). Lead concentrates from the Lead belt are reported to contain from 1 to 2 ounces of silver per ton. Ore mined in the Flat River area in 1965 may be calculated to contain slightly more than 0.04 ounce of silver per ton. By contrast, ores mined in the Viburnum area in 1965 may be calculated to contain slightly more than 0.08 ounce silver per ton. Lead and copper concentrates are recovered at the St. Joseph Lead Co. mill at Flat River, whereas lead, zinc, and copper concentrates are recovered at the St. Joseph Lead Co. mill at Viburnum. The proportion of silver in these various concentrates is not known to the author, thus it may be that Viburnum ores are no richer in silver than those mined in the Flat River area but that more silver is recovered in the trimetal concentrates at Viburnum.

Wagner (1947, p. 367) notes that zinc concentrates of the Lead belt contain about 25 ounces of silver per ton. This presence of silver in sphalerite has been confirmed recently by the U.S. Geological Survey (Heyl, 1966, personal communication). Two samples of sphalerite, one from the National Lead Co. mine at Fredericktown and the other from the No. 8 shaft at Flat River, were carefully sorted to remove all other visible minerals and then spectrographically analyzed. The former sample contained 2.92 ounces of silver per ton of sphalerite, and the latter 43.75 ounces of silver per ton. The sphalerite samples were then checked by electron probe to determine if the silver occurred in discrete mineral grains, but as no silver mineral was found it was concluded that silver substitutes for zinc in the space lattice of the sphalerite.

Zinc and lead concentrates from the Tri-State district, part of which is in southwestern Missouri, are reported by Fowler and Lyden (1932, p. 31) to carry from a trace to 0.7 ounce silver per ton, but to average about 0.1 ounce silver per ton.

The Einstein silver mine area in Madison County (fig. 20), about 9 miles west of Fredericktown, is the only mine area in the State known to have been worked principally for silver. (Tungsten was also mined here, see p. 92.) The mineralized area has been known since before 1879, but it has been worked only sporadically and has never been very productive. Two quartz veins have been developed at the property, both of which are in Precambrian granite and both of which parallel joints in the country rock. The No. 1 vein can be traced for about 1,000 feet at the outcrop, and, where seen in old trenches, it is about 2 feet thick. In the mine workings the vein is described as being up to 6 feet thick, of which 2 feet was mineralized. Mine workings have explored the vein along a strike length of about 550 feet and through a vertical range of about 350 feet. The ore is argentiferous galena. Fifty assays of the galena averaged 46 ounces per ton of silver, although the overall grade of the vein material mined is believed to have been low. Tolman (1933, p. 34) notes that production from the vein consisted of 50 tons of lead and 3,000 ounces of silver. Although the No. 2 vein also was explored, it is not believed to have been too productive.

MINOR METALS ASSOCIATED WITH ZINC-LEAD ORES

(By P. W. Guild, U.S. Geological Survey, Washington, D.C.)

Small amounts of several metals which occur with zinc and lead ores are recovered at refineries but not ordinarily identified as to source. No statistics, either as to quantity or total value, are given; however, it is known that some have been produced from Missouri ores in the past and presumably at least one is being recovered now. They are discussed very briefly below.

Cadmium.—Cadmium is a soft, silver-white metal used principally for electroplating, in solders, and in increasing amounts for nickel-cadmium and silver-cadmium batteries for space and small-appliance purposes (Schroeder, 1965a). Cadmium sulfide, selenide, and lithopone are used as pigments in the range yellow-orange-red. The United States uses about 10 to 12 million pounds a year, and produces roughly the same amount, in part from imported zinc concentrates and cadmium flue dust. The price has fluctuated somewhat in the range of $2 to $3 per pound in the last few years.

Cadmium occurs in the sphalerite lattice in zinc ores from both the Tri-State and southeast Missouri districts. Greenockite, the yellow cadmium sulfide, may also be present as a secondary coating on the primary ore minerals. Bishop (1949, p. 14) states that the Tri-State ores yield about 14 pounds of cadmium per ton of zinc; there has, of course, been no cadmium production from the Missouri part of this district in recent years (p. 58). At least part of the cadmium recovered by the St. Joseph Lead Co. presumably comes from zinc concentrates made from southeast Missouri ores; it seems probable that the new mines of other companies (p. 55) will also produce cadmium-bearing zinc concentrates. The proportion of cadmium to zinc in the sphalerite of the Southeast district is variable (Davis, 1958) but not stated; as the zinc content of the Southeast district is itself low and variable, no estimate can be made of the production potential.

Germanium.—Germanium is a semiconductor used principally for solid-state electronic devices such as transistors and diodes (Moulds, 1965, pp. 382–383). The United States uses from about 50,000 to 100,000 pounds a year, valued at roughly $100 per pound, of which about 30,000 pounds is from newly mined material and the balance reprocessed scrap. It is known that the ores of the Tri-State district constitute a principal source. The germanium occurs in the sphalerite lattice; Bishop (1949, p. 32) estimated recovery at about 1 pound per 1,500 tons of zinc concentrates. Whether any germanium was recovered from Missouri ores in the past is not known, but as most production from the Missouri part of the district antedated the start of germanium recovery by the Eagle-Picher Co. in about 1940, the total quantity could not have been large. None has been reported from ores of the southeast Missouri district.

Gallium.—Gallium is a rare metal associated with sphalerite in the Tri-State district and with bauxite in Arkansas that is used in some semiconductor devices and for various other purposes (Eilertsen, 1965, p. 352). Prices are in the range of $500 per pound. The Eagle-Picher Co. produces gallium in Oklahoma; as recovery only began in

the 1940's, it is unlikely that much has come from Missouri ores. None has been reported from the southeast Missouri ores.

Indium.—Indium is a soft silvery white metal present in very small amounts in some zinc and other ores. It is used in electronic devices, bearing alloys, and various special alloys. The price is $2 to $2.75 per troy ounce. A little indium has been produced from Tri-State ores (Bishop, 1949, pp. 32–33) but it is not usually mentioned as accompanying them (see e.g., Schroeder, 1965b, pp. 441–445), and it is doubtful that Missouri has any significant potential for this metal.

IRON

(By William C. Hayes, Missouri Geological Survey and Water Resources, Rolla, Mo., and Philip W. Guild, U.S. Geological Survey, Washington, D.C.)

INTRODUCTION

Iron ore can rightly be called the foundation upon which our civilization rests; its consumption for iron and steel products is commonly used as an index of the level of industrialization of a nation. Annual per capita consumption in the United States today is about three-fourths of a ton, many times greater than that of all other metals combined.

More than 99 percent of all iron ore mined is used for making iron and steel products; the remainder goes into cement, paint pigments, aggregate for high-density concrete, heavy media for coal processing plants, and other minor uses. World output of ore in 1965 was about 606 million long tons, of which the United States produced nearly 88 million, in second place after the U.S.S.R. with 150 million tons. Approximately 94 percent of the iron ore consumed in the United States goes into blast furnaces for making pig iron, and of this pig iron, 93 percent is processed to steel. Scrap is added, in varying proportions, according to the type of steelmaking furnace employed, its availability and price relative to pig iron, the quality of steel desired, etc., so that on average the output of steel closely approximates the consumption of iron ore in the United States. The United States produces about one-fourth of the world's total steel; output was 131.5 million short tons of ingots and castings in 1965, compared with a world total of some 507.5 million tons. Russia was second with 100 million tons, followed by Japan, West Germany, the United Kingdom, and France.

The United States consumed about 132 million long tons of iron ore in 1965, of which two-thirds was of domestic origin and one-third imported. The Lake Superior district supplied 66 million tons, or 76 percent of the domestic ore and 50 percent of the total; the remaining domestic sources were fairly well distributed around the country from New York, Pennsylvania, and Alabama to Wyoming, Utah, and California. Missouri's output of 1,784,000 tons constituted about 2 percent of the total domestic supply.

Imports came from Canada (23.8 million tons or 18 percent of the total supply), and Venezuela (12.3 million tons or 9 percent), with lesser amounts from Liberia, Chile, Brazil, and other countries.

Although early records are not complete, it is estimated that total production of iron ore in the United States to date has been about 4.7

billion tons, of which the vast preponderance came from the Lake Superior district and in particular the great Mesabi Range in Minnesota. Additional substantial amounts (e.g., 300 million from the Birmingham, Ala., district) have been mined elsewhere in the United States. By comparison, Missouri has produced only 18.7 million tons to date (see table 9, p. 78); its iron ore has, however, played a significant part in the early development of the Mid-West. Recent discoveries insure that this role will increase.

Iron rarely occurs in the native (metallic) form in nature, but rather is combined with oxygen, sulfur, carbon, silicon, or other elements to form many minerals. The ore minerals, those from which the iron can be extracted economically, are chiefly oxides and hydroxides. Magnetite, Fe_3O_4, is a black, hard, heavy mineral that is strongly magnetic, as its name implies. It contains 72.4 percent iron. Hematite, Fe_2O_3, ranges from the hard, dense, steel-gray variety known as specularite to a fine-grained, almost earthy, dark red type. All have a red streak (whence the name, from the Greek word for blood, haima), and are only very weakly magnetic. Hematite contains 69.94 percent iron. Limonite is the term used for various mixtures of hydrous iron oxides that are brown to yellow and have a brown streak. Goethite, $Fe_2O_3H_2O$, which is the only recognized mineral species, theoretically contains 62.85 percent iron, but most limonite ores, known as brown ores in commerce, are mixed with various contaminants and contain considerably less iron. Siderite, $FeCO_3$, contains 48.2 percent iron when pure. It is not an ore mineral in Missouri. Pyrite and marcasite, two forms of iron sulfide, FeS_2, have been mined for their sulfur content, and, through oxidation, have been the source of iron ores as well. They contain 46.6 percent iron.

Iron ores are widespread and very abundant in the world. The value of a particular deposit depends upon many factors that together determine the cost of making steel from it and hence its ability to compete on the market with ores from other sources. Among these are: (1) location and availability of transportation to market; (2) size, shape, and attitude, which control the capital investment and operating expenses of extracting it; (3) the grade (iron content) and presence of impurities that must be removed; and (4) the amenability of the crude ore to beneficiation (upgrading).

Steelmaking practice is evolving rapidly today, and with this the specifications for raw materials are changing. The usual processing involves reduction of ore to pig iron in the blast furnace, where burning coke provides heat and a reducing gas, carbon monoxide, to remove oxygen from the ore. Limestone or dolomite are added to the charge to combine with the silica and alumina of the ore in a slag that is periodically drawn off. The quantities of coke and flux needed per ton of product diminish sharply as the iron content of the charge increases; hence far more attention is paid today than formerly to providing high-grade feed. Phosphorus, and to some extent sulfur, cannot be removed in the blast furnace, so ores with appreciable quantities of these elements must be beneficiated before smelting. In addition, the components of the furnace charge must be properly sized and strong enough to resist packing down and obstructing the blast. The development in recent years of very fine grinding to release the ore minerals from gangue (waste) particles, concentration of the iron

77-270 O—67——6

fraction by magnetic or other means, and pelletizing to achieve good physical characteristics has, at one stroke, accomplished the needs sketched out above. Consequently, use of beneficiated ore has supplanted that of the "direct-shipping" ores from all but a few places, and it has, as an added feature, increased the total capacity of the Nation's blast furnaces without the cost of new construction because the pellets reduce more quickly.

Missouri's principal iron ore resources are admirably suited to provide the pellets demanded by industry today.

Iron has been concentrated into many types of deposits by various geological processes. Quantitatively the most important are the sedimentary "iron-formations" in which iron-bearing minerals were laid down simultaneously with the enclosing rocks as extensive beds. Principal examples are the well known Precambrian deposits of the Lake Superior district and elsewhere; the Silurian Clinton ores of the Appalachians; and the Jurassic deposits of eastern France and adjacent countries. Missouri's only deposits of this type are insignificant and have not been mined. Thin discontinuous beds of hematite occur near the contact of the Mississippian and Pennsylvanian strata in parts of Lincoln, Warren, Montgomery, and Callaway Counties, and in the Silurian rocks, at depths of more than 1,800 feet, in northwestern Missouri (Nason, 1892, p. 70–84; Crane, 1912, p. 146–149; E. B. Kisvarsanyi, 1966, p. 51). Iron carbonate beds and nodules occur widely in the Pennsylvanian coal-bearing rocks of northwestern Missouri.

Igneous processes have concentrated iron into ore deposits of several types and subtypes, and it is to this general class that the most important deposits of the State belong. Several have long been known in the St. Francois Mountains, and additional deposits have been discovered in recent years by magnetic means under the sedimentary rocks that cover the igneous rocks of the basement. All the igneous-affiliated deposits known in Missouri are of Precambrian age.

Alteration—oxidation and (or) hydration—of iron-bearing minerals, with or without local transportation and redeposition of the iron in solution, has tended to form deposits on or near surfaces of long-continued erosion. The Ozark province has had many such periods of mild uplift and exposure to the atmosphere (see p. 16), and there are numerous deposits of this type in Missouri. Many of these are unusual in being derived directly from pyrite and marcasite that had earlier been deposited in circular structures that probably were themselves products of a previous erosion cycle (Grawe, 1945, p. 192). These deposits, the "hematites of the filled sinks," (Crane, 1912, p. 84–106) are believed to be unique to Missouri; they were formerly of considerable importance but are now of only historical and scientific interest. The brown ores of the Ozarks are accumulations of limonite, also derived at least in part from sulfides, that have been mined extensively but have only a minor and decreasing importance today.

HISTORY AND PRODUCTION

Mining of iron ore began in Missouri about 1815 when the Ashebran furnace, first to be erected west of the Mississippi River, commenced

operating near Ironton in Iron County. Small deposits of Precambrian magnetite on Shepherd Mountain nearby furnished the ore. (Winslow, 1892, p. 304). Hematite ores from filled-sink deposits was first smelted at the Harrison-Reeves bloomery near Bourbon, Crawford County, in 1819 and 1820. By 1823 limonitic brown ores were being used in conjunction with the ores from Iron Mountain in a furnace north of Caledonia in Washington County. Thus in a span of a few years all the chief ore types of the State had been smelted, though these earliest furnaces were rather short lived.

The first iron works of economic consequence was that at Meramec Spring in Phelps County, 6 miles southeast of St. James. This furnace went into blast in April 1829 and was an important factor in the economic development of a large part of the Ozarks until 1875 (Norris, 1964). A number of other furnaces were erected, each based on a local source of ore, forests for charcoal, and limestone or dolomite from the vicinity. For example, a furnace was erected at Iron Mountain in 1846 and one at Pilot Knob in 1848. In all, about a dozen furnaces based on charcoal had been constructed by 1880, of which three were operating in 1892 (Winslow, 1892, p. 329). In addition, several furnaces using coke (from eastern coal) were erected in and near St. Louis shortly after the Civil War. Missouri's greatest iron production, 123,700 tons, was in 1887; in all, about 3,300,000 tons of iron was smelted in Missouri between 1815 and 1925, when the industry virtually ceased in the State. The last furnace to operate, near Houston in Texas County, was active intermittently through the late 1930's. Table 8 summarizes the production and value of iron smelted in Missouri.

TABLE 8.—*Production and value of iron in Missouri, 1815–1925 (after Bishop, 1949)*

Year	Long tons	Value per ton	Total value	Year	Long tons	Value per ton	Total value
1815-49	35,714	$50.00	$1,785,700	1898	35,000	$9.90	$346,500
1850-60	98,214	50.00	4,910,700	1899	35,000	18.00	630,000
1861-69	187,500	50.00	9,375,000	1900	40,000	18.85	754,000
1870	64,735	33.25	2,152,439	1901	40,000	15.25	610,000
1871	65,916	35.12	2,315,300	1902	40,000	20.92	836,800
1872	90,320	48.87	4,414,390	1903	40,000	19.12	764,800
1873	76,367	42.75	3,264,689	1904	25,000	14.13	353,250
1874	67,693	30.25	2,047,713	1905	60,000	16.63	997,800
1875	53,318	25.50	1,359,609	1906	60,000	19.98	1,198,800
1876	60,913	22.25	1,355,314	1907	60,000	20.56	1,233,600
1877	65,683	18.87	1,239,767	1908	60,000	15.96	957,600
1878	42,409	17.62	747,459	1909	60,000	16.25	975,000
1879	75,600	21.50	1,625,400	1910	55,536	18.26	1,014,213
1880	94,239	28.50	2,685,812	1911	66,665	16.63	1,108,940
1881	98,028	25.12	2,462,954	1912	20,000	13.93	278,600
1882	101,461	25.75	2,612,621	1913	19,000	15.08	271,440
1883	92,222	22.37	2,063,467	1914	30,000	13.42	402,600
1884	53,606	19.87	1,065,419	1915	30,000	13.21	396,300
1885	45,897	18.00	826,146	1916	39,018	16.96	661,745
1886	66,534	18.75	1,247,512	1917	83,266	27.29	2,272,329
1887	123,780	21.00	2,599,380	1918	83,432	36.96	3,084,136
1888	81,943	18.87	1,546,674	1919	49,383	33.40	1,649,271
1889	76,950	17.75	1,365,862	1920	81,682	45.04	3,678,623
1890	89,771	18.40	1,651,786	1921	17,028	28.19	479,957
1891	29,229	17.52	512,092	1922	10,000	21.98	219,800
1892	57,020	15.75	898,065	1923	4,513	24.68	111,381
1893	32,360	14.52	469,867	1924	21,371	21.41	457,553
1894	30,000	9.76	292,800	1925	3,758	20.08	75,461
1895	20,000	11.14	222,800				
1896	20,000	10.47	209,400	Average		25.95	
1897	23,883	12.10	288,984	Total	3,292,074		85,435,620

Table 9 gives the production and value of iron ore mined in Missouri from 1815 to 1965 by varying increments of time and by major ore classes. Total production to the end of 1965 was nearly 19 million tons valued at more than $122 million. Precambrian ores constitute 69 percent of the total, hematite of the filled sinks 19 percent, and brown ores 12 percent. Although early records are incomplete and have been gathered from many fragmentary sources (Winslow 1892, p. 324–328), the largest single year's production in the 19th century was apparently 1887, when 427,785 tons was mined. Output declined to less than 100,000 tons in 1893 and remained small for many years. No iron ore was mined in Missouri in 1933. The previous record was only surpassed in 1957, when 529,989 tons was mined. With the opening of the new Pea Ridge mine (p. 83) in 1964, output exceeded a million tons for the first time.

Records of the quantities of ore smelted in Missouri and those exported from the State are not available, but comparison of the iron and ore production records strongly suggests that at least half the ore mined during the period from 1850 to 1890, or perhaps somewhat more than 3 million tons, was sent to furnaces in other States. By contrast, ore output from 1891 to 1925 was about sufficient to supply the Missouri production of iron, and presumably the exports were small. Since 1925 all production has been sent out of State.

TABLE 9.—*Production in long tons and value of iron ore in Missouri, by major geologic type, 1815–1965*

	Precambrian (magnetite and hematite)	Filled sink (hematite)	Brown ore (limonite)	Total	Value
1815-92 [1]	5,201,841	2,289,283	24,000	7,515,124	$30,050,612
1893-1910 [2]	420,958	623,184	375,358	1,419,500	2,448,079
1911-15	29,717	169,591	29,350	228,658	505,949
1916-20	58,126	138,975	53,183	250,104	975,698
1921-25	131,481	115,838	21,670	268,989	1,221,461
1926-30	423,697	166,542	11,841	602,080	2,395,462
1931-35	4,403	60,533	78,760	143,696	431,052
1936-40	3,631	45,185	99,560	148,376	327,751
1941-45	118,234	32,646	108,025	258,905	984,483
1946-50	826,916		4,803	831,719	5,239,365
1951-55	977,568		171,763	1,149,331	9,863,288
1956-60	1,113,110	3,853	879,174	1,996,137	18,906,097
1961	240,740		99,825	340,565	3,632,545
1962	241,934		103,867	345,801	3,187,607
1963	242,318		102,901	345,219	3,085,214
1964	1,075,960		40,214	1,116,174	14,907,225
1965	1,753,913		30,531	1,784,444	24,607,000
Total	12,864,547	3,645,450	2,234,825	18,744,822	122,768,888

[1] Winslow, 1892, p. 322.
[2] Crane, 1912, p. 4–13.

ORE DEPOSITS

Figure 18 shows the general distribution of the three principal types of iron-ore deposits in Missouri. An imperfect concentric arrangement is apparent, with the Precambrian ores in and near the center of the Ozark Dome, the filled-sink deposits on its northwest flank, and the brown ore districts nearly surrounding the dome. The small sedimentary deposits (p. 76), which have not been mined and

probably never will be, are north and northwest of the Ozarks. These deposits are not shown.

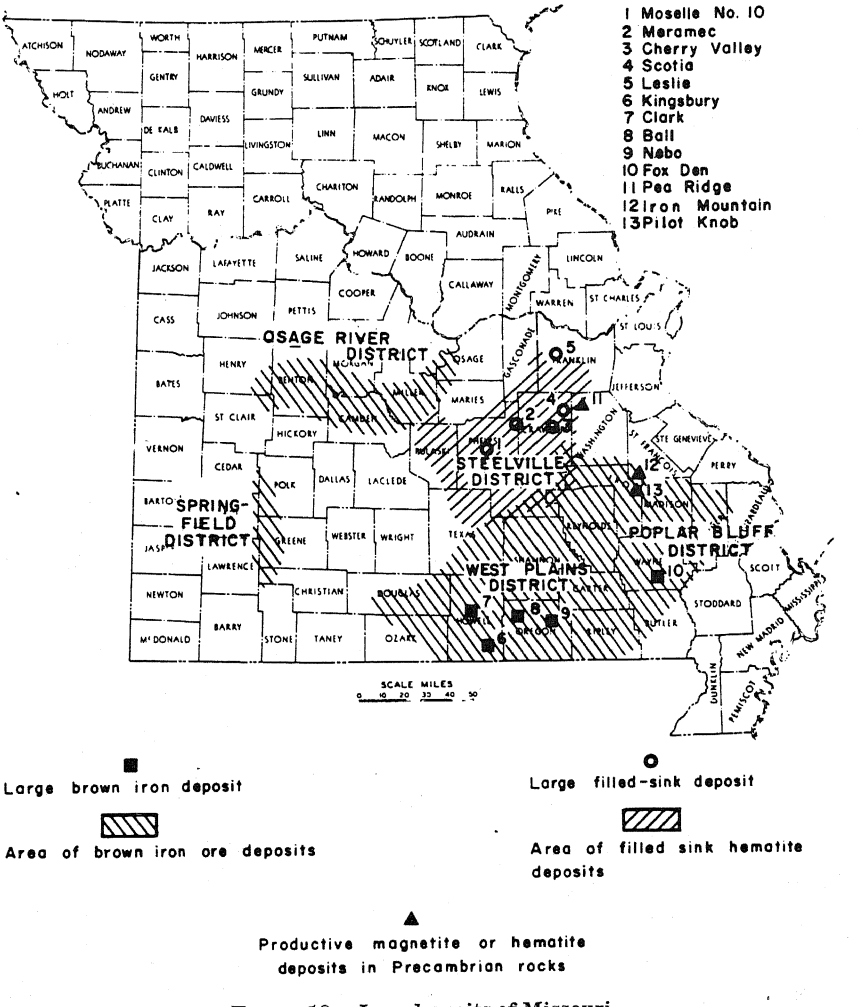


FIGURE 18.—Iron deposits of Missouri.

Precambrian deposits

The magnetic-hematite deposits occur as vein fillings and tabular replacement bodies in Precambrian felsites, tuffs, and tuff breccias of the St. Francois Mountains and adjacent areas (fig. 19). More than 20 deposits are known, but only three have had any appreciable production to date. The group of close-spaced deposits at Iron Mountain, the first to be exploited on a large scale, yielded about 9 million tons of ore, three-fourths of the Precambrian output or one-half the State's total, during the span from 1843 to 1966. Operations at Iron

Mountain ceased in August 1966. Pilot Knob produced about 1½ million tons from 1848 to 1890; discovery of new deep ore 10 years ago will soon revitalize this property. Pea Ridge is just getting started, as production began in 1964; it is destined to far outstrip the old mines in both annual and total output.

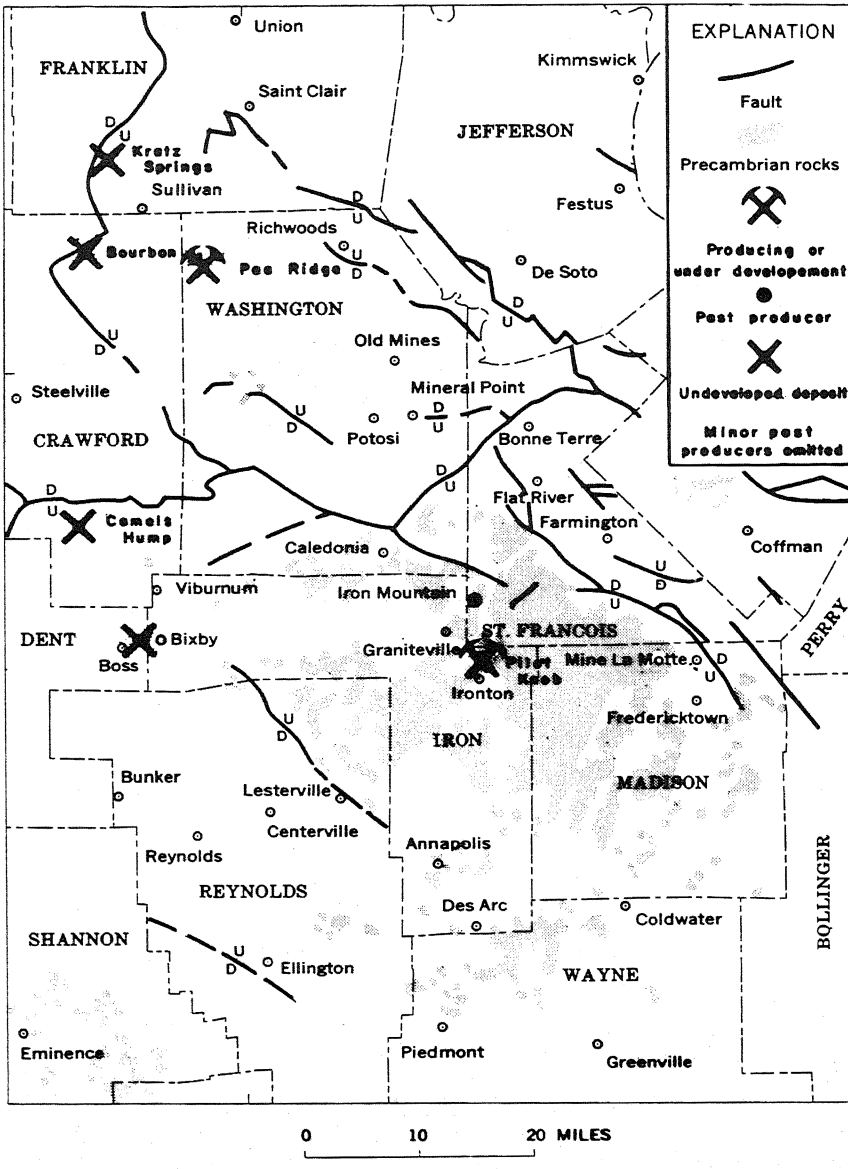


FIGURE 19.—Precambrian iron deposits of Missouri.

Although the deposits are all related genetically to the magmatic activity which produced the volcanic and intrusive igneous rocks, they vary in mineralogy of both the ore and gangue minerals, the country rocks in which they occur, structural setting, and shapes. In this lack of uniformity they contrast strongly with the taconites of Lake Superior and elsewhere; the Missouri deposits are far more difficult to find (especially those composed predominantly of nonmagnetic hematite) and to evaluate than the extensive sedimentary deposits. All those which crop out were undoubtedly discovered long ago. Magnetic surveys have indicated targets for drilling in areas where Paleozoic sedimentary rocks cover the Precambrian basement, and a number have been found (fig. 19), but future exploration will be difficult and costly.

Iron Mountain.—Veinlike, irregular masses of specular hematite cut porphyry at intervals along a northeast-trending zone several thousand feet long at Iron Mountain in sec. 31, T. 35 N., R. 4 E., St. Francois County. Prolonged weathering and erosion resulted in extensive accumulations of rubble or conglomerate ore on the flanks of the old knob that were covered by the Upper Cambrian sedimentary rocks; some ore fragments were also incorporated in the basal sedimentary rocks themselves. After uplift and removal of the Paleozoic rocks, renewed weathering of the prophyry left accumulations of surficial boulder ore in clay that completely masked the ore veins and led early geologists to greatly overestimate the tonnage available (Litton, 1855, p. 75–77).

By 1872 a number of open cuts had exposed veins in bedrock, of which the largest, some 60 feet thick at its widest point, was that in the Big Cut on the summit of the knob (Schmidt, 1873, p. 99–109). Twenty years later the veins of the Big Cut were virtually exhausted, as they had pinched out downward at depth of about 150 feet. In the meantime, the conglomerate ores had been found and were being mined by underground methods (Nason, 1892, p. 23–32). In addition, an ore vein in Little Mountain was worked by open pit (the Hayes Cut) at the southwest end of the zone in conjunction with overlying conglomerate ore. Although drilling had shown some ore to be present in this general area, the outlook was not promising. By 1912 production had totaled 3½ million tons, but the rate was far below the high point of 270,000 tons in 1872 and the chief reserves seemed to be in pillars, dumps, and minor veins (Crane, 1912, p. 108–120). As Iron Mountain was the only property mining any significant quantity of Precambrian ore after 1892, table 9 illustrates its precipitous decline in output.

The M. A. Hanna Co. acquired Iron Mountain in 1927. Ground magnetic surveys and drilling found considerable reserves under Little Mountain (Lake, 1932), but mining was desultory until World War II stimulated new demand for ore. Most of the ore was in a triangular, inverted domelike body approximately 1,500 feet on each side that extended downward more than 500 feet before pinching out (Murphy and Mejia, 1961). A northwest ore body, sickle-shaped in cross section, nearly joined the main ore body and extended to a similar depth. Mining was chiefly by underground methods, but the old Hayes Cut was deepened to extract part of the near-surface ore.

Approximately 4½ million tons was produced in this second and final mining phase. The mine closed in 1966 when all the ore believed economically extractable was exhausted.

Iron Mountain ore was chiefly hematite with only minor amounts of magnetite. It varied from massive, nearly pure ore to material with substantial amounts of silicates and carbonates; parts of it contained coarse apatite crystals that raised its phosphorus content to unacceptable levels. Leaching of the surface ores by the prolonged weathering yielded material with average compositions of up to 68.5 percent iron and 0.03 percent phosphorus (Schmidt, 1873, pp. 52–56), fully equal to top quality ores or concentrates from any deposits of the world, but the deeper ores contained more contaminants and required beneficiation of run-of-mine material to produce usable concentrates. Crushing and gravity concentration in recent years yielded material believed to average about 50 percent iron (roughly equivalent to the Lake Superior direct-shipping ores) and large quantity of tailings ("trap rock") that have been sold for various purposes (see p. 164). The generally nonmagnetic character of the ore did not permit the use of magnetic separators.

Pilot Knob.—A tabular, fine-grained hematite body lying parallel to the layering of the enclosing volcanic rocks was mined from 1848 to 1890 on Pilot Knob, a conical hill rising some 700 feet above Arcadia Valley in sec. 29, T. 34 N., R. 4 E., Iron County. Two ore "beds," of variable thicknesses ranging up to about 30 feet each and separated by a "clay seam," cropped out along the north and east sides of the knob about 100 feet below its crest. An agglomerate of coarse porphyry fragments in a hematitic matrix overlies the ore to the top of the knob. The entire sequence strikes west to northwest and dips gently to moderately southwest into the hill. Open-cut mining along the outcrop was succeeded by underground room and pillar excavation. The ore both thinned and graded laterally into siliceous, less mineralized rock, and mining ceased in 1890 after most of the pillars had been removed and the roof allowed to cave. The area mined measured about 900 by 1,500 feet. Conglomerate ores lie at the base of the Paleozoic rocks north of the knob, and boulder ores in clay lie on the present surface. Litton (1855, pp. 79–80), Schmidt (1873, pp. 109–118), and Nason (1892, pp. 32–40) describe Pilot Knob as it appeared during its period of active mining; Crane (1912, pp. 121–131) studied the deposit during a revival when renewed mining of conglomerate ore was briefly undertaken.

The ore was highly variable in grade, ranging from material too lean to mine up to about 65 percent iron in the center of the main (lower) ore seam (Schmidt, 1873, pp. 56–60). Production was estimated (Crane, 1912, p. 121) at 1,580,000 tons.

Hanna Mining Co. and Granite City Steel Co. in 1957 announced discovery, by drilling following geophysical studies, of a new ore body at Pilot Knob. The deposit lies west of the base of Pilot Knob and extends westward across the valley at depths of a few hundred to about 1,500 feet. Mining will be underground through a shaft 1,365 feet deep that was completed in 1966. Mine development and mill construction have a target date for completion of February 1968. Magnetite is the chief ore mineral in the new deposit; average grade is near 40 percent iron, but fine grinding and magnetic separation will

permit concentration to 63 percent iron with silica content of about 5 percent (L. J. Erpenbach; oral communication, Nov. 18, 1965). Capacity will be 1 million long tons of pellets per year, to be shipped to the Granite City Steel Co. plant in Illinois. No figures have been announced, but reserves are believed to be sufficient for several decades of mining.

Other outcropping deposits.—Several minor deposits that cropped out in the St. Francois Mountains were discovered and worked in the 19th century. Veins of magnetite on Shepherd Mountain, 1¼ miles southwest of Pilot Knob, yielded 75,000 tons of ore averaging around 65 percent iron (Crane, 1912, pp. 131–136). Drilling at the north base of the mountain in 1888 found an ore body of medium-grade ore, too lean and deep to be economic then, which may be the edge of the new Pilot Knob deposit.

A deposit of hematite on Cedar Hill, 1½ miles northwest of Pilot Knob, yielded 25,000 tons of ore in the early 1870's (Crane, 1912, pp. 136–137).

Other ore occurrences are known in the outcropping porphyries but none has had any appreciable production.

Pea Ridge.—Aeromagnetic studies conducted by the U.S. Geological Survey in cooperation with the Missouri Geological Survey and private industry (p. 22) revealed a very pronounced anomaly in sec. 9, T. 39 N., R. 1 W. (Dempsey and Meuschke, 1951) that had not been detected in the earlier ground magnetic surveys because it is in an isolated part of Washington County (fig. 19). Drilling by the St. Joseph Lead Co. found a deposit of magnetite in Precambrian volcanic rocks under 1,300 feet of flat lying lower Paleozoic sedimentary rocks. The Meramec Mining Co. was formed in 1957 as a partnership of St. Joe and the Bethlehem Steel Corp. to exploit the deposit.

The ore body is a somewhat crescent-shaped tabular mass half a mile long and up to 600 feet thick that strikes nearly east-west and dips steeply south, transecting the enclosing rhyolite and rhyolite porphyry flows at a low angle. Drilling shows that it extends to a depth of at least 3,300 feet, or 2,000 feet below its "suboutcrop" on the old Precambrian surface. The ore is largely coarse magnetite and averages 55 percent iron. Specular hematite is present in variable amounts, in places comprising most of the ore. Pyrite, apatite, and quartz are the chief impurities.

More than 5 years and $52 million were required to develop the mine and mill. Two shafts were sunk to about 2,500 feet, 6 levels driven, and concentrating and pelletizing plants constructed. A 26-mile spur was constructed to connect Pea Ridge with the main line of the Missouri Pacific Railroad at Cadet in Washington County. Production started in early 1964. Annual capacity is about 2 million short tons (1,785,000 long tons) of pellets averaging 68 percent iron and less than 2 percent silica (Eng. and Mining Jour., 1964). During beneficiation a nonmagnetic fraction that includes quartz, hematite, pyrite, and apatite is further separated into its component minerals. Pyrite and some of the hematite is recombined with the magnetite in controlled quantities, but some of the ore contains more hematite than can be used efficiently in the pelletizing process (R. C. Harmon, oral communication, Nov. 18, 1966). Construction of a new unit to use the excess hematite is being considered (S. S. Cort, press conference, Oct.

5, 1966); this would expand total plant capacity by 400,000 tons per year. The apatite is being retained for possible use as phosphate raw material.

Reserves have been announced as at least 100 million tons; as the full extent of the deposit in depth is not known, the total tonnage available is believed to be well in excess of this figure.

Other concealed Precambrian deposits.—A magnetic anomaly at Bourbon, Crawford County, found by ground methods in the 1930's, was drilled by the U.S. Bureau of Mines in 1944 with favorable results. (McMillan, 1946). The St. Joseph Lead Co. drilled part of the area in the early 1950's and acquired land on the southern part of the anomaly; subsequently the American Zinc Co. (formerly American Zinc, Lead, and Smelting Co.) and the Granite City Steel Co. explored the northern part and discovered about 200 million tons of medium-grade ore in a complex series of superposed deposits lying 1,700 to 3,500 feet below the surface. The Paleozoic cover rocks are about 1,500 feet thick and include formations from the Gasconade to the Lamotte (Cullison and Ellison, 1944). The ore minerals are magnetite and subordinate hematite which replace and fill fractures in a sequence of moderately dipping rhyolite flows (G. Kisvarsanyi, 1966, p. 88). Apatite is locally abundant.

Exploitation of the Bourbon deposit must await development of a firm market for the ore, according to R. A. Young, chairman of American Zinc Co. (St. Louis Post Dispatch, Nov. 18, 1966), but consideration has been given to opening it up after the Pilot Knob construction is completed (Am. Metal Market, June 3, 1965, p. 19).

The St. Joseph Lead Co. has found a medium-grade magnetite deposit at Kratz Springs, northwest of Sullivan, Franklin County (fig. 19). No announcement has been made of its size, or of plans for development. Another deposit is known near Camels Hump, Crawford County (Weigel, 1965, p. 78).

An iron-copper deposit near Boss in easternmost Dent County (fig. 19) has been explored since 1956 by the American Zinc Co. and Granite City Steel Co. As for the deposits discussed above, the first clue to the presence of ore was a prominent anomaly on the State Magnetic Map published in 1943; additional ground magnetometer surveys refined the target and guided drilling. Annual reports have stated that quantities and grades are commercial, but no tonnage or percentage figures have been released or announcement made of plans for exploitation. On the other hand, Weigel (1965, p. 82), infers that both iron and copper are marginal, though together they may sustain a profitable operation. As the deposit lies just a few miles west of the Viburnum trend, the new railroad spur to Buick (p. 53) will greatly increase transportation facilities and could influence a decision to develop the property.

Filled-sink deposits

Deposits of hematitic ore in Cambrian and Ordovician rocks are numerous on the northwest flank of the St. Francois Mountains (fig. 18). More than 125 deposits are known in Crawford, Phelps, Dent, Iron, Reynolds, Pulaski, Maries, Miller, and Washington Counties; of these, approximately three-fourths are in Crawford, Phelps, and Dent. The area has been named the Steelville district (Hayes, 1957).

In earlier reports these deposits were described as "specular ores in sandstone" (Schmidt, 1873, p. 124–168), "specular ores of the sandstone region" (Nason, 1892, p. 116–157), "hematites of the filled sinks" (Crane, 1912, p. 84–106), or simply as central Missouri specular ores. However, the ores are only in part specular and generally contain some limonite; their distinctive feature is their mode of occurrence in sink structures, which involve rocks from the Potosi Dolomite to possible Pennsylvanian beds but are most common in the upper part of the Gasconade Dolomite near the contact with the overlying Roubidoux Formation (Grawe, 1945, p. 51–64). Individual deposits range from a few tens of feet in diameter to more than 5 acres in surface extent and have depths of up to 200 feet.

Sandstone beds, particularly those of the Roubidoux Formation, are associated with many deposits and characteristically have slumped into the sink holes leaving a "rim rock" peripheral to the sink and dipping toward the center. Many large masses of sandstone and residual chert fragments and boulders are encountered in mining but in most places are not so intimately associated with the ore as to require crushing and grinding for separation.

Open pit methods of mining were used throughout the district and underground methods employed in some of the larger deposits. Usually the ore was not beneficiated in any manner: the soft hematite and the boulders of hard blue specular hematite were selectively mined and shipped directly to ore buyers.

By 1900 production from the filled sinks had accounted for approximately 30 percent of the total iron ore production of Missouri, but by 1965 this proportion had dropped to slightly less than 20 percent. Crawford County has been the largest producer, having produced over a million tons of ore previous to 1892 (Winslow, 1892, p. 21), followed by Dent and Phelps Counties. Maximum annual production probably occurred in either 1887 or in one of the years between 1872 and 1879. Since 1893 the maximum production was achieved during the early years of the 20th century when production for at least 2 years was over 60,000 tons. Since the 1930's production has been sporadic, and there has been no mining of hematite from the filled sinks since 1960.

The ores are chiefly soft red to purple hematites containing isolated and subordinate quantities of hard blue specular hematite boulders. Limonite in various shades of brown to yellow forms a part of each deposit, especially near the surface, and at depth where the limonite is pseudomorphic after pyrite and marcasite.

The soft red hematites vary greatly in chemical and physical character even within the same deposit. A soft granular type is perhaps the most common throughout the district, but the soft "paint" ore—a nearly pure, fine-grained, clayey, red to purple hematite having a greasy feel—occurs in many deposits though seldom in large quantity.

Fine-grained specular hematite occurs in massive boulders of steel-blue color and metallic luster. The boulders commonly contain numerous but small irregular cavities lined with quartz crystals and irridescent specular hematite crystals. Ores shipped from 12 producing mines just previous to 1912 ranged from 44.5 to 58.4 percent iron and gave a weighted average of 51.86 percent iron (Crane, 1912, p. 97).

Quartz crystals are common lining cavities in the ore and amethystine quartz has been found in several deposits. Isolated quartz sand grains are distributed sporadically throughout most of the ore. Crane (1912, p. 93) reports that the average silica content of the ores smelted between 1897 and 1910 ranged from 7 to 20 percent and averaged 10.83 percent.

Pyrite and marcasite are important gangue minerals and represent the "mother lode" from which the limonitic and hematitic ores were derived. The iron sulfides form large quantities in some deposits, especially near the base of the deposits beneath the hematite ores. A considerable number of iron mines became "sulfur" mines at depth (Grawe, 1945).

The ores contain about 0.1 percent phosphorus and up to 0.15 percent manganese. Insignificant amounts of alumina, lime, and magnesia are present in the hematite itself but are of no concern in regard to the grade of the ore except where the operator was careless and allowed waste rock to be combined with the ore.

When production of hematite from filled sinks was at its peak a part of the soft hematite ores were shipped to paint and cement manufacturers. This was also true during the slight resurgence of mining in the middle 1950's. At present, quality demands for iron ore discount the use of the specular hematite, and physical (as well as chemical) standards eliminate the soft hematite as a resource for iron ore. All known deposits of consequence have been worked to the point where the remaining available ore is of such minor quantity that it is doubtful these deposits will ever be worked in the future.

Brown ores

Brown iron ore deposits occur in the central, south-central, and southwestern parts of Missouri (fig. 18). The most productive areas have been the West Plains and Poplar Bluff districts. Brown ores were mined in Washington County as early as 1823 near the Perry furnace, approximately 8 miles south of Potosi.

Crane (1912, p. 54) distinguishes two types of brown ores, primary and secondary. The primary ores were believed to have been deposited as "ferric hydrate" in their present position by replacing the residuum in which they occur. These deposits generally exhibit a greater horizontal than vertical extent and the ore may be hard or exceedingly porous or earthy. The iron content of the ores ranges from 40 to 50 percent, silica is usually above 12 to 15 percent, phosphorus and sulfur are characterstically low, and manganese is rather high (0.3 to 3.0 percent). Deposits of the primary type are restricted to a rather narrow belt roughly paralleling the northwest margin of the Mississippi Embayment (or Southeast Lowlands) in Stoddard, Butler, Bollinger, Wayne, and Carter Counties. There was minor production of these ores in the early 1870's but it was not until 1902 that the ores were utilized to any degree.

By far the more important type of brown ore, in regard to production, is the secondary type of deposit. These deposits are scattered throughout the districts mentioned and isolated small deposits are known in almost every township of the Ozarks. Hayes (1957). According to Hayes there were 265 deposits in the West Plains and Poplar Bluff districts larger than one acre in surface extent that had been

worked, tested, or indicated a good potential for ore. Over 95 percent of these are in Howell, Oregon, and Wayne Counties.

The deposits occur in cherty clay residuum derived from weathering of Ordovician dolomites. Deposits range in size from a few tens of feet in diameter up to a surface area of 10 acres or more and to depths of about 150 feet. Concentrations of limonite boulders on the surface have led to the discovery of all known deposits. The deposits are roughly circular or elliptical in shape and have rather steep sides. Limonite is the ore mineral and occurs as irregular masses, boulders, stringers, and pockets where concentrated in the cherty clay residuum. Pseudomorphs of limonite in the form of pyrite or marcasite are present in all deposits. Two common forms are the pseudomorphic pyrite cubes and stalactitic masses referred to as "pipe ore." All transitions from pyrite and marcasite to limonite may be observed. Several deposits have proved to be uneconomic because of the high sulfur content of the ores due to partial oxidation of the original iron sulfide minerals.

All mining operations have been by open pit methods using power shovels, draglines, hi-lift loaders, and bulldozers. Selective mining is used by the operators to avoid lean or waste areas. The ore is usually concentrated by a log washer to break up the material and to remove the associated clay. The overflow from the washer is hand picked (called "cobbing") on a belt conveyor to remove chert and other rock fragments. Mechanical jigs were employed by several of the larger operators and in the 1950's heavy-media separation methods were used in several operations in Howell and Oregon Counties.

Although the brown ores account for less than 12 percent of the total production of iron ores of Missouri, they have been of local economic importance and have been desirable at times because of their low phosphorus content. Maximum annual production was attained in 1957 when 281,427 tons was produced.

With the advent of mechanization and mechanical handling of ores the potential of the brown ore deposits has decreased. Because of their relatively small individual size and scattered occurrence they are not well suited to large mechanized operations. Only a few have proven large enough to sustain production over a period of 5 years or longer. Based on the 1957 investigation of the Missouri Geological Survey, approximately 1,876,000 tons of measured ore was tabulated and 3,334,000 tons of inferred ore was estimated. It is doubtful if mining of the brown ores will ever again achieve the production of 1957, but it may continue at the existing rate to supply low-phosphorus ores to the Birmingham area and raw powdered material to the cement industry.

OUTLOOK

Missouri production of iron ore will increase when the new Pilot Knob mine and mill commence operations in 1968. Expansion of the Pea Ridge plant to utilize the hematite fraction of the deposit should raise total installed capacity in Missouri to 3 million tons per year of pellets fully equal to those from other sources. Undoubtedly at least some of the other known deposits will be developed when the iron ore market in the area expands sufficiently to absorb additional output.

The industry is becoming increasingly competitive on a worldwide basis, however, and many factors will be carefully weighed before the large capital investment required to exploit the buried Precambrian deposits will be made. Reserves are believed adequate to support a substantially increased production rate for many decades, so that Missouri's eventual output of iron ore will total many times the amount mined to date.

MANGANESE

(By J. V. N. Dorr II, U.S. Geological Survey, Washington, D.C.)

Manganese is an essential raw material in the manufacture of steel, its ferroalloys being used primarily to scavenge sulfur and phosphorus in the steel furnace. The element is also used in alloying with brass and bronze and in high-manganese steels. The oxides are used in the chemical, battery, ceramic, and paint industries, among others, and the sulfate is used as an additive to fertilizers.

Domestic consumption of manganese ores in 1965 was 2.67 million tons, of which 99 percent was imported. Domestic production of material containing 35 percent or more manganese was slightly less than 30,000 tons, most of it from Montana and the rest from New Mexico.

By contrast, Missouri has produced only about 3,000 tons in all (table 10), and less than 1,000 tons in the 20th century. The 302 tons mined during the 1953–58 period, when the U.S. Government paid more than twice the average world price for manganese of domestic origin, came from five different deposits.

TABLE 10.—*Estimated production and approximate value of ore and concentrates containing more than 35 percent* [1] *manganese, 1872–1965* [2]

Year	Short tons	Value	Average price per ton
1872	100	$500	$5.00
1881	2,000	25,000	12.50
1890	35	1,000	28.57
1899	16	160	10.00
1916	45	1,200	26.67
1917	45	1,500	33.33
1918	45	1,800	40.00
1936–37	50	750	15.00
1941	12	500	41.66
1942	239	10,600	44.35
1943	180	8,000	44.44
1954–58	302	25,000	82.78
Total	3,069	76,010	----------

[1] Small additional quantities containing 10 to 35 percent manganese sold to U.S. Government stockpiles in period 1953–58.
[2] No production recorded in years not shown.

Source: 1872–1943—Bishop (1949, p. 52); 1944–65, U.S. Bureau of Mines.

The principal manganese ore minerals are oxides. Concentration of manganese into ore deposits results from both igneous and sedimentary processes, and secondary enrichment on or near erosion surfaces has formed many of the major ore deposits of the world.

In Missouri veins of manganese oxides are present in rhyolite porphyry at a number of places in the Precambrian knobs of the St. Francois Mountains, and tuffaceous beds have been replaced by manganese oxides at one (Grawe, 1943, p. 26–28). Individual veins are at most only a few inches thick, however, and though they may occur

in brecciated zones several feet across, much hand labor is required to yield a product of acceptable grade. Grawe cites seven analyses of vein ore that averaged about 37 percent manganese and 33 percent insoluble residue. The tuffaceous ore consists of small masses of hard, high-grade (50 percent or more manganese) ore in low-grade soft material; various attempts have been made to mine this material, and one to mill it. These deposits are believed to be closely related in origin to the volcanic activity which produced the host rocks.

A second type of mineralization resulted from the concentration during weathering of sparsely disseminated manganese from a variety of rocks. As elsewhere in the world, such deposits are found associated particularly with clays residual after dolomite or tuff, along unconformities, or in breccias. They are most common along contacts between the Gasconade and Eminence and the Eminence and Potosi Formations, and in residuum derived from these horizons. The manganese oxide forms concretions in the clays, cements the breccias, replaces the cement of sandstones and locally the sand grains themselves, and fills joints and fissures. Such ores, except in unusual circumstances, are high in silica and/or alumina and in iron and are difficult to concentrate into a merchantable product. Individual concretions and selected samples give the analysis of high-grade ore but in most localities the high-grade ore is too sparsely scattered in the clay or other rock to permit production at commercial scale. The deposits are characteristically erratic in grade and geometrically irregular. The ores of these deposits, and particularly the manganiferous chert breccias, characteristically contain from a tenth to 1 or 2 percent cobalt (Grawe, 1943, p. 29–33; see also chapter on cobalt, p. 70).

Grawe (1943) lists 57 deposits and occurrences of manganese oxide minerals in Missouri. Many of these are mineralogical occurrences of no possible commercial value; most of those which have produced are shown on figure 20. The principal occurrences and deposits are in Iron, Madison, Wayne, Reynolds, Shannon, and Carter Counties.

The Cuthbertson or Marble Creek deposit in Iron County (fig. 20, no. 1) has yielded the greatest quantity of manganese ore mined in Missouri and has had the longest history. It was visited by Pumpelly (1873, p. 20–24) and presumably was the source of the production shown for that year (table 10). It was credited with 2,000 tons in 1881 (Weeks, 1886, p. 346–348). Attempts were made to operate the property during World War I, and in 1939–41 (Grawe, 1943, p. 40–43); a small mill was installed but was apparently unsuccessful in making a satisfactory concentrate. Hard lumps of manganese oxides in low-grade, ferruginous wad replace Precambrian tuff that lies parallel and close to the steep south-dipping face of Cuthbertson Mountain. Mining has been by open cut over an area about 500 feet square.

Veins in porphyry have been mined at the following properties:

No., fig. 20	Name	Description by Grawe (1943) (pages)
2	Lindsay Mine	59–61
4	Reeves prospect	73–74
5	Thorny Mountain Mine	74–76
6	Elliot prospect	71–72
7	C. P. Turley shaft	35–36

The Clover mine (fig. 20, no. 3) produced small amounts of hand-sorted manganese oxides from shallow pits in clay residuum during World War I (Grawe, 1943, p. 49–53).

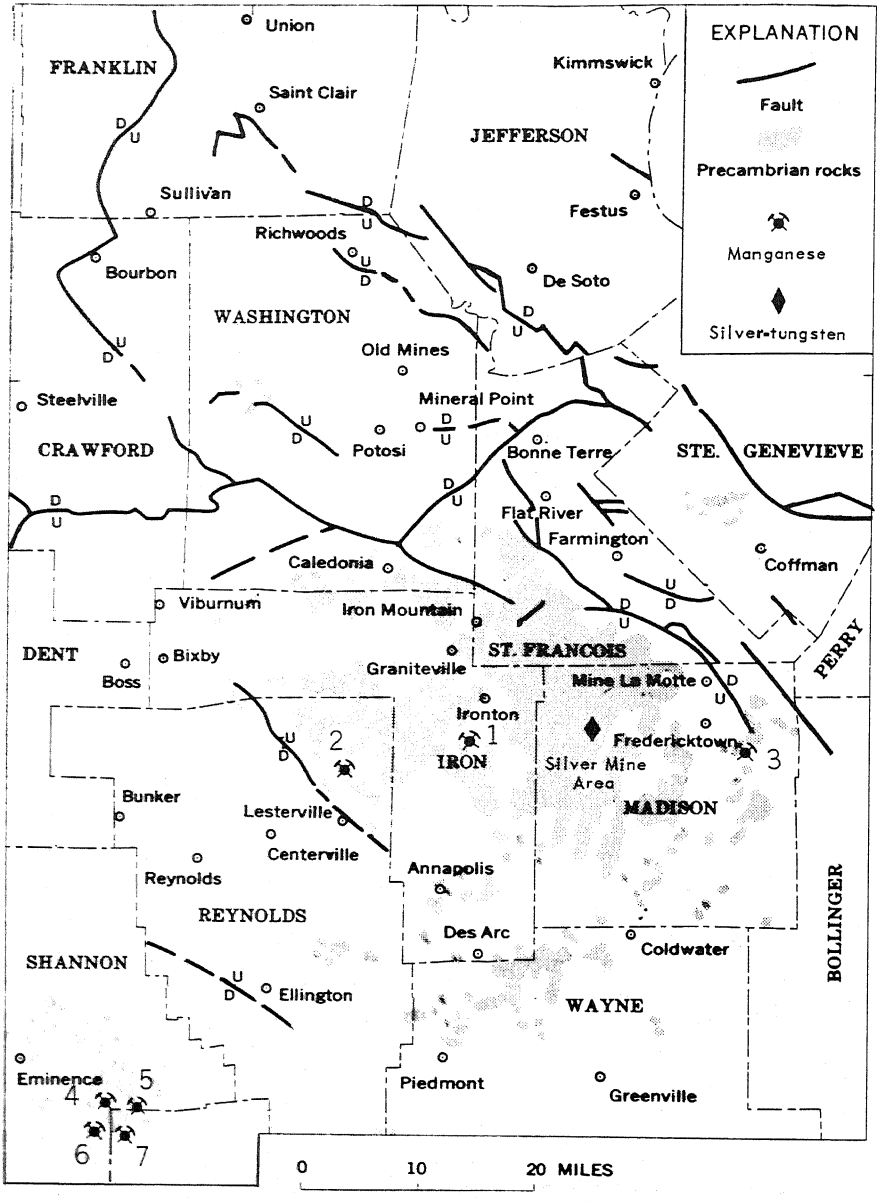


FIGURE 20.—Deposits known to have produced manganese, and silver and tungsten, in southeastern Missouri.

In spite of the widespread occurrence of manganese in southeastern Missouri, the very small size and low grade of known deposits, and the poor experience to date with attempts to make acceptable concentrates by mechanical methods, do not encourage optimism for significant future production.

TUNGSTEN

(By S. W. Hobbs, U.S. Geological Survey, Denver, Colo.)

Although Missouri is one of the 17 States in the United States that has recorded tungsten production, the metal has never been important in the mineral economy of the State. Production has been restricted to the Silver Mine area in Madison County on the St. Francis River about 9 miles west of Fredericktown (fig. 20). Small amounts of tungsten concentrates have been produced from this area at intervals from 1916 to 1950, mostly from old mines that were originally operated for silver and lead. The total production is but a small fraction of 1 percent of the total for the United States (Holliday, 1960).

Tungsten is an important industrial commodity because of certain unique physical and chemical properties of the metal, its compounds and its alloys. These properties include unusual strength, hardness, heat resistance and electrical characteristics. A familiar usage of the pure metal is for filaments in electric light bulbs, but the greatest usage is in alloy steels for high temperature applications, in nonferrous alloys and in tungsten carbide for cutting tools and other uses where extreme hardness and heat resistance is required. Various chemical compounds are used for dyes, inks and the fluorescent coatings in lamps.

The pure metal is light gray, very heavy (specific gravity 19.3) and has the highest melting point of all the metals (3,410° C.). It does not occur as a native element in nature but is always combined with other elements in one or another of some 14 minerals of which only scheelite (calcium tungstate) and the gradational members of the wolframite group—ferberite (iron tungstate), wolframite (iron and manganese tungstate), and huebnerite (manganese tungstate)—are commercially important. These minerals occur in pegmatites, quartz veins, contact metamorphic deposits (tactite or skarn), hydrothermal replacement deposits, stockworks or breccia zones, hot spring deposits associated with manganese oxides, and as placer deposits. The world's largest reserves are in vein deposits—mainly in Red China—and the major part of the world's production has come from deposits of this type; in the United States, however, about 75 percent of the total production to date has come from contact metamorphic deposits and most of the remainder from veins (Stevens, 1965).

Most primary tungsten deposits are closely associated both areally and genetically with rocks of granitic or monzonitic composition. The search for new deposits has in many places successfully utilized this concept to outline favorable areas for prospecting and to eliminate much terrain in which a search would be futile.

The United States has long been the chief consumer of tungsten concentrates, but only during the period 1953–56, when premium prices were guaranteed by the government, did the domestic production exceed consumption (Stevens, 1965). In spite of a protective tariff that

77-278 O—67——7

currently is $0.50 per pound of metallic tungsten ($7.93 per short ton unit WO_3), the United States has traditionally relied on imports of tungsten concentrates to fulfill part of its demand. Domestic consumption has been in the range of about 12 to 14 million pounds annually since 1960, whereas production has averaged about 8 million pounds.

The low grade of most tungsten ore requires concentration to a product that contains 60 to 70 percent of WO_3 before it is marketable. Impurities of tin, copper, bismuth, antimony, arsenic, molybdenum, phosphorus, sulfur, lead, and zinc must be less than certain tolerances to avoid penalties that reduce the prices received for the concentrate. The price is based on the short ton unit (20 pounds of WO_3, containing 15.862 pounds of tungsten metal), which has ranged from $2 in the early part of this century to $85 in 1916. At the time of maximum domestic production in 1955 the price was $63; in December 1966 it was approximately $43.

The only known occurrences of tungsten in Missouri are located near Silver Mine on the St. Francis River in Madison County about 9 miles west of Fredericktown. The Silver Mine area includes four mines within an area of about 1½ square miles on the west side of the river and principally in the S. ½ sec. 12, T. 33 N., R. 5 E. Detailed studies of the area were made by Singewald and Milton (1929) and by Tolman (1933).

The deposits occur in Precambrian granite and felsite of the St. Francois Mountains. Quartz veins and brecciated zones are the main ore structures; they contain, in addition to quartz, lesser amounts of fluorite, topaz, mica, and altered wall rock. Sulfides of lead, zinc, and copper, together with wolframite, are the minerals of economic interest.

Four mines, the Einstein, Apex, Ozark, and Martin, have been worked intermittently since the first discoveries were made in the area in 1877. Between 1877 and 1894 a little silver and lead were produced from the Einstein and Apex mines. (See Silver section, p. 72). At intervals between 1916 and 1950, small amounts of tungsten concentrates were recovered, largely by reworking tailings and mining tungsten-bearing ore exposed in the old silver workings; most of the ore came from the Einstein and Apex mines, but small amounts also came from the Ozark and perhaps the Martin properties. Records are poor, but the total production probably has not exceeded 2,200 units, or 35,000 pounds of tungsten (Holliday, 1960).

The Einstein, Apex, and Martin mines are developed on quartz veins that strike east and dip south at angles of 45° to 60° and that appear to be controlled by jointing in the country rock. The widths of the veins reportedly range from less than a foot to over 6 feet although generally the ore-bearing portion is 2 feet wide or less. Along the vein walls, the country rock is altered to greisen—a mixture of quartz, sericite, and topaz with locally disseminated fluorite. The veins contain wolframite, argentiferous galena, pyrite, arsenopyrite, sphalerite, and chalcopyrite. A few other minerals including cassiterite, scheelite, and stolzite have been reported.

The principal vein of the Einstein mine, Vein No. 1, was opened by an adit driven 548 feet westerly from a point about 50 feet above the river bed. An inclined shaft was sunk at the portal of the adit to a depth of 180 feet, and two other levels were opened at 75 and 150 feet.

The workings represent a vertical range of about 350 feet. Vein No. 2, 1,200 feet north, was opened by a 100-foot adit and the Gabriel shaft.

The Apex and Martin mines were opened by shallow inclines with a small amount of drifting at the bottom. These have been filled with water for some years and little is known about them.

The Ozark mine, opened by a 100-foot incline, is in greisenized volcanic rocks in which the metallic minerals are disseminated or occupy small veinlets in brecciated zones. A small amount of oxidized tungsten ore was mined at the surface.

The production of both silver and tungsten from this district has been small and the geologic characteristics are not favorable for significant expansion. As with so many tungsten deposits, and particularly those in veins that have characteristics like the Silver Mine group, the distribution of the tungsten minerals is sporadic and generally unpredictable. Although sizable pockets of high-grade material are to be found, their discovery is difficult and involves much unproductive work in barren or very low grade parts of the vein. Furthermore, the veins appear to be lens-shaped and discontinuous along the strike, and probably also down the dip. Little if any change in the character of the ore has been found to the depth explored and no sound reason exists to expect any systematic improvement in the tenor at greater depths. It is possible that some small production will again be made from the known veins and also that other small occurrences may be found in the vicinity. Such efforts will be stimulated, however, only by a significant increase in the price of tungsten.

URANIUM

(By A. P. Butler, Jr., U.S. Geological Survey, Denver, Colo.)

Uranium is a heavy metal of great significance as a concentrated source of energy both for nuclear explosives and increasingly as a fuel for generating electric power in nuclear reactors.

Uranium ores occur as lenticular or tabular bodies in beds of sandstone, conglomerate, and limestone and as veins along fractures. In recent years deposits in conglomerate in Canada and South Africa and in sandstone in the Western United States have been the most productive. Uraninite, an oxide, coffinite, a silicate, and brannerite, a multiple oxide of uranium and titanium, are important ore minerals in different deposits. Deposits of the foregoing types will continue to yield most of the world's supply of uranium for many years, but ultimately the world will probably derive most of its uranium from low-grade deposits in marine phosphorites and black shales which contain from 0.005 to 0.012 percent uranium.

No deposits of types that have been mined are known in Missouri, and no uranium has been mined in the State, but minor concentrations of uranium occur (Muilenberg, 1957). These are: (1) secondary uranium minerals on joint surfaces of fireclay in southwest Franklin County and in limestone of the Salem Formation at the Charles Bussen quarry north of Ste. Genevieve, Ste. Genevieve County; (2) uranium in unidentified form in small local accumulations of pitchlike, bituminous, or asphaltic substances in various sedimentary rocks of early Paleozoic age in Callaway, Douglas, Oregon, and Madison Counties; and (3) uranium in some units of marine black shales.

The last include the Chattanooga Shale of Late Devonian(?) age, in which uranium probably does not exceed 0.003 percent on the average; some thin beds of phosphatic black shale of Pennsylvanian age, which are slightly richer in uranium but generally only 2 to 4 feet thick (Swanson, 1956); and a thin shale parting in limestone at the Bussen quarry mentioned above.

Known occurrences of the first two groups are too small and scattered to be of significance as a resource but support a very tenuous possibility that useful concentrations of uranium might be found. The marine shales are so lean in uranium or so thin as to represent only a possible resource for the distant future.

SELECTED REFERENCES

Bain, H. F., and Ulrich, E. O., 1905, The copper deposits of Missouri: U.S. Geol. Survey Bull. 267, 52 p.

Bilbrey, J. H., Jr., 1960, Nickel *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 549–563.

——— 1962, Cobalt, a materials survey: U.S. Bur. Mines Inf. Circ. no. 8103, 140 p.

Bishop, O. M., 1949, The mineral industry of Missouri in 1946 and 1947, with total production summarized: Missouri Div. Geol. Survey and Water Resources Inf. Circ. no. 4, 93 p.

Bridge, Josiah, 1930, Geology of the Eminence and Cardareva quadrangles: Missouri Bur. Geology and Mines, 2d ser., v. 24, 228 p.

Buckley, E. R., 1909, Geology of the disseminated lead deposits of St. Francois and Washington Counties: Missouri Bur. Geology and Mines, v. 9, pt. 1, 259 p.

Buckley, E. R., and Buehler, H. A., 1905, The geology of the Granby area: Missouri Bur. Geology and Mines, 2d ser., v. 4, 120 p. [1906].

Callahan, W. H., 1966, Paleophysiographic premises for prospecting for stratabound base metal mineral deposits in carbonate rocks, *in* Pacific Southwest Mineral Industry Conference: Nevada Bur. Mines Rept. 13, pt. 6, p. 5–50.

Cornwall, H. R., 1966, Nickel deposits of North America: U.S. Geol. Survey Bull. 1223, 62 p.

Crane, G. W., 1912, The iron ores of Missouri: Missouri Bur. Mines and Geology, 2d ser., v. 10, 434 p.

Cullison, J. S., and Ellison, S. P., Jr., 1944, Diamond-drill core from the Bourbon High, Crawford County, Missouri: Am. Assoc. Petroleum Geologists Bull., v. 28, no. 9, p. 1386–1396.

Dake, C. L., 1930, The geology of the Potosi and Edgehill quadrangles: Missouri Bur. Geology and Mines, 2d ser., v. 23, 233 p.

Davis, J. H., 1958, Distribution of copper, zinc, and minor metals in the southeast Missouri lead district [abs.]: Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1551.

Dempsey, W. J., and Meuschke, J. L., 1951, Total intensity aeromagnetic map of Sullivan quadrangle and part of Union quadrangle, Missouri: U.S. Geol. Survey Geophys. Inv. Map GP–78.

Eilertson, D. E., 1965, Gallium, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 630, p. 351–354.

Engineering and Mining Journal, 1964, Meramec iron ore project starts production at Pea Ridge: Eng. and Mining Jour., v. 165, no. 4, p. 93–108.

Fleischer, Michael, 1953, Recent estimates of the abundances of the elements in the earth's crust: U.S. Geol. Survey Circ. 285, 7 p.

Fowler, G. M., 1960, Structural deformation and ore deposits: Eng. and Mining Jour., v. 161, no. 6, p. 183–188.

Fowler, G. M., Hernon, R. M., Conrow, J. M., and Stone, E. A., 1955, Prospecting and developing ore deposits in bedded formations: Eng. and Mining Jour., v. 156, no. 3a, p. 6–18.

Fowler, G. M., and Lyden, J. P., 1932, The ore deposits of the Tri-State district (Missouri-Kansas-Oklahoma): Am. Inst. Mining Metall. Engineers Tech. Pub. no. 446, 46 p.

Fowler, G. M., Lyden, J. P., Gregory, F. E., and Agar, W. M., 1934, Chertification in the Tri-State (Oklahoma-Kansas-Missouri) mining district: Am. Inst. Mining Metall. Engineers Tech. Pub. 532, 50 p.

Grawe, O. R., 1943, Manganese deposits of Missouri: Missouri Div. Geol. Survey and Water Resources 62d Bienn. Rept., app. 6, 77 p.

——— 1945, Pyrites deposits of Missouri: Missouri Geol. Survey and Water Resources, 2d ser., v. 30, 482 p.

Hayes, W. C., Jr., 1957, Exploration and development of the sedimentary iron ores of Missouri: Missouri Div. Geol. Survey and Water Resources Inf. Circ. no. 14, 33 p.

——— 1959, Geology and exploration of Missouri iron deposits: Missouri Geol. Survey and Water Resources Misc. Pub., 16 p.

Hayes, W. C., Jr., and others, 1961, Guidebook to the geology of the St. Francois Mountain area, Association of Missouri Geologists, 8th annual field trip, 1961: Missouri Div. Geol. Survey and Water Resources Rept. Inv. no. 26, 137 p.
Henshaw, P. C., 1965, Exploration for lead in southeast Missouri: Mining Cong. Jour., v. 51, no. 12, p. 28–30.
Heyl, A. V., and Bozion, C. N., 1962, Oxidized zinc deposits of the United States—Pt. 1, General geology: U.S. Geol. Survey Bull. 1135–A, 52 p.
Heyl, A. V., Brock, M. R., Jolly, J. L., and Wells, C. E., 1965, Regional structure of the southeast Missouri and Illinois-Kentucky mineral districts: U.S. Geol. Survey Bull. 1202–B, 20 p.
Holliday, R. W., 1960, Tungsten, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 903–917.
James, J. A., 1949, Geology relationships of the ore deposits in the Fredericktown area, Missouri: Missouri Geol. Survey and Water Resources Rept. Inv. no. 8, 25 p.
Johnson, C. H., Editor, 1963, Guidebook to the geology in the vicinity of Joplin, Missouri: Assoc. Missouri Geologists 10th Ann. Field Trip, 50 p.
Kiilsgaard, T. H., 1964, Silver: Mining Cong. Jour., v. 50, no. 9, p. 60–64.
Kisvarsanyi, E. B., 1966, The potential of metallic and nonmetallic mineral resources of north Missouri: Missouri Mineral Industry News, v. 6, no. 4, p. 50–58.
Kisvarsanyi, Geza, 1966, Geochemical and petrological study of the Precambrian iron metallogenetic province of southeast Missouri: Ph.D. Dissert., Missouri Univ., Rolla, Mo., 198 p. (unpub.).
Kline, H. D., Calhoun, W. A., and Reynolds, B. M., 1961, Mining and milling methods and costs, Madison mine, National Lead Co., St. Louis Smelting and Refining Division, Madison County, Mo.: U.S. Bur. Mines Inf. Circ. no. 8028, 26 p.
Lake, M. C., 1932, The iron ore deposits of Iron Mountain, Missouri, *in* Mining districts of the Eastern States: Internat. Geol. Cong., 16th, Washington 1933, Guidebook 2, p. 56–67.
Lim, B. H., 1965, Cobalt: Eng. and Mining Jour., v. 166, no. 2, p. 156–157.
Litton, Abram, 1855, A preliminary report on some of the principal mines in Franklin, Jefferson, Washington, St. Francois, and Madison Counties, Missouri, *in* G. C. Swallow, Missouri Geol. Survey 1st and 2d Annual Report: Missouri Geol. Survey, pt. 2, p. 1–94.
Lynde, H. W., Jr., 1967, Cobalt, *in* U.S. Bur. Mines Minerals Yearbook 1965—V. 1, Minerals and metals (except fuels): Washington, D.C., p. 329–335.
McKnight, E. T., 1935, Zinc and lead deposits of northern Arkansas: U.S. Geol. Survey Bull. 853, 311 p.
McMillan, W. D., 1946, Exploration of the Bourbon magnetic anomaly, Crawford County, Missouri: U.S. Bur. Mines Rept. Inv. no. 3961, 9 p.
Marbut, C. F., 1908, The geology of Morgan County: Missouri Bur. Geology and Mines, 2d ser., v. 7, 97 p.
Martin, A. J., 1946, Summarized statistics of production of lead and zinc in the Tri-State (Missouri-Kansas-Oklahoma) mining district: U.S. Bur. Mines Inf. Circ. no. 7383, 67 p.
Mather, W. B., 1946, The mineral deposits of Morgan County, Missouri: Missouri Geol. Survey and Water Resources Rept. Inv. no. 2, 207 p.
——— 1947, Barite deposits of central Missouri: Am. Inst. Mining Metall. Engineers Tech. Pub. 2246, 15 p.
Merrill, C. W., McKnight, E. T., Kiilsgaard, T. H., and Ryan, J. P., 1965, Silver—facts, estimates, and projections: U.S. Bur. Mines Inf. Circ. no. 8257, 22 p.
Moulds, D. E., 1965, Germanium, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 630, p. 379–385.
Muilenberg, G. A., 1957, Notes on uranium: Missouri Div. Geol. Survey and Water Resources Inf. Circ. no. 5, revised ed., 22 p.
Murphy, J. E., and Mejia, V. M., 1961, Underground geology at Iron Mountain *in* Guidebook to the geology of the St. Francois Mountain area, Association of Missouri Geologists, 8th annual field trip: Missouri Geol. Survey and Water Resources Rept. Inv. no. 26, p. 129–137.
Nason, F. L., 1892, A report on the iron ores of Missouri: Missouri Geol. Survey, 1st ser., v. 2, 366 p.
Neuschel, V. S., and McKnight, E. T., 1948, Map showing metallic mineral deposits of Missouri: U.S. Geol. Survey Missouri Basin studies no. 18.

Nicholson, Frank, 1882, A review of the Ste. Genevieve copper deposit: Am. Inst. Mining Engineers Trans. v. 10, p. 444–456.
Norris, J. D., 1964, Frontier iron, the Maramec Iron Works 1826–1876: Wisconsin State Hist. Soc., Madison, 206 p.
Ohle, E. L., and Brown, J. S., Editors, 1954a, Geologic problems in the Southeast Missouri lead district: Geol. Soc. America Bull., v. 65, no. 3, p. 201–221.
Ohle, E. L., and Brown, J. S., Editors, 1954b, Geologic problems in the Southeast Missouri lead district—Supplement: Geol. Soc. America Bull. no. 9, v. 65, p. 935–936.
Pumpelly, Raphael, 1873, Notes on the geology of Pilot Knob and its vicinity, *in* Preliminary report on the iron ores and coal fields, 1872: Missouri Geol. Survey, pt. 1, p. 3–28.
Ruhl, Otto, Allen, S. A., and Holt, S. P., 1949, Zinc-lead ore reserves of the Tri-State district, Missouri-Kansas-Oklahoma: U.S. Bur. Mines Rept. Inv. no. 4490, 59 p.
Schmidt, Adolf, 1873, The iron ores of Missouri, *in* Preliminary report on the iron ores and coal fields. 1872: Missouri Geol. Survey, pt. 1, p. 45–214.
——— 1874, The lead region of central Missouri, *in* G. C. Broadhead, Report of the Geological Survey of the State of Missouri, 1873–1874: Missouri Bur. Geology and Mines, p. 503–577.
Schroeder, H. J., 1965a, Cadmium, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 630, p. 165–173.
——— 1965b, Indium, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 630, p. 441–445.
Siebenthal, C. E., 1916, Origin of the zinc and lead deposits of the Joplin region, Missouri, Kansas, and Oklahoma: U.S. Geol. Survey Bull. 606, 283 p.
Singewald, J. T., Jr., and Milton, Charles, 1929, Greisen and associated mineralization at Silver Mine, Missouri: Econ. Geology, v. 24, no. 6, p. 569–591.
Snyder, F. G., and Emery, J. A., 1957, Geology in development and mining, southeast Missouri Lead Belt: Am. Inst. Mining, Metall., and Petroleum Engineers Trans., 1956, v. 205, p. 1216–1224.
Snyder, F. G., and Odell, J. W., 1958, Sedimentary breccias in the southeast Missouri lead district: Geol. Soc. America Bull., v. 69, no. 7, p. 899–925.
Stevens, R. F., Jr., 1965, Tungsten, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 630, p. 991–1006.
Swanson, V. E., 1956, Uranium in marine black shales of the United States, *in* Page, L. R., Stocking, H. E., and Smith, H. B., Compilers, Contributions to the geology of uranium and thorium . . .: U.S. Geol. Survey Prof. Paper 300, p. 451–456.
Tarr, W. A., 1936, Origin of the southeastern Missouri lead deposits: Econ. Geology, v. 31, no. 7, p. 712–754; no. 8, p. 832–866.
Tolman, Carl, 1933, The geology of the Silver Mine area, Madison County, Missouri: Missouri Bur. Geology and Mines 57th Bienn. Rept., app. 1, 39 p.
U.S. Congress, Senate Committee on Armed Services, 1962, Inquiry into the strategic and critical stockpiles of the United States, Hearings—pt. 8: U.S. 87th Cong., 2d sess., p. 2587–3056.
U.S. Geological Survey, 1914–1918, Mineral resources of the United States: Washington, U.S. Govt. Printing Office [annual volumes for years indicated].
Vhay, J. S., 1952, Cobalt resources, chap. 6 *of* Materials survey, cobalt: U.S. Bur. Mines [Rept.], 56 p.
Wagner, R. E., 1947, "Lead-Belt" geology: Mining and Metallurgy, v. 28, no. 488, p. 366–368.
Weeks, J. D., 1886, Manganese, *in* Mineral resources of the United States, 1885: U. S. Geol. Survey [Rept.], p. 303–356.
Weigel, W. W., 1965, The inside story of Missouri's exploration boom—pts. 1 and 2: Eng. and Mining Jour., v. 166, no. 11, p. 77–86, 170, and 172; no. 12, p. 81–83, 161–162.
Weller, Stuart, and St. Clair, Stuart, 1928, Geology of the Ste. Genevieve County, Missouri: Missouri Bur. Geology and Mines, 2d ser., v. 22, 352 p.
Winslow, Arthur, 1892, Historical and statistical sketch of the iron industry of Missouri, *in* Nason, F. L., A report on the iron ores of Missouri: Missouri Geol. Survey, 1st ser., v. 2, app. B, p. 303–334.
——— 1894, Lead and zinc deposits: Missouri Geol. Survey, v. 6 and 7, 763 p.

NONMETALLIC MINERAL RESOURCES

BARITE

(By Donald A. Brobst, U.S. Geological Survey, Denver, Colo., and R. Joseph Wagner, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Barite ($BaSO_4$) is a relatively soft, generally white to gray, heavy mineral that has a specific gravity of 4.5. The properties of softness, chemical inertness, and weight make it valuable for a number of purposes. About 90 percent of the barite consumed annually in the United States is ground to minus 325 mesh and added to the fluid used in the rotary drilling of oil and gas wells; the heavy weight thus imparted to the fluid assists in the drilling process and in controlling high oil and gas pressures at depth. The remaining 10 percent is used directly as barite or in the preparation of barium compounds for a great variety of products and industial processes, such as fillers and extenders in paint, ink, paper, textiles, rubber goods, asbestos products, and linoleum; heavy aggregate for concrete construction material; electronic equipment; ceramics, and flux in glass manufacture. Ground barite has recently come into use as ballast in the tires of tractors and heavy construction equipment. A newly developed fuel cell uses barium with oxygen or chlorine as an oxidizer. After 1 hour's operation, it still has about three times the energy of a silver-zinc battery. Some barite is still used in the manufacture of lithopone, a white pigment of barium sulfate and zinc, but production has declined greatly since the introduction of titanium dioxide pigments.

The quality standards and prices of barite vary for different uses. The chemical and many other industries require a product of higher purity than does the petroleum industry. Various product specifications and other aspects of the barite industry have been discussed by Brobst (1960) and Lewis (1965a). The following price quotations are f.o.b. shipping points in November 1965: drilling-grade barite (sp. gr. 4.2 to 4.3, 3 to 12 percent iron oxide), $12 to $16 per ton; chemical-grade barite, $18.50 to $23.50 per ton; water-ground barite (99.5 percent minus 325 mesh), $45 to $49 per ton; imported crude barite, $11 to $14 in Gulf ports.

Barite occurs in many geological environments in sedimentary, igneous, and metamorphic rocks. In ore deposits barite occurs alone or, more commonly, in association with quartz, jasper, chert, fluorite, celestite, and various carbonate and metallic-sulfide minerals. Three types of deposits can be defined: vein and cavity-filling, bedded, and residual. The geologic features of these types of deposits and some well known examples of each have been described by Brobst (1958).

The major domestic sources of barite are the extensive residual deposits of Missouri and the southern Appalachian region and the large high-grade bedded deposits of Arkansas and Nevada. Since the early

days of barite mining the residual deposits have continued to be economically valuable for many reasons. They are close to the major markets. The ores are inexpensive to mine in open cuts and easy to beneficiate, generally by washing, screening, and jigging (Muilenburg, 1954, pp. 47–48). The product from these deposits is usable not only in the oil fields but also in the chemical and other industries that require white, high-purity barite. The bedded deposits are of great economic value chiefly because large volumes of rock containing 30 to 90 percent barite are available in single deposits, as at Magnet Cove, Ark. This ore can be concentrated by flotation methods to yield a product especially suitable for well drilling (Sackett, 1962, pp. 48–49).

The first barite mines in the United States were opened in the vein deposits of Virginia and Connecticut about 1845. Mining of the residual deposits of Missouri began about 1850. By 1914, production also had been recorded from Kentucky, Tennessee, Georgia, Nevada, Alabama, and the Carolinas. The modern domestic barite industry began during World War I when east coast markets were cut off from their supplies in England and Germany. In the expanding economy after World War I, a vigorous domestic barite industry supplied increasing demands. After the use of barite in well drilling was introduced in 1925, the domestic production and consumption rose to an alltime high in the period 1955–57 and has declined only slightly since then.

The United States has been the world's leading consumer and producer of barite since World War I. Domestic consumption currently is about 1.5 million tons annually. The domestic production of 0.75 to 1 million tons annually is supplemented by imports, chiefly from Canada, Mexico, Peru, Ireland, England, Morocco, and Greece.

More barite has been mined in Missouri than in any other State. Nearly 10 million tons of barite valued at $85 million dollars was mined from 1850 to 1964. More than 6 million tons has been mined since 1940. Production reached 100,000 tons annually in 1925 when the pioneer work in the use of barite drilling fluid was done with Missouri barite. After 1925, production in Missouri generally has ranged from 150,000 to 300,000 tons annually (fig. 21). In 1965 it was 328,585 tons, valued at $4,219,000. Since World War II, the annual production of barite in Missouri has been exceeded only in a few years by that from Arkansas.

Barite deposits have been exploited in two areas of Missouri (fig. 22). The Washington County district, about 75 miles southwest of St. Louis, includes adjacent parts of St. Francois, Jefferson, and Franklin Counties. Its extensive residual deposits have yielded most of the barite mined in Missouri. The Central district includes several areas in parts of seven counties but lies principally in Cole, Miller, Moniteau, and Morgan Counties. Only small amounts of barite have been mined intermittently from these small, scattered deposits. The geology of these barite districts has been described by Tarr (1918, 1919), Weigel (1929), Dake (1930), Mather (1946, 1947) and Muilenburg (1954). Geological studies by the Missouri Geological Survey are continuing in the Washington County district.

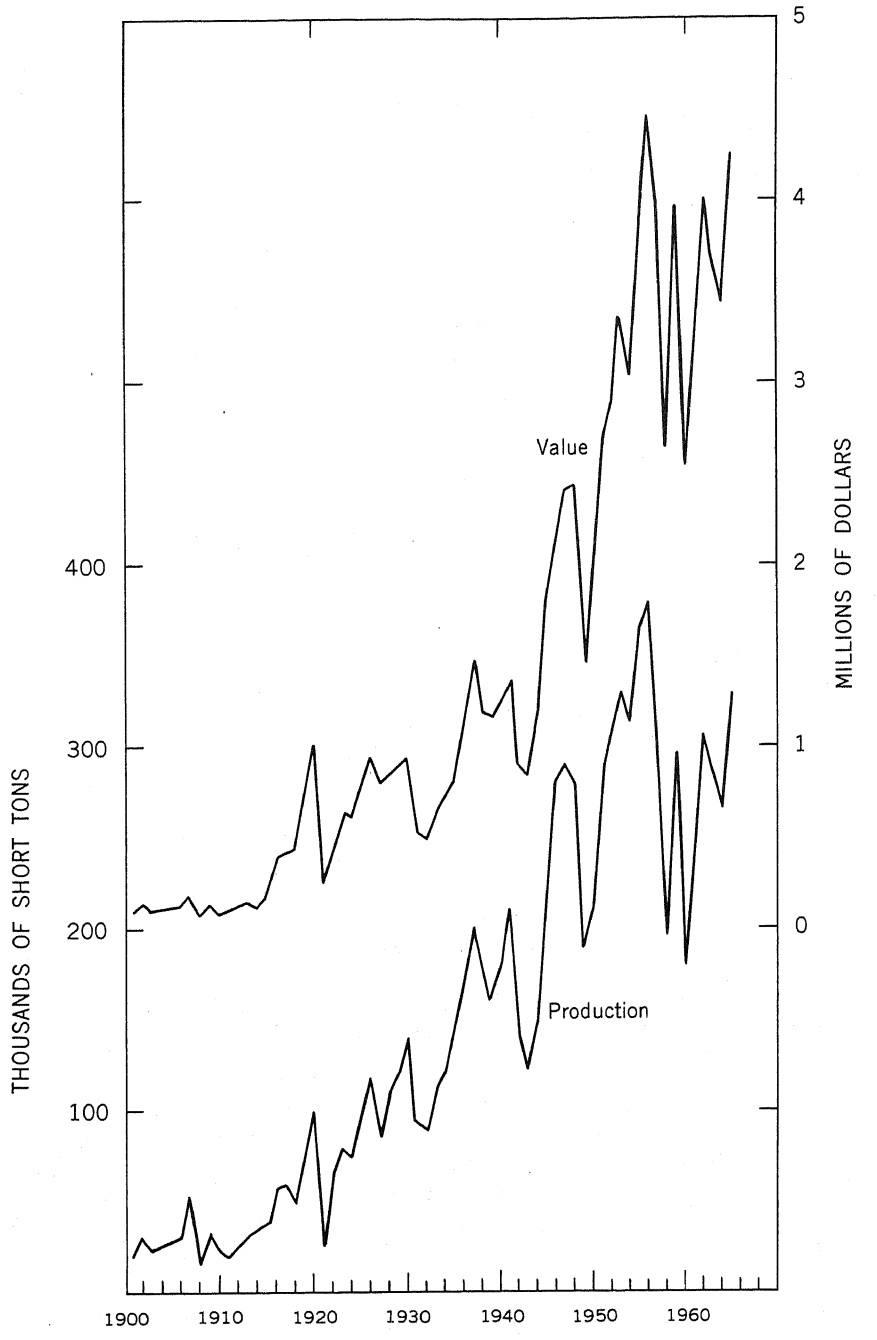


FIGURE 21.—Production and value of barite in Missouri 1901–65. (Data from U.S. Bureau of Mines, Minerals Yearbooks 1932–64, U.S. Bureau of Mines, Mineral Resources of the U.S. 1924–31, U.S. Geological Survey, Mineral Resources of the U.S. 1901–23.)

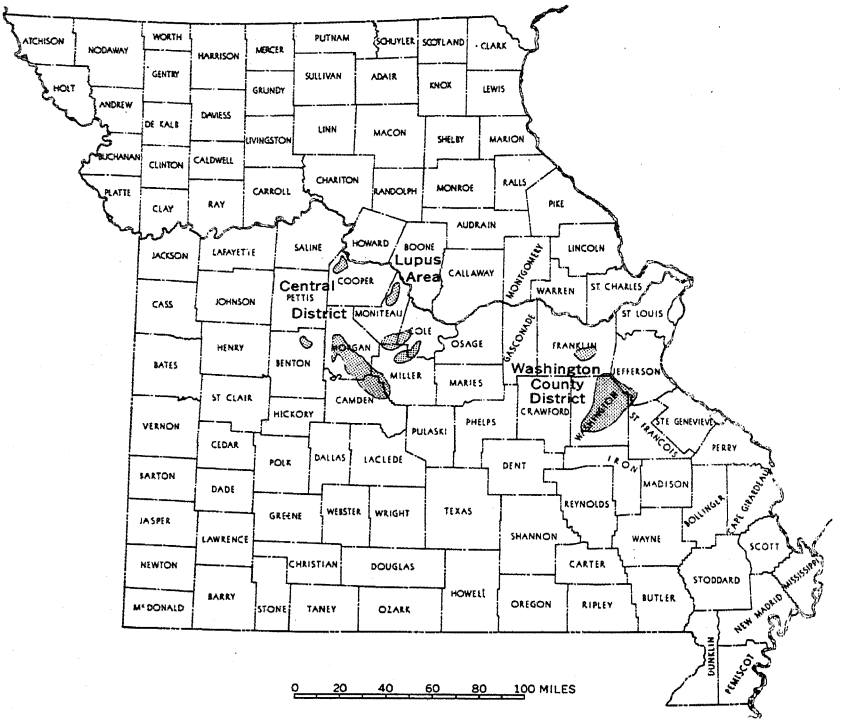


FIGURE 22.—Barite-producing areas of Missouri.

In the Washington County district, barite occurs in fractured bedrock and in the red clay residuum derived chiefly from the Potosi and Eminence Dolomites of Cambrian age. Only the concentrations of barite in the residuum are of commercial importance. Most of these residual deposits are associated with the Potosi Dolomite; about 95 percent of the deposits occur in an interval that includes approximately the upper half of the Potosi and the lower two-thirds of the Eminence. Some barite in veins and small isolated residual deposits is associated with the dense and little-fractured rocks of the Gasconade Dolomite in northeastern Washington County and southeastern Franklin County. A little barite is also present at places in the Roubidoux Formation and the Jefferson City and Cotter Dolomites. The stratigraphy of the Washington County district is summarized in table 11.

TABLE 11.—*Stratigraphy of the Washington County barite district*

Age and Rock Unit	Thickness (in feet)	Description
Lower Ordovician:		
Cotter Dolomite Jefferson City Dolomite	175–420	Heterogeneous sequence of thin- to thick-bedded, light-colored dolomitic limestone; thin-bedded limestone, shale, and argillaceous dolomitic limestone.
Roubidoux Formation	125–175	White sandstone interlayered with thin beds of dolomitic limestone. Ripple marks common. Weathers red.
Gasconade Dolomite	150–225	Thin- to thick-bedded, light-gray, medium to coarsely crystalline dolomitic limestone. Unconformity at base.
Upper Cambrian:		
Eminence Dolomite	125–175	Massive to poorly bedded, medium- to coarse-grained dolomitic limestone. Light gray on fresh exposures; dark gray on weathered exposures. Some seams of green clay and nodules of black and white chert. Gradational contact with the Potosi.
Potosi Dolomite	300–375	Mixture of varying proportions of algal reef rock, oolitic carbonate rock and thinly bedded carbonate "slime" rocks deposited in deep or quiet water. Predominantly a reef complex as much as 300 ft. thick characterized by poorly bedded, medium crystalline, light-brown dolomite. Good barite host rock. Gradational contact at base.
Derby-Doerun Dolomite	80–100	Light-gray to buff, finely crystalline to earthy dolomite.
Davis Formation	150–170	Gray to green shale, thin-bedded limestone, massive limestone and limestone conglomerate.
Bonneterre Formation	250–350	Massive, gray to buff, crystalline dolomite.
Lamotte Sandstone	0–350	White to buff or reddish brown, crossbedded sandstone. Many shale beds. Variable thickness; unconformably overlies rocks of Precambrian age.

Fractures and voids in the bedrock controlled the original emplacement of the barite. The porous and easily fractured algal reef structures, most abundant in the Potosi, were the most favorable host rocks for the deposition of the barite. The lower part of the Eminence with its similar algal reefs was also a favorable host rock. The rocks of other formations which are less porous and fractured contain less barite.

The barite deposits are believed to have formed as follows: After deposition and induration the host rocks were fractured and solutions permeating the fractures deposited chalcedony and drusy quartz. Renewed fracturing was followed by the deposition of pyrite and then barite, along with smaller amounts of galena and sphalerite from solutions that ascended along steep fractures and moved out laterally in favorable host rocks. Weathering and the removal of many constituents left behind a clay residuum sufficiently rich in barite to be minable.

These residual clays have an average depth of about 10 feet; locally, however, as much as 50 feet of residuum have been found. The deposits range in size from a few to more than 100 acres.

Several varieties of barite, or tiff as it is locally called, are found in the residual deposits. Ball or bladed tiff, the most common variety, occurs as dense clusters of white, opaque, crystalline barite. Chalk tiff is a white opaque porous barite possibly derived by the leaching of bladed tiff. Glass tiff is the rare translucent to transparent variety. The barite fragments in the residuum range from clay-size particles to masses several feet in diameter, but most of the fragments are between one-half inch and 6 inches in maximum dimension. Most of the barite is covered with a thin film of limonite, which is removed during

beneficiation. The chief source of iron in the final product is limonite retained in vugs in the interior of the barite. Small amounts of pyrite, galena, and sphalerite also are associated with barite. Chalcedony and drusy quartz are the other major coarse constituents of the red clay residuum.

Current economic conditions require a minimum of 218 pounds of barite per cubic yard of residuum for a profitable mining operation, although some deposits containing as little as 125 pounds of barite per cubic yard have been mined. The grade of ore varies considerably within deposits and from one deposit to another.

The barite deposits of the Central district occur in Ordovician, Mississippian, and Pennsylvanian rocks. Several hundred are known in the Gasconade Dolomite, Jefferson City Dolomite, and Burlington Limestone, and a few in the Roubidoux Formation and in the Cherokee Group, the latter of Pennsylvanian age.

The most important deposits, described as circle deposits by Mather (1946, pp. 45–47) are bell, flask, or cone shaped in vertical section with apex up, and approximately circular in plan. According to Mather (1947, pp. 98–99), they probably formed by the enlargement of solution channels through caving of large volumes of roof and wall rocks. The caving extended upward until the roof attained the character of a stable arch, thus producing the cone- or bell-shaped enclosure filled with broken rock. The solution of the debris continued during the formation of the structure. Barite, calcite, and some associated galena, sphalerite, and chalcopyrite were deposited after the structure was stabilized. Barite cemented the rock fragments, and by strengthening the structure probably prevented further solution of the walls and rock debris. The remaining open spaces were then filled with a red tallowlike clay deposited during erosion of the overlying ground. The weathering of these deposits resulted in the formation of some commercially valuable residual barite deposits.

Barite replaced the Burlington Limestone along one side of a solution channel in the walls of sinks in the Lupus area, Moniteau County (Muilenburg, 1954, p. 47). The original sedimentary structure, fossils, and crystalline texture of the limestone were perfectly preserved. The known deposits in the Lupus area are exhausted.

Most of the ore deposits in the Central district were small, the largest being about 200 to 250 feet in diameter. One deposit was worked to a depth of 125 feet, but the depths of most are unknown because mining operations generally ceased before reaching the bottom. The grade of the ore varied greatly and no general figures can be given. Small amounts of galena and sphalerite were recovered in some operations (see p. 62).

Large exploration programs for the discovery of additional barite deposits have not been necessary in the Washington County district. New tracts of land are explored and developed as other deposits are depleted. Muilenburg (1954, p. 50) estimated that the district comprises about 75 square miles of which some 15,000 acres may contain a minimum of 150 pounds of barite per cubic yard in residuum averaging 8 feet thick. This works out to a reserve of about 15 million tons of barite. In the past decade, the district has yielded about 1.7 million tons of barite, or about 11 percent of the reserve estimated in 1954.

According to the compilation by Kisvarsanyi (1965), shown here in figure 23, productive residuum has been found or worked to some extent in an area of about 150 square miles. It appears, therefore, that Muilenburg's estimate of reserves in 1954 was conservative. Despite the rise in minimum grade of ore to 218 pounds of barite per cubic yard, a standard met and exceeded in many deposits, the reserves are still believed to be at least 15 million tons of barite.

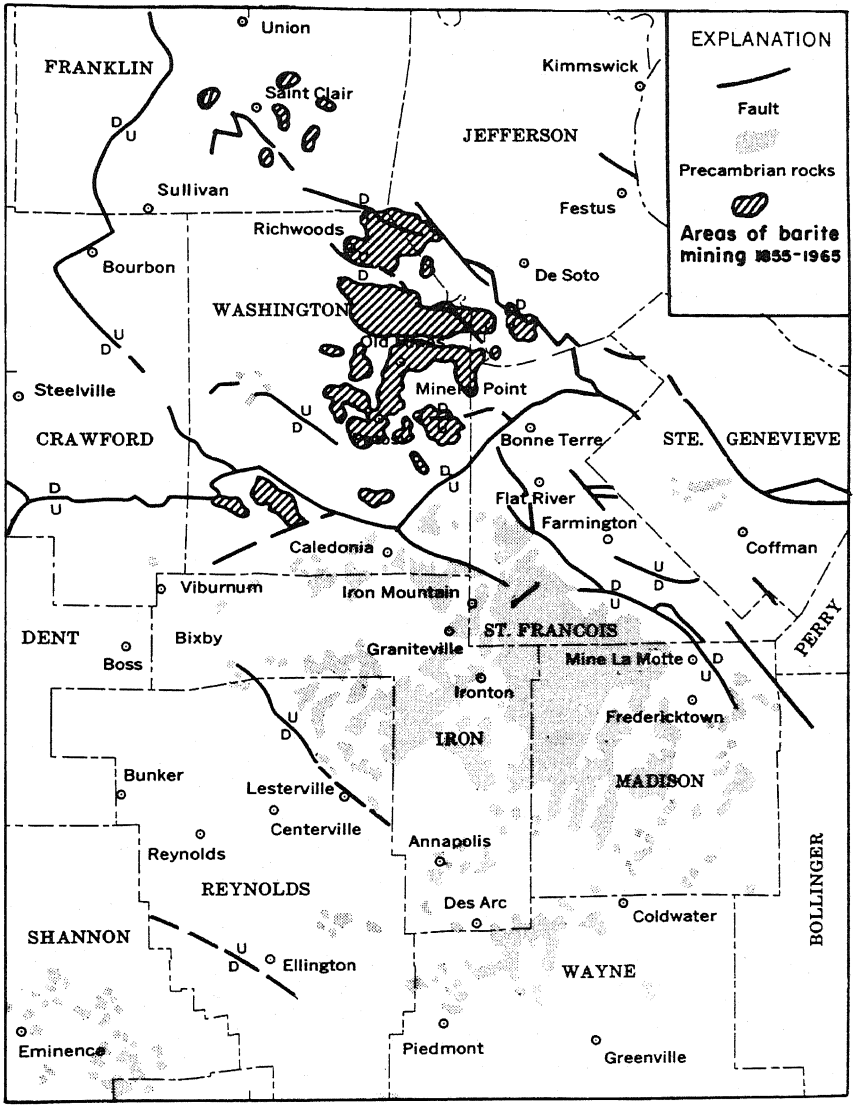


Figure 23.—Barite-producing areas of the Washington County district, Missouri.

In addition to the estimated reserves, large resources of barite undoubtedly occur in the Washington County district. Many acres of residuum in the district contain barite in amounts that might be mined under more favorable economic conditions. Some barite may be recovered in the future from the tailings ponds at the former sites of washer plants. Tests run by the Missouri Geological Survey indicated that the tailings nearest some of the former washer sites contain from 5 percent to as much as 35 percent barite (G. A. Muilenburg, oral communication, 1954) in fragments ranging downward from about three-quarters inch to particles of clay size.

More barite deposits may be found in the great areas where the Eminence and Potosi formations crop out beyond the known limits of the district. Chances for successful prospecting will increase as the lithologic, stratigraphic, and structural controls of the emplacement of the original barite and the evolution of the residual deposits are better understood. The further search for ore may be aided by the application of geochemical and geophysical methods. Uhley and Scharon (1954) reported some success in prospecting with gravity surveys in the Washington County district and concluded (p. 56) that a large commercial body of barite could be outlined and tonnages of ore computed with an error of 35 percent or less. They checked their gravity data by test pitting and the results strongly suggested that areas lacking significant positive gravity anomalies contained no near-surface ore bodies of commercial value and that, consequently, those areas could be eliminated from further consideration.

The Washington County area is not only one of the Nation's leading barite-mining districts, but its known reserves and favorable resource potential also assure continued support of a large barite-mining industry.

The small, scattered barite deposits of the Central district can at best support only small mining operations under present economic conditions. The aggregate tonnage of barite in these numerous deposits, however, constitutes a resource that may be large but exploitable only under more favorable economic conditions.

CLAY AND SHALE

(By W. V. Searight and Eva B. Kisvarsanyi, Missouri Geological Survey and Water Resources, Rolla, Mo.; A. L. Bush, U.S. Geological Survey, Denver, Colo.; and S. H. Patterson, U.S. Geological Survey, Beltsville, Md.)

Clay and shale comprise a number of different types of materials that are used in many different products. In Missouri such products include refractory brick, common brick and tile, pottery, absorbent clays, and lightweight aggregate. As a whole, products made from clay and shale are of low unit value; however, Missouri's refractory or fire clays are an especially valuable mineral resource and are the basis of an important industry in the State. Based on value, clay and shale rank in eighth place in mineral production in Missouri.

Clays include a wide variety of materials that can be generally described as composed principally of various clay minerals, which are

hydrous aluminum silicate compounds of extremely minute particle size. Clay minerals occurring commonly in Missouri are classified into major groups according to their composition and crystal structure. These are kaolinite, montmorillonite, illite, chlorite, and mixed-layer clays. The composition and atomic structures of these clays are complex and beyond the scope of this report, but are outlined by Murray (1960) and Grim (1953, 1962). Virtually all clay deposits also contain varying quantities of one or more nonclay minerals such as quartz, mica, limonite, and pyrite, as well as organic matter. Most clay deposits are nonbedded.

The term shale is applied to sedimentary rocks that are typically laminated and composed of one or more of the clay minerals and generally considerable proportions of silt-sized particles of quartz and other nonclay minerals. Most of the constituents of shales represent materials derived from the weathering of older rocks with subsequent transportation to depositional sites.

The value of clays and shales for different products depends upon individual physical and chemical properties, one or more of which make them suitable for various uses. Properties that determine the value of clays include plasticity, bonding strength, color both before and after firing, vitrification temperature, resistance to shrinkage and deformation during drying and firing, resistance to high temperature, particle size, ion-exchange capacity, and absorbency. Plastic clays can be formed into desired shapes that are retained during drying and firing. This property of some clays was discovered by prehistoric man; pottery found in archeological excavations shows that the use of clay was one of the earliest mineral industries in human history. Fire clay is refractory to varying degrees, a property related to high alumina content. Refractory properties enable firebrick to withstand extremely high temperatures and pressures, such as those which are developed in the linings of metallurgical furnaces and kilns. Some shales expand when fired, resulting in products having high volume and low density that are used for lightweight aggregate. China clay and ball clay are types of kaolin which are of value because of their purity, color, plasticity, or particle size. They are used in ceramics and many other products. The particle size and shape, absorbent qualities, and the ion-exchange capacity of some clays control properties that are valuable in decolorizers and filters, soil conditioners, suspending agents, and for many other uses.

FIRE CLAY

(By W. V. Searight, Missouri Geological Survey and Water Resources, Rolla, Mo.; and S. H. Patterson, U. S. Geological Survey, Beltsville, Md.)

Fire clay includes nearly all clay that fuses at temperatures above approximately 2,770° F. and can be used to make firebrick and other refractory products. The most abundant clay mineral in fire clay is kaolinite (85 percent or more in high-grade clay). Some very high grade fire clay contains appreciable amount of diaspore, a mineral that is 85 percent Al_2O_3. The fire clays are commonly classed as plastic,

semiplastic, semiflint, flint, and superrefractory clays (burley and diaspore). McQueen (1943a, p. 5–6) describes the different clay types as:

(1) Plastic to semiplastic or semiflint fire clay, varies from soft to fairly hard, varies also in color and texture; grades imperceptibly into, (2) flint fire clay, a hard, compact nonplastic fire clay. Flint fire clay is characterized by a conchoidal fracture and sharp splintery edges, and grades into (3) burley clay, so called because of the presence of "burls" or shot-like particles (oolites) or small nodules (pisolites), which usually are highly aluminous in character. As the number and aluminous content of particles increase, this clay grades into (4) diaspore clay, which is usually a rough textured, compact clay of varying color and hardness, and distinguished by a high alumina content. Diaspore clay is the designation used in Missouri for clay containing a minimum of 70 percent alumina (Al_2O_3). More recently, the grades of clay have been designated in Missouri as flint, less than 55 percent alumina, and diaspore, above 65 percent alumina.

History and production.—The first firebrick plant in Missouri was built at St. Louis about 1845, and others were operating before the Civil War. By 1896, 12 firebrick plants were operating, and the annual value of their output was estimated at $900,000 to $1 million (Wheeler, 1896). The firebrick industry continued to expand up to about the time of World War I, but like most industries using clay, it too suffered severely during the depression of the 1930's. The recovery following World War II was characterized by construction of a few new plants, by the closing down of some of the obsolete ones, and by the modernization of others, chiefly by installing efficient tunnel kilns.

The major refractories companies active today in Missouri and their principal plants are:

Company	Location of plant	County
General Chemical Division of Allied Chemical Corp.	Owensville (calcining plant)	Gasconade.
General Refractories Co.	St. Louis	St. Louis.
Green, A. P., Firebrick Co.	Mexico	Audrain.
Harbison-Walker Refractories Co.	No. 1, Fulton	Callaway.
Do.	No. 2, Vandalia	Audrain.
Refractories & Chemical Division of Kaiser Aluminum & Chemical Corp.	Mexico	Do.
Porter, H. K., Co., Inc.	No. 1, Laclede	St. Louis.
Do.	No. 2, Christy	Do.
Do.	No. 3, Fulton (under construction).	Callaway.
Walsh Refractories Corp.	Vandalia	Audrain.
Wellsville Firebrick Co.	Wellsville	Montgomery.

Fire-clay production from 1900 to 1945 totaled some 18 million tons valued at $47 million (Bishop, 1949, p. 18–19). Annual production prior to World War II was usually well under one-half million tons, but since 1942 it has exceeded 1 million tons except in 1963. Table 12 gives the record of the last two decades; production reached a peak of 1,851,000 tons in 1952 and is rising again after declining for a number of years. Output in 1965 was 1,128,000 tons valued at $4,313,000.

TABLE 12.—*Clay and shale production in Missouri, 1946–65*

Year	Fire clay		Miscellaneous clay and shale [1]		Total clay and shale	
	Thousand short tons	Thousand dollars	Thousand short tons	Thousand dollars	Thousand short tons	Thousand dollars
1946	1,173	2,823	516	334	1,689	3,157
1947	1,206	3,715	538	336	1,744	4,051
1948	1,497	4,824	639	485	2,136	5,309
1949	1,201	3,740	619	474	1,820	4,214
1950	1,221	4,031	726	625	1,947	4,656
1951	1,573	9,699	782	861	2,355	10,560
1952	1,851	10,460	1,140	1,639	2,991	12,099
1953	1,556	10,281	746	1,125	2,302	11,406
1954	1,209	4,527	712	1,288	1,921	5,815
1955	1,529	6,035	873	867	2,402	6,902
1956	1,766	7,117	892	899	2,658	8,016
1957	1,732	6,727	916	921	2,648	7,648
1958	1,212	5,139	848	847	2,060	5,986
1959	1,657	5,921	978	978	2,635	6,899
1960	1,541	6,208	999	999	2,540	7,207
1961	1,112	4,019	1,020	1,020	2,132	5,039
1962	1,081	4,061	973	973	2,054	5,034
1963	850	3,568	896	899	1,746	4,467
1964	1,002	3,905	964	969	1,966	4,874
1965	1,128	4,313	1,098	1,126	2,226	5,439

[1] Includes that used for structural products, for expanded shale aggregate, and in cement manufacture.

Source: U.S. Bureau of Mines Minerals Yearbooks.

Occurence.—Deposits of fire clay occur in three areas (fig. 24): The northern fire clay district (McQueen, 1943a), north of the Missouri River; the St. Louis district in the City of St. Louis and in St. Louis County; and the southern fire clay district (McQueen, 1943a; Allen, 1935; 1937), south of the river.

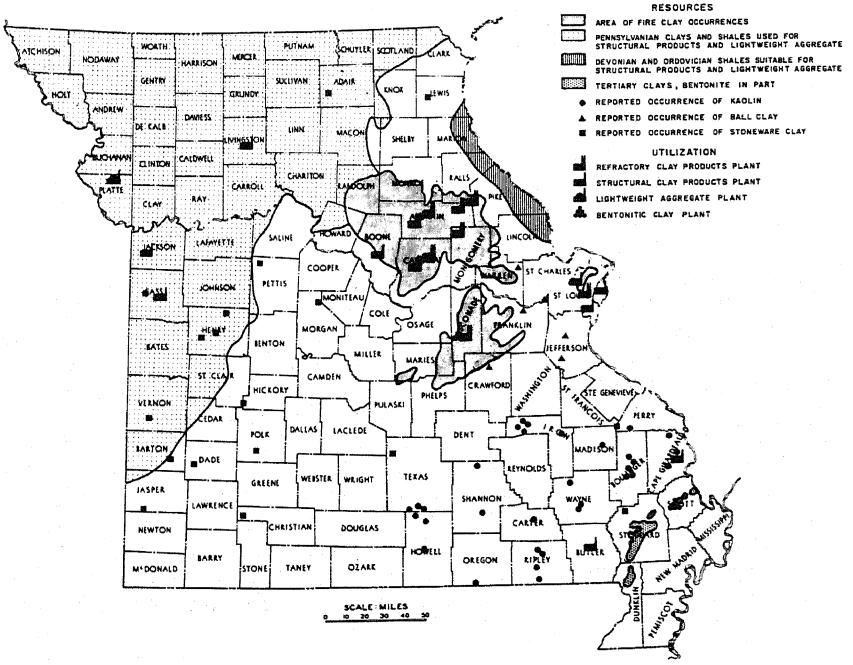


FIGURE 24.—Resources and utilization of clays and shales in Missouri.

Northern district.—The northern fire clay district occupies parts of several counties, but most deposits that have been mined are in Monroe, Audrain, Callaway, and Montgomery Counties. The southeastern, southwestern, and much of the northeastern boundaries of the district coincide approximately with the contact of the Desmoinesian Series with older rocks, but to the northwest, the boundary is overlapped and concealed by younger Pennsylvanian beds. Following the depletion of the deposits in the St. Louis area, this district has become the main source of plastic clays in Missouri.

Deposits in the northern district occur in the Cheltenham Formation of Pennsylvanian age and consist chiefly of plastic clays. The lower part of the Cheltenham Formation in the district is irregular in extent and thickness, and clay in this part of the formation occurs chiefly in sink-like structures. The middle part of the Cheltenham is a blanket-like deposit; it yields the largest tonnage of plastic clays in the district. It is present over wide areas in Audrain, Callaway, and Montgomery Counties where its average thickness is 15 feet. The upper part of the Cheltenham is discontinuous and contains the least refractory clays of the district.

Flint and semi-flint clays also occur in the northern district but are less abundant than in the southern district. Although deposits of these clays are scattered over much of the district, most are outliers separated from the main mass of Pennsylvanian rocks in Callaway, Montgomery, and Warren Counties. The deposits occur in restricted circular or oval sink structures in older rocks, many of which are steep-sided or even have one or more vertical walls.

St. Louis district.—The St. Louis district includes the fire clay area of the County and City of St. Louis. The plastic fire clays were first mined in Missouri from the area between Forest Park and Tower Grove Park. When the more refractory flint clays were discovered in other districts, they were shipped to the St. Louis area and blended with the plastic clay. As a result of the depletion of most deposits in the district, the growth of plants outside the St. Louis area, and the encroachment of metropolitan St. Louis, this district is no longer important as a source of raw clay. Most of the clay used in the fire brick plants still operating in the St. Louis area is shipped from the northern and southern districts.

Southern district.—The southern fire clay district is a large discontinuous area south of the Missouri River and west of St. Louis County. It covers parts of Osage, Gasconade, Franklin, Maries, Pulaski, Miller, Crawford, and Phelps Counties (fig. 24). The clay lies above the conglomerate and sandstone at the base of the Pennsylvanian, which by their outcrops indicate the general area in which the clay deposits occur. Many of the scattered deposits are filled-sink structures (Keller, 1952; Keller, Wescott, and Bledsoe, 1954). Most deposits are small, the typical ones containing about 15,000 tons. A few are much larger, being as much as 800 feet long, 500 feet wide, and having a maximum thickness of about 25 feet. Some smaller deposits are known to extend to depths of as much as 100 feet. Flint and semi-flint clay are the principal types occurring in these deposits; bedded plastic clay does not occur in the district. Super-heat-duty refractory burley and

diaspore clays are associated with many deposits, but these high-grade clays have been mined extensively, and their reserves are not large. According to D. C. Wysor (Thornberry, 1925), the typical deposit containing diaspore consisted of about 8,000 tons of flint clay, 250 tons of abrasive-grade diaspore, 750 tons of no. 1 grade diaspore, and 6,000 tons of no. 2 and no. 3 grades diaspore.

Estimates of the total resources of fire clay in Missouri have not been made; however, reserves of plastic clay are ample to sustain the refractory industry in the State for more than 25 years, and the industry uses more of this type of clay than of other types having smaller reserves. Virtually all plastic clay reserves are in the northern district. Appreciable quantities of flint clay occur in scattered deposits in both the northern and southern districts, but most deposits of diaspore clay suitable for super-heat-duty refractories are in scattered small bodies that are costly to mine. The deficiency in diaspore is made up by shipping calcined bauxite from Arkansas and elsewhere. Chances of finding more plastic clay in the nothern district and the relatively smaller quantities of flint clay associated with it are good because deposits are more continuous than in other districts, and they are scattered over large areas. Diaspore occurs only in the southern district and is in small scattered deposits. Though undiscovered deposits of diaspore undoubtedly exist, they are difficult and ordinarily unprofitable to locate. Nearly all prospecting is done by exploratory drilling of the type described by Miller and Moore (1947), and no deposits have been found by surface prospecting in the last 25 years.

CLAY AND SHALE RESOURCES FOR STRUCTURAL PRODUCTS

(By Eva B. Kisvarsanyi, Missouri Geological Survey and Water Resources, Rolla, Mo.)

A wide variety of commonly occurring clays and shales are utilized in the manufacture of structural products in Missouri. The raw materials are generally listed in U.S. Bureau of Mines statistics as "miscellaneous clay and shale," and that terminology is used in this report where appropriate. Some fire clay is also used in these products in Missouri, and when so used is commonly classified in this group. Structural clay products made from miscellaneous clay and shale include common brick, face brick, drain tile, roofing, and other types of construction tile, sewer pipe, and terra cotta. Paving brick and burnt gumbo, a fired railroad ballast, were formerly made from clay and shale, but neither product has been made in recent years.

Illite and kaolinite are the most abundant clay minerals in clay and shale used in the manufacture of structural products, but other clay minerals are commonly present in appreciable quantities. Virtually all deposits contain nonclay minerals such as quartz, feldspar, and mica as well as organic matter, and in some the quantity of nonclay materials exceeds the clay minerals. Iron oxide, Fe_2O_3, is desired in some structural clay products because it lowers the temperature of vitrification. It also imparts red and brown colors desired in some products but not others, such as buff face brick. Most clay containing less than 1 percent Fe_2O_3 is white-burning, that with 1 to 5 percent

is buff-burning, and that with 5 percent or more Fe_2O_3 is red-burning.

The important properties of miscellaneous clay and shale from which structural clay products are made are plasticity, tensile strength, low shrinkage, proper vitrification range, and fired color. These properties may be evaluated in the laboratory by methods outlined by Klinefelter and Hamlin (1957). Though such laboratory tests give an indication of the suitability of clay and shale for many products, tests should also be made in plant kilns to assure that the desired product can be made. Most manufacturers therefore rely on their own testing in evaluating their raw materials. Some blend several types of clay and shale to suit their requirements.

Clays and shales having a wide range of geologic ages are utilized for the manufacture of structural products. Shale and underclay beds of Pennsylvanian age are particularly good sources and are used extensively. Impure residual clays of various ages and Pleistocene clays and loesses are also used. Semiplastic and semiflint fire clays are utilized in some parts of the country.

Production.—Of the more than 39 million tons of miscellaneous clay and shale produced in the United States during 1965, nearly 52 percent, valued at $25 million, was used for structural products. Production was reported from every State except Alaska and Rhode Island. About 97 percent of the total output was produced in captive operations, as manufacturers usually mine their own supply of clay and shale, and only a relatively small quantity is sold in the open market. Because of this relationship, the price of miscellaneous clays is not quoted in trade journals. Based on the total amount and value of production in 1965, the unit value of raw miscellaneous clay was $1.22 per short ton.

The utilization of Missouri clays and shales for building brick is a relatively old industry in the State. The French began to manufacture common brick when they established the first communities along the Mississippi River early in the 18th century. The sewer pipe, drain tile, and paving brick industries developed later; by the end of the 19th century, the manufacture of structural clay products had become a large industry.

In 1896, there were 358 building brickyards, 5 sewer pipe plants, 13 paving brick plants, 3 terra cotta plants, 37 drain tile plants, and one roofing tile plant in operation with an annual output of products valued at more than $5 million (Wheeler, 1896). The number of individually operated small plants decreased sharply during the depression of the 1930's. The production of paving brick declined sharply as highway construction methods shifted to the use of concrete and asphalt; roofing tiles have similarly been displaced by other roofing materials. The expansion in production of structural clay products that followed the Second World War was near large cities or in other major market areas. During this period, the number of bricks plants operating decreased, but the construction of large, highly mechanized plants resulted in an increased rate of productivity. The producers of brick and tile in Missouri in 1966 and the geologic formations from which they mine their raw material are shown in Table 13.

TABLE 13.—*Companies producing brick and tile in Missouri*

Producer	Location of plant (county)	Source of raw material	Product
Acme Brick Co	Harrisonville (Cass)	Pleasanton Group (shale)	Red face brick, buff and pink brick.
Do	Raytown (Jackson)	do	Red face brick.
Alton Brick Co	Maryland Heights (St. Louis).	Lagonda Formation	Building brick, sewer pipe.
Columbia Brick & Tile Co.	Columbia (Boone)	Lagonda Formation Cheltenham Formation (fire clay).	Face brick.
W. S. Dickey Clay Manufacturing Co.	St. Louis	Lagonda Formation	Building brick, sewer pipe.
Hydraulic Press Brick Co.	do	do	Building brick and tile, sewer pipe.
Kasten Clay Products, Inc.	Jackson (Cape Girardeau).	Residual clay and Pleistocene loess.	Brick.
Midland Brick & Tile Co.	Chillicothe (Livingston).	Pleasanton Group (shale)	Brick and tile.
A. D. Willis & Son Industries.	Poplar Bluff (Butler)	Cretaceous(?) clay	Do.

During 1965 the production of miscellaneous clay and shale, including a minor quantity of fire clay used for structural clay products, amounted to 1,098,000 short tons valued at $1,126,000 (table 12). According to the U.S. Bureau of Mines Minerals Yearbook for 1964, Missouri ranked 14th in tonnage of miscellaneous clay and shale produced and 15th in dollar value. The miscellaneous clay and shale output was 58 percent of the tonnage and 20 percent of the value of all clays produced in the State. About 28 percent of the total tonnage was used for structural clay products, and the remainder for the making of cement and lightweight aggregate.

Occurrence.—Clay and shale of Pennsylvanian age are the most important sources of raw material for structural products in Missouri. Most of the clay is underclay associated with coal beds. Deposits that are currently mined or have been mined in the past occur throughout the outcrop area of Pennsylvanian sediments in western, northwestern, and north-central Missouri, and in St. Louis County (see fig. 24).

Underclays occur beneath coal beds and range in thickness from a few inches to several feet. They are generally nonbedded, slickensided, irregularly fractured, and contain the remains of plants. Some underclays in Missouri are refractory, notably those in Warren and Montgomery Counties, but most of them have low fusion points and contain many impurities. They are, however, suitable for making structural clay products. The Tebo and Weir-Pittsburg underclays near Calhoun in Henry County were mined for this purpose in the past. For a short period, the Tebo underclay was mined near Montrose, Henry County, for use in the manufacture of buff and pink brick at Harrisonville. The Weir-Pittsburg underclay at Oskaloosa, Barton County, is a dark gray to blue plastic clay that was used in making buff face brick. The light gray underclay below the Croweburg coal bed and the overlying drab or gray shale have been used quite extensively in making brick and pottery in Henry County. Recent investigations indicate that the Weir-Pittsburg, Tebo, and Mineral underclays in Barton, Vernon, St. Clair, and Henry Counties are suitable for the manufacture of common brick, tile, sewer pipe, terra cotta, stoneware, and ladle brick (Tennissen, 1963).

Shales occur as the thickest and most abundant members of the cyclic successions of shale, sandstone, limestone, clay, and coal that occur throughout the Pennsylvanian System. The most common type for use in brick and tile manufacture is argillaceous shale, which usually is bluish gray when fresh and drab when weathered. Some of the shale beds are sandy and grade into sandstone; others contain appreciable amounts of calcium carbonate and limestone concretions. Economically important shale beds occur in the Cherokee Group, the Pleasanton Group, and the Pedee Group.

The Riverton Formation contains beds of dark gray to black shale that have been used in making brick, hollow building block, and drain tile at plants in Vernon County (W. E. Davis, written communication, 1950). It burns to a pleasing dark red color and yields structural products of good quality. The thickness of the beds varies from about 5 to 15 feet. Weathered shales above the Warner Formation have been used in the manufacture of drain and building tile and silo blocks at Deerfield, Vernon County. These shales are plastic, yellowish gray, slightly sandy, and iron stained. Shales above the Rowe coal in the Cherokee Group have been utilized extensively in the vicinity of Deepwater, in Henry County, for the manufacture of sewer pipe by the W. S. Dickey Clay Manufacturing Co. These shales are hard and silty, dark to medium gray, thin bedded, micaceous, and grade upward into platy shale and siltstone. Yellow surface clay or weathered shale was mixed into this material to improve its workability and strength.

The Lagonda Formation contains shale beds that are mined for use in structural clay products. The thickness of the beds ranges locally to as much as 50 feet. At the present time, it is mined extensively in St. Louis County and used in the manufacture of a variety of structural products as well as in making cement. Lagonda shale is also mined in Boone County and mixed with fire clay from the Cheltenham Formation for the manufacture of face brick. It was formerly used at Fayette for common brick.

Thick shale beds in the Pleasanton Group occur in Jackson and Cass Counties where they are mined for the manufacture of red face brick. The thickness of the shale here varies from 30 to 60 feet. This shale is also mined at Utica, Livingston County.

The shales in the Kansas City Group frequently lie between limestone strata and generally are too calcareous to be suitable for structural products. The Wea Shale Member of the Cherryvale Formation has been used for common and face brick at plants in the Kansas City area. Shales in the Lane, Wyandotte, and Bonner Springs Formations appear to be suitable for use in common brick and tile in Jackson, Platte, Clay, and Caldwell Counties, although they have not yet been used in the State as a ceramic raw material.

The lower shale member of the Upper Pennsylvanian Lawrence Formation has been used for building and paving brick at several plants in northwestern Missouri. It is bluish gray to drab, has a wide range of vitrification temperatures, burns red to reddish brown, and makes an excellent stiff mud face brick. Sewer pipe may also be made from this shale (Larson, 1947). Its thickness varies from 80 feet in

southwestern Buchanan and northwestern Platte Counties to approximately 50 feet at St. Joseph in Buchanan County, and to about 75 feet at Savannah in Andrew County.

Thick shale beds of Ordovician and Devonian ages are exposed in Ralls and Pike Counties. The Grassy Creek Shale is exposed in northern Pike County and is underlain by the Maquoketa Shale. Their combined thickness at the outcrop is 39 feet. The Grassy Creek is overlain in Ralls County by 20 feet of dark gray to black fissile shale of the Saverton Formation. These shales have not been used for the manufacture of structural products but may be adaptable for this purpose. At present, they are used in cement manufacture (p. 182).

Clays of Cretaceous and Tertiary age have been utilized for the manufacture of a variety of structural clay products in southeastern Missouri, principally in Scott, Stoddard, and Butler Counties. A light gray to brownish black lignitic clay, locally known as the "Zadoc clay," occurs in the upper part of the Cretaceous McNairy Formation. Common brick and tile were manufactured from this clay at Commerce in Scott County. A black plastic clay locally exceeding 120 feet in thickness occurs as pocket fillings in Lower Ordovician rocks in the vicinity of Popular Bluff, in Butler County. Several of these sinkhole type deposits were mined in the past. The clay was used in the manufacture of electrical porcelain, saggers, and for brick and tile. One plant is manufacturing brick and tile at Popular Bluff at the present time.

Clay of Tertiary age (Wilcox Group) is exposed along Crowley's Ridge in Scott, Stoddard, and Dunklin Counties. The historic Dexter pottery in Stoddard County, which started operations about 1851, utilized these clays mainly for the manufacture of brown stoneware and unglazed flower pots. The same clays have also been used for drain tile and brick manufacture at Dexter and Commerce. Several clay deposits in Scott and Stoddard Counties have been sampled and tested (Davis, Herold, McManamy, 1941). The results indicate that some are suitable for the manufacture of brick, drain tile, terra cotta, roofing tile, hollow building blocks, and face brick.

Deposits of Pleistocene till and loess, which cover most of the northern part of the State (p. 19), consist of clay, silt, sand, and gravel. Some of the impure, dark gray, plastic glacial clays that are usually restricted to upland areas have been used in producing burnt gumbo for railroad ballast in DeKalb, Buchanan, Clay, and Montgomery Counties. Loess has been extensively used for making common brick. A plant at Jackson, Cape Girardeau County, uses red residual clay and overlying Pleistocene loess for brick manufacture.

The alluvial deposits in the flood plains of present streams and rivers commonly contain extensive clay beds. Burnt gumbo was produced from some of these deposits in the past.

Most of the clay and shale units that are now or have in the past been mined and used in the manufacture of structural clay products occur in virtually inexhaustible quantities. Problems in supply of raw material for making brick and tile are mainly related to costs of transportation (location of deposits with respect to plant sites and markets), fuel supply, and other economic factors.

BENTONITIC CLAYS

(By W. V. Searight, Missouri Geological Survey and Water Resources, Rolla, Mo., and S. H. Patterson, U.S. Geological Survey, Beltsville, Md.)

Missouri has important resources of clay (Porters Creek Clay) that is probably bentonitic. Relatively large areas in Scott, Stoddard, and Dunklin Counties (fig. 24) are underlain by the Porters Creek, which is Paleocene in age. The formation is as much as 200 feet thick in outcrop.

According to Farrar, Grenfell, and Allen (1935), the clay is dark gray or almost black when wet, whereas dry surfaces that are partly wetted are light gray or cream colored. Large nodules of impure iron carbonate are abundant locally and form more or less continuous layers in a few places. Some beds are rich in iron oxide which causes them to have a brown banded appearance. Montmorillonite constitutes from 80 to 95 percent of the clay according to estimates by Allen (Farrar, Grenfell, and Allen, 1935, p. 75). Allen identified volcanic shards in thin section and described the material as bentonitic, implying that it is altered volcanic ash or tuff. Pryor and Glass (1961), however, believe that the montmorillonite accumulated by selective deposition rather than by the alteration of volcanic particles after deposition.

The absorbent qualities of bentonitic clays such as the Porters Creek make them useful as filters and fillers, in decolorizing oils, as a carrier or suspending agent for insecticides and pesticides, and for other purposes. Physical tests reported by Farrar, Grenfell, and Allen (1935, pp. 51–71) indicate that the Porters Creek has oil bleaching qualities and low density (0.57–0.86 grams per cubic centimeter). Historically, such clays were identified as fuller's earth and used in cleansing and fulling wool.

The Porters Creek is mined at localities near Olmstead, Ill., and Paris, Tenn. Currently the Illinois material is processed chiefly for floor sweep of the type used to absorb oil, grease, and miscellaneous fluids in factories and repair and service installations, for animal litter of the type used for household pets and stabled horses, for carriers or suspending agents in pesticides and insecticides, and for fillers of several types. Many years ago the Illinois clay was used for decolorizing mineral and vegetable oils, fats, and greases (Lamar, 1928, p. 19), but the plant that processed the clay for these purposes is no longer operating. A plant, including a calcining kiln, is currently under construction near Oran, Mo., by the Mid-American Clay & Minerals Corp. It will produce material for use as an insecticide and herbicide carrier.

Clays that are somewhat similar to Porters Creek are used for drilling mud, for bonding foundry sands, and in refining petroleum, but the Missouri material is generally inferior for these uses. The Porters Creek has been investigated as a possible source of material for use as a binder in iron-ore pelletizing. Tests on samples from Illinois (Jackman and others, 1965) indicate that the Porters Creek imparts to pellets a somewhat lower green and dry strength but greater fired strength than does Wyoming bentonite, which is widely used in the industry.

STONEWARE AND POTTERY CLAYS

(By W. V. Searight, Missouri Geological Survey & Water Resources, Rolla, Mo.)

Stoneware or pottery clays include plastic, white, or very light burning clays with a relatively low vitrification temperature and a wide firing range. They should be tough as well as plastic, of low but even drying and firing shrinkage. Deposits of these clays in Missouri have been investigated by Wheeler (1896) and by Davis, Herold, and McManamy (1941). Occurrences of stoneware clays have been reported from many places (fig. 24); deposits of established economic significance are in Henry, Stoddard, and Scott Counties. The Henry County clays are in Pennsylvanian strata, and those of southeast Missouri are in the Wilcox Group of the Eocene Series.

The stoneware or pottery clays used in Henry County at the turn of the century were from Lower Pennsylvanian beds now included in the Krebs Subgroup of the Cherokee Group. Some if not all of the deposits near Calhoun lie at the top of the Krebs and those near Clinton are lower in the Subgroup. The Calhoun clays were the source of the largest shipments of stoneware or pottery clays in the history of the State; 4,000 to 5,000 tons were shipped annually to Fort Scott, Kan., Boonville, Mo., and elsewhere. These clays were also used in potteries at Calhoun. The Clinton clays were used in large local potteries. The Calhoun clays are notable in that the vitrification point is from 2,300 to 2,500 F., relatively high for clays of this type.

In the Missouri portion of Crowley's Ridge in Stoddard, Scott, and Dunklin Counties, clays occur in the McNairy Formation of Cretaceous age and in the Wilcox Group of Tertiary age (fig. 24). These have been investigated by the Missouri Geological Survey and Water Resources (Davis, Herold, and McManamy, 1941). Tests indicate that stoneware clays occur in both the McNairy ("Ripley") and the Wilcox, but that the most widespread and thickest deposits are in the Wilcox Group in Stoddard County. From the data available, it appears that more than 175 acres are underlain by clay of sufficient thickness to be worked in Stoddard County. Little use has been made of these clays. Bauxitic nodules are reported in the base of the Wilcox in Stoddard County by Stewart, McManamy, and McQueen (1943), but no large deposits have been found.

KAOLIN

(By W. V. Searight, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Kaolin clays are the weathered products of feldspathic or other aluminous rocks and contain kaolinite as the chief clay mineral. These clays are also referred to as china clay because of their use in whiteware porcelain. The clay, when pure or nearly so, is white and very plastic and burns to a white body. Deposits of kaolin in Bollinger and Cape Girardeau Counties have been utilized in the past. They consist of white clay commonly associated with red and yellow clay, sandstone, and chert. At some places, chert and gravel are mixed with the clay. Some deposits, particularly those in Cape Girardeau

County, are highly siliceous. Tennissen (1960) reports that they contain fom 30 to 60 percent kaolinite and a relatively high percentage of silica, much of which is in the form of very fine sand.

Wheeler (1896) assumed these clays to be the residium from weathering of argillaceous and siliceous limestone, whereas Stewart (1945) regards the deposits as remnants of the NcNairy Formation.

Other deposits of kaolin or china clay have been reported from several counties surrounding the core of the Ozark uplift, including Iron, Wayne, Madison, Perry, Carter, Shannon, Ripley, Oregon, Texas, and Howell Counties (fig. 24). Most of these deposits consist of coarse chert residum intermixed with clay that is commonly stained yellow, red, and purple and with minor quantities of other rocks. Some white clay is also present, however.

A thin deposit of white nonplastic clay occurs in Sec. 28, T. 26 N., R. 25 W., 5 miles southwest of Aurora in Lawrence County (Wheeler, 1896). According to Wheeler, this clay contains more than 37 percent alumina. He described it as being halloysite, but presumably this identification has not been verified by modern methods.

Several thousand tons of kaolin clay were mined in the southeastern part of the State before 1896 and shipped to potteries, paper mills, and plants for use in calsomine. Destinations included such distant places as East Liverpool and Cincinnati, Ohio, Indianapolis, Ind., and Peoria, Ill. Lack of uniformity of the unwashed clay, which contains sand and other impurities, is reported to have been reason for closing down this mine (Wheeler, 1896).

BALL CLAY

(By W. V. Searight, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Ball clays are white plastic clays which are used as a bond in china manufacture and in other ceramic products. Because of their fine grain size (much finer than most kaolin clays), they can absorb much more water than other kaolins before becoming plastic. Their dry strength is on the order of 1,000 pounds, as compared to that for kaolin of approximately 125 pounds.

One of several deposits reported by Wheeler (1896) is in the NE¼ Sec. 6, T. 41 N., R. 4 E., in Jefferson County (fig. 24); it was the source of more than 20,000 tons of ball clay that was shipped to East Liverpool, Ohio, and other china-making centers. Considerable quantities of clay were encountered in the lead diggings at Mammoth Mine, Sec. 12, T. 39 N., R. 3 E., 7 miles southwest of DeSoto. Shipment of about 100 cans of clay to Cincinnatti and East Liverpool, Ohio, and Newark, N. J., was also reported (Wheeler, 1896).

Neither the resources nor the prospects for the future use of kaolin and ball clay in Missouri can be evaluated from information now available. Most deposits that have been mined in the past were small or impure as compared with deposits in other states, and few have been investigated sufficiently to determine their size and grade. Probably the kaolin and ball clay deposits in Missouri will not be mined on a large scale for a decade or two, but they will increase in value as large high-grade deposits in other States are exhausted.

LIGHTWEIGHT AGGREGRATE

(By A. L. Bush, U. S. Geological Survey, Denver, Colo.)

A number of materials qualify as lightweight aggregates for use in concrete, or as ultralightweight aggregates for use in cements and plasters. Expanded clays, shales and slates, and expanded blast furnace slag are the most commonly used lightweight materials. Expanded perlite (a volcanic glass) and exfoliated vermiculite (a mica-like mineral) are the dominant ultralightweight materials; besides aggregate they are used for loose-fill insulation, and increasingly as inert carriers in chemical processes, as fillers in a number of products, as filter aids, and as soil conditioners.

Missouri has ample reserves and resources of expandable clay and shale, but the other naturally occurring materials and expanded slag must be imported. Blast furnaces in the St. Louis metropolitan area (at Granite City, Ill.) supply slag for the market in eastern and parts of central Missouri. Crude perlite, mined in New Mexico, is expanded at plants in St. Louis and in the Kansas City metropolitan area (at Kansas City, Kans.). Crude vermiculite, imported from both Montana and South Carolina, is expanded at plants in St. Louis and Kansas City.

The first really significant development in the lightweight aggregate industry took place in Missouri late in World War I. In 1918, Stephen J. Hayde of Kansas City patented a method of expanding clays, shales, and slates by heating in an upright kiln. Later in 1918, the Atlas Portland Cement Co. used a modification of the Hayde process (substituting a rotary for an upright kiln) in the production of expanded shale aggregate at their Illasco plant in Ralls County, just south of Hannibal (Anonymous, 1919). The first use of expanded shale aggregate was in the construction of a number of lightweight concrete ships in yards along the Gulf and Atlantic coasts. In 1920, Hayde began the commercial production of expanded shale aggregate in Kansas City. A number of other plants throughout the country were operated under his license until his patent expired in 1945, and many others have come into production since then. The American Society for Testing Materials (1965) has published standard specifications and tests for both lightweight aggregates and concretes.

Production of expanded shale in Missouri has been virtually continuous since 1920; until 1948, the major operations were at Kansas City; subsequently, they have been at New Market in Platte County. Total production since 1920 has been only a few million tons, but total consumption has been considerably larger. Production of shale for lightweight aggregate in Missouri is included with "other clays" in Table 12. Expanded shale aggregate has been imported in large quantities from Illinois, Iowa, Kansas, and Oklahoma. Annual in-State production of expanded shale is about 100,000 short tons, probably representing between 60 and 70 percent of the total annual Missouri consumption (R. L. Coleman, oral communication, March 16, 1966).

Processing.—High-temperature heating causes many clays and shales to develop a bloated, vesicular texture, and thus reduce the

unit weight. The factors that cause the bloating, and the conditions for most efficient and economical controlled expansion have been discussed by Austin, Nunes, and Sullivan (1942), Ehlers and Richardson (1958) Plummer and Hladik (1951), Riley (1951), and White (1960). The methods of testing and evaluating possible suitable raw materials have been discussed by Conley and others (1948), Hamlin and Templin (1962), and Klinefelter and Hamlin (1957).

Clays and shales can also be crushed, mixed with combustible material (usually ground coal), and sintered. As the coal is burned out of the mixture, the clayey materials become pyroplastic, stick together, and voids are left; some bloating may also occur, but it is incidental to the sintering. Because of the voids, the product is light, and so materials that may not bloat of themselves can be sources of lightweight aggregate. Clayey materials, therefore, should be tested for both bloating and sintering suitability before being classed as unfit for lightweight aggregate.

Gases are evolved in raw clays and shales by heating; if the gas is formed at about the temperature where the material is soft and plastic, the gas will be trapped and the material will expand. Above and below this range the gas will escape. Small changes in the composition of minor components and in the amount of iron, lime, carbonate, and organic compounds and silt affect the temperatures of gas formation and material softening (which determine the width of the bloating range), the amount of expansion, and the weight of the expanded material.

Commercial bloating is done in rotary kilns and is difficult to control if the temperature range between softening and liquefaction is narrow. The most economical production is usually between 1800° F. and 2200° F., but bloating can be done as low as 1600° F., or as high as 2400° F. Suitable materials can thus have a wide range of bloating temperatures.

The bloating characteristics of a lithologic unit may vary greatly in short vertical distances, but commonly they are more uniform laterally. Interrelationship of composition, weathering, structure, and thickness affect the suitability. In one area, a unit may not bloat, may bloat imperfectly, or may bloat at an uneconomically high temperature, but a short distance away it may be quite suitable. A thorough sampling and testing program (including numerous rotary kiln tests) is necessary to define suitable materials and to outline favorable areas for lightweight aggregate production.

Many kinds of clayey sediments and sedimentary rocks are suitable for lightweight aggregate, and so it is difficult to single out characteristics that distinguish favorable from unfavorable materials. Deposits containing illitic and montmorillonitic clays seem to be more consistently favorable than those with kaolinitic clays. Dark-colored clays and shales with a moderate organic content generally are more suitable than light-colored (particularly reddish) ones, but some black shales do not bloat, and some red shales do. Common clays and shales generally are more suitable than fire, flint, or ball clays.

Lightweight aggregates range in weight from about 30 to 75 pounds per cubic foot (Washa, 1956, p. 380). Conventional aggregates weigh

about 110 to 120 pounds per cubic foot. Conley and others (1948, p. 8) have found that worthwhile savings in weight require the concrete be made with aggregate that weighs about 50 pounds per cubic foot, but Kluge, Sparks, and Tuma (1949, p. 628–630) have pointed out that improving the workability of lightweight concrete often requires an increased amount of the finer, heavier aggregate size fractions, so that the weight of the aggregate may approach 80 or even 90 pounds per cubic foot. Depending on material gradings and proportions, lightweight concrete plasters and concretes range from 20 to 115 pounds per cubic foot, compared with normal-weight concretes and plasters at 140 to 160 pounds per cubic foot (Washa, 1956, p. 379).

Suitable raw materials in Missouri.—Some 30 clays and shales in Missouri appear to be bloatable raw materials (table 14), on the basis of tests of Missouri samples (Herold and others, 1958) or of similarity to suitable lithologic units in Illinois (White, 1960; Sweeney and Hamlin, 1965), Iowa (Sweeney and Hamlin, 1964), Kansas (Plummer and Hladik, 1951), and Oklahoma (Burwell, 1954). A few of these materials already have proved to be economically suitable for lightweight aggregate, and others that are known or presumed to be bloatable probably will prove to be economic. Some will be uncompetitive because of mining, processing, or transportation costs, or some combination of these factors. Evaluation of the economic potential of each of these materials cannot be done in this report; therefore, few bloatable materials have been purposely omitted from the listing.

TABLE 14.—*Clays and shales in Missouri suitable for lightweight aggregate*

[Suitability based on commercial production (C); laboratory tests (L); similarity to known suitable materials outside Missouri (S)]

Rock units	System and series	Geologic map symbol (fig. 2)	Suitability	References and remarks
Loess	Quaternary—Pleistocene	None	L	Herold and others, 1958, p. 14, 36.
McNairy Formation	Cretaceous—Gulfian	K	S	Possibly suitable in Illinois according to White, 1960, p. 18.
Willard Formation	Pennsylvanian—Virgilian	Pv	S	Suitable in Kansas according to Plummer and Hladik, 1951, p. 26-27.
Emporia Formation: Harveyville Shale Member.	do	Pv	L	Herold and others, 1958, p. 14, 29.
Calhoun Formation	do	Pv	S	Suitable in Kansas according to Plummer and Hladik, 1951, p. 26-27.
Kanwaka Formation: Jackson Park Shale Member.	do	Pv	S	Do.
Lawrence Formation	do	Pv	S	Do.
Weston Formation	Pennsylvanian—Missourian	Pm	C	1948-66 production in Platte County.
Vilas Formation	do	Pm	S	Suitable in Kansas according to Plummer and Hladik, 1951, p. 24-25.
Bonner Springs Formation	do	Pm	S	Do.
Lane Formation	do	Pm	L	Herold and others, 1958, p. 14, 33.
Chanute Formation	do	Pm	S	Herold and others, 1958, p. 14, 33-34.
Cherryvale Formation:				
Quivira Shale Member	do	Pm	S	Suitable in Kansas according to Plummer and Hladik, 1951, p. 24-25, 53.
Wea Shale Member	do	Pm	C & S	1920-48 production at Kansas City; suitable in Kansas according to Plummer and Hladik, 1951, p. 24-25.
Fontana Shale Member	do	Pm	S	Suitable in Kansas according to Plummer and Hladik, 1951, p. 24-25.
Pleasanton Group	do	Pm	S (C)	Production in Iowa according to Sweeney and Hamlin, 1964, p. 32.
Holdenville Formation	Pennsylvanian—Desmoinesian	Pd	L	Herold and others, 1958, p. 14, 31.
Bandera Formation	do	Pd	S	Gentile, 1965, p. 44.
Pawnee Formation: Mine Creek Shale Member.	do	Pd	L	Gentile, 1965, p. 45.
Lagonda Formation	do	Pd	L	Herold and others, 1958, p. 14, 36.
Scammon Formation	do	Pd	L	Called "shale above Tebo coal" by Herold and others, 1958, p. 14, 32-33.
Tebo Formation	do	Pd	L	Herold and others, 1958, p. 14, 32.
Rowe Formation	do	Pd	L	Herold and others, 1958, p. 14, 31.
Renault Formation	Mississippian—Chesterian	M	L	Herold and others, 1958, p. 14, 36-37.
Hannibal Formation	Mississippian—Kinderhookian	M	S	Suitable in Illinois according to White, 1960, p. 19.
Saverton Formation	Devonian—Upper	DS	C & L	1918 production in Ralls County; Herold and others, 1958, p. 14, 35.
Grassy Creek Shale	do	DS	C & L	Do.
Chattanooga Shale	do	DS	L	Herold and others, 1958, p. 14, 32.
Orchard Creek Shale	Ordovician—Upper	Occ	L	Herold and others, 1958, p. 14, 37.
Maquoketa Shale	do	Occ	L	Do.

The suitable raw materials range in age from Ordovician to Pleistocene, but more than two-thirds are Middle or Late Pennsylvanian in age, about equally distributed among the Desmoinesian, Missourian, and Virgilian Series. Because of their wide geographic and stratigraphic distribution, the geologic map of Missouri (fig. 2) can best be used to show the locations of the suitable formations, and these formations are keyed to the geologic map by letter symbols in table 14.

The rock units that have been used commercially in Missouri and in the adjoining states of Iowa, Illinois, Kansas, and Oklahoma are described briefly in the paragraphs that follow. The Missouri sources are listed in order of geologic age, which by coincidence is also the order in which they came into production in Missouri.

The Grassy Creek and Saverton Formations of Devonian age were the first source of raw material for lightweight aggregate production in Missouri. They were used by the Atlas Portland Cement Co. in 1918 for the production of aggregate for the concrete ships of World War I (mentioned above). There has been no additional production of lightweight aggregate from them since 1919. The Grassy Creek shale and the overlying Saverton Formation have a combined maximum thickness of about 55 feet and thin rapidly to the south and east from northern Pike County (Koenig, in Howe and Koenig, 1961, p. 46); they are about 40 feet thick at the Illasco pit in Ralls County where they were mined for aggregate.

From 1920 to 1948, practically all the expanded shale aggregate consumed in Missouri was produced at Kansas City from the Wea Shale Member of the Cherryvale Formation (W. B. Howe, written communication, March 1966). The Quivira Shale Member, in the upper part of the Cherryvale, is present in the Kansas City pit where the Wea Member was mined, and it, too, may have been utilized.

At the present time, all the expanded shale produced in Missouri is from the Weston Formation of the Pedee Group of Pennsylvanian age. The shale thickens northward from about 60 feet in central Platte County to 100 feet or so in Buchanan County, and thence thins markedly to the north and west (Howe, in Howe and Koenig, 1961, p. 108). At the Carter-Waters plant at New Market (see fig. 24), in northern Platte County, the shale is from 95 to 100 feet thick.

In the Illinois part of the St. Louis metropolitan area, the Modesto Formation has been the source of raw material for a large amount of lightweight aggregate produced near East St. Louis. The Modesto is in the lower part of the McLeansboro Group of Pennsylvanian age (Sweeney and Hamlin, 1965, p. 6) and correlates with upper Marmaton and Pleasanton strata of Missouri.

Near Centerville, Iowa, a few miles north of the Missouri boundary, thick shale in the Pleasanton Group is used for the production of lightweight aggregate.

The materials discussed above and the others included in table 14 are bloatable, but they may be suitable for sintered aggregate as well. In addition, clays and shales that have not been tested may be suitable for bloating, some that were tested and found unsuitable may be suitable at other localities, and some of both groups may be suitable for

77-278 O—67——9

sintering. At present, the only definitive suitability test is a batch test under commercial conditions.

Economic aspects.—Expanded clay and shale aggregates are bulky, low unit value materials that incur high transportation costs, and that must meet aggressive competition from normal weight and by-product lightweight aggregates. Most of the lightweight aggregate is consumed in the building and highway construction industries, and so plants must be close to metropolitan areas or else very favorably located for low-cost transportation. Diamond and others (1964) have made an analysis of the lightweight aggregate industry in the South Central States (including Missouri) and have pointed out that the marketing radius for most plants is about 200 miles, but that it is less than that for Missouri. All of Missouri is within 200 miles of a producing plant, and much of it is within 100 miles, which is the usual marketing radius for most plants in the area at the present time.

Expanded clay and shale aggregate basically cost more than normal weight and expanded slag aggregates because of the additional cost of expansion. These higher costs must be and generally are offset by advantages that directly or indirectly reduce other costs, in such matters as need for smaller quantities of structural steel, ease of placement, better insulation, and so forth. Lower cost light weight aggregate can be produced in large-capacity plants, but there is little need for additional plant capacity until the market in Missouri is substantially increased.

Considerable opportunity for the development of the market exists. Inadequate public knowledge of the advantages of lightweight aggregate concrete and concrete block is reflected in the consumption patterns. About 90 percent of the lightweight aggregate produced in Missouri in 1960 was used in structural blocks, but less than 50 percent of all the structural block used was made with lightweight aggregate. In contrast, more than 90 percent of the blocks made in Texas, Louisiana, and Mississippi in 1960 were made with lightweight aggregate (Diamond and others, 1964, p. 19). The extra cost of lightweight block in Missouri as compared with the Gulf Coast States was only $0.01 to $0.02 per block, which seems inadequate to explain the difference in acceptance.

There are many opportunities for new uses of lightweight precast, prestressed, or structural concrete, and these are fields whose potential consumption of lightweight aggregate is very large. Further research into highway construction may open large new markets. Lightweight aggregates have been used for many years in concrete for bridge decks, but not in the highway surface itself. Recent investigations in Tennessee (E. A. Whitehurst, written communication, Mar. 17, 1966) show that a lightweight aggregate used in the pavement made a highly satisfactory, skid-resistant surface for highways.

Prospects for the lightweight aggregate industry in Missouri appear generally favorable, with adequate supplies near most of the major marketing centers and markets capable of considerable expansion in both established and new uses.

STONE

(By James A. Martin, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Stone is the major mineral commodity presently produced in Missouri. It has ranked first in value since 1962 and first in tonnage since 1946. In 1965, output was 36.2 million tons valued at $53.5 million. Production was reported from 79 of the State's 114 counties. Stone production is reported from every State and in 1964, the U.S. total was 725 million tons with a value of $1.13 billion. For the same year, Missouri ranked 7th in value and 8th in tonnage among the 50 States. Figure 25, page 135 reflects the overall trend in stone production in the State and shows the dramatic increase since 1945. In the period 1945–65 there has been a sevenfold increase in stone production, and output is expected to continue to rise. Stone will remain the No. 1 commodity in tonnage but is expected to be surpassed in value by lead and possibly by cement within the next 5 to 10 years. If the 1965 values of cement ($47.2 million) and lime ($16.8 million), derived from the same raw materials but reported separately, are added to the $53.5 million value for stone, the importance of this resource to the Missouri economy is even more striking.

Stone production is reported by the U. S. Bureau of Mines as (1) crushed and broken stone and (2) dimension and building stone. In Missouri more than 99 percent of the total tonnage produced during the past 5 years has been crushed and broken stone. Dimension stone, which commands a higher unit price, represented between 4 and 5 percent of the value for the same period.

Principal uses of crushed and broken stone and their approximate percentages of the 1965 tonnage are: concrete aggregate, roadstone, and screenings (58 percent); cement and lime manufacturing (18 percent); agricultural limestone (10 percent); riprap (9 percent); and railroad ballast (1 percent). Miscellaneous uses accounted for about 4 percent. Major items in this latter category are mineral fillers, terrazzo chips, roofing granules, flux, and mineral feeds.

Uses of dimension and building stone, which include marble, are: dressed and polished, rough construction, flagging, rubble, and rough architectural stone. Dressed stone, principally marble and granite, is the most important in both tonnage (56 percent) and value (93 percent). Most dimension stone quarries produce crushed stone as a by- or coproduct.

Limestone and dolomite are the principal rock resources in Missouri for both crushed and dimension stone. In 1965 they accounted for slightly over 97 percent of the total tonnage of stone. Other important rock types are: marble, sandstone, granite, and felsite. Stone is produced from all of the Paleozoic systems, and also from the Precambrian.

Factors governing the utilization of a stone deposit vary in importance with intended use, availability, and demand. Local availability and haulage distance are the determining factors for many crushed stone uses. Physical characteristics of the stone, such as soundness and durability, are important in the higher value types of aggregate

and dimension stone. In the manufacture of cement and lime, the stone must meet fairly rigid chemical requirements. Where quality, either physical or chemical, is a governing factor stone usually commands a higher unit price, may undergo more elaborate processing, and is often shipped to distant markets.

The following sections, prepared by several individuals, give details on the geologic and geographic distribution of the various rock types utilized by industry, qualities the stone must have to be economically attractive, major uses, past production, and the outlook for the future.

LIMESTONE AND DOLOMITE

(By James A. Martin, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Possibly no other rock type plays as important a role in the modern economy as do the carbonate rocks. They are outstanding in the diversified uses to which they are put and in their interrelation with other commodities. Limestone and dolomite, the principal carbonate rocks, are the major mineral commodity in both tonnage and value presently produced in Missouri. From an early use as stone blocks in construction and the raw material for lime, the production and use of limestone and dolomite has evolved into an industrial giant. They are the chief raw materials used in the manufacture of cement and lime, the State's principal sources of aggregate and broken stone, and the basis of the Missouri marble industry. In 1965, the value of limestone and dolomite plus their principal related commodities—cement and lime—was $115 million. This amounted to about 51 percent of the total value of mineral production in the State for that year.

Limestone and dolomite form the predominant bedrock type over nearly 60 percent of the state and comprise approximately the same percentage of the total Paleozoic section (table 1, page 16). Both rock types are absent in the Precambrian and the Cretaceous and Tertiary Systems. The main areas of outcrop are the Ozarks, the Osage Plains and the eastern one-third of the Dissected Till Plains (fig. 1, page 14). In general the older carbonate rocks (Cambrian and Ordovician) are dolomites or dolomitic limestones, whereas the younger (Devonian, Mississippian, and Pennsylvanian) are essentially limestones. Although there can be no absolute shortage of carbonate rock in the State, quality rock meeting both chemical and physical requirements of industry are not everywhere present at or near the surface. In some parts of the state, notably the Southeast Lowlands and Dissected Till Plains, bedrock is buried by several hundred feet of alluvium and glacial drift respectively. In areas of rapid urban expansion, the more accessible and better quality deposits are being depleted and zoning regulations or housing developments are limiting access to nearby sources of raw materials.

Table 15 lists the major carbonate rock units in Missouri, their general character, ranges of thickness, chemical and physical qualities, distribution, and their principal uses.

TABLE 15.—*Principal carbonate rock units in Missouri*

System	Series	Map designation	Unit	Character of unit	Generalized ranges: Thickness (feet)	Chemical composition (percent): $CaCO_3$	$MgCO_2$	SiO_2 [2]	Al_2O_3 Fe_2O_3	Physical properties [1]: Specific gravity	Absorption (percent)	Wear [3] (percent)	Area(s) of principal outcrop	Principal uses
Pennsylvanian	Virgilian	Pv	Deer Creek Fm.: Ervine Creek Ls. Mbr.	Limestone; irregular wavy bedding; small amount of chert.	15 to 25	75 to 85	1.0 to 8.0	------	------	2.30 to 2.60	1.0 to 6.5	24 to 60	Northwest: Holt and Nodaway Counties.	Aggregate for bituminous surfacing, base, and surfacing; aglime; riprap.
			Oread Fm.: Kereford Ls. Mbr.	Limestone; thin to massive.	2 to 10	------	------	------	------	2.50 to 2.62	1.0 to 2.5	22 to 30	Northwest: Andrew, Buchanan, and eastern Nodaway Counties.	Aggregate for portland cement and asphaltic concrete, base, and surfacing; aglime; riprap.
			Oread Fm.: Plattsmouth Ls. Mbr.	Limestone; medium bedded; cherty.	20	90	------	5.6	0.98	2.25 to 2.60	2.0 to 7.0	28 to 40	Northwest: Andrew, Buchanan, eastern Nodaway, and western Gentry Counties.	Aggregate for asphaltic concrete, bituminous surfacing, base, and surfacing; aglime; riprap.
			Lawrence Fm.: Amazonia Ls. Mbr.	Limestone; massive; irregular thickness.	2 to 15	------	------	------	------	2.50 to 2.63	0.2 to 2.0	31 to 41	Northwest: Andrew and Buchanan Counties (St. Joseph area).	Aggregate for portland cement and asphaltic concrete, bituminous surfacing, base, and surfacing; aglime; riprap.
	Missourian		Iatan Fm	Limestone; massive; irregular thickness.	5 to 15	------	------	------	------	2.62 to 2.63	0.9 to 1.5	30±	Northwest: Buchanan and Platte Counties.	Aggregate for base and surfacing; riprap.
			Stanton Fm.: Stoner Ls. Mbr	Limestone; irregular wavy bedding.	15±	80 to 93	0.5 to 5.0	1.0 to 4.5	0.9 to 2.0	2.40 to 2.65	1.0 to 5.0	26 to 37	Northwest: Buchanan, Clinton, De Kalb, Gentry, and Platte Counties.	Aggregate for asphaltic concrete, base, and surfacing; aglime; riprap.
			Plattsburg Fm.: Spring Hill Ls. Mbr.	Limestone; thin to medium bedded; cherty; shale partings common.	10 to 20	78 to 94	1.0 to 4.0	1.0 to 8.0	0.5 to 4.5	2.30 to 2.60	1.9 to 5.5	22 to 34	Northwest: Platte Clinton, De Kalb, and Gentry Counties.	Aggregate for asphaltic concrete, base, and surfacing aglime; riprap.
			Wyandotte Fm.: Argentine Ls. Mbr.	Limestone; small amount of chert; shale partings; irregular thickness and bedding.	1 to 35	92 to 97	0.3 to 3.5	0.5 to 3.0	0.5 to 2.0	2.40 to 2.57	1.0 to 4.5	30 to 35	Northwest and west-central: Jackson, Cass, Clay, Platte, and Ray Counties.	Aggregate for asphaltic concrete, base, and surfacing; riprap.

See footnotes at end of table, p. 133.

TABLE 15.—*Principal carbonate rock units in Missouri*—Continued

System	Series	Map designation	Unit	Character of unit	Generalized ranges								Area(s) of principal outcrop	Principal uses
					Thickness (feet)	Chemical composition (percent)				Physical properties [1]				
						$CaCO_3$	$MgCO_3$	SiO_2 [2]	Al_2O_3 Fe_2O_3	Specific gravity	Absorption (percent)	Wear [3] (percent)		
Pennsylvanian	Missourian	Pm	Drum Fm.: Cement City Ls. Mbr.	Limestone; thin bedded.	5 to 10	86.4	6.2	6.7	4.1	-----	-----	-----	West-central: Jackson County.	Aggregate for base and surfacing; riprap.
			Cherryvale Fm.; Westerville Ls. Mbr.	Limestone; cross-bedded, oolitic in upper part; massive beds in lower part.	5 to 20	-----	-----	-----	-----	-----	-----	-----	West-central and northwest: Jackson, Platte, and Harrison Counties.	Dimension stone; aggregate for base and surfacing; riprap.
			Dennis Fm.: Winterset Ls. Mbr.	Limestone; thin to thick bedded; abundant shale partings; very cherty in upper part.	20 to 35	70 to 90	4 to 11	5 to 15	2 to 11	2.30 to 2.65	0.9 to 6.0	25 to 56	Northwest, west-central, and north-central: Caldwell, Cass, Clay, Daviess, Grundy, Harrison, Jackson, Johnson, Lafayette, Livingston, Mercer, and Ray Counties.	Cement manufacturing; aggregate for asphaltic concrete, bituminous surfacing, base, and surfacing; aglime; riprap.
			Swope Fm.: Bethany Falls Ls. Mbr.	Limestone; massive to nodular bedding; chert free.	20 to 25	80 to 97	0.1 to 7.0	0.5 to 6.0	0.4 to 5.5	2.20 to 2.65	0.8 to 5.0	25 to 55	Northwest, west-central, and north-central: Caldwell, Cass, Clay, Daviess, Grundy, Harrison, Jackson, Johnson, Lafayette, Livingston, Mercer, and Ray Counties.	Cement manufacturing; aggregate for portland cement and asphaltic concrete, bituminous surfacing, and base; aglime; riprap.
			Hertha Fm.: Sniabar Ls. Mbr.	Limestone and dolomitic limestone; medium to massive beds with shale partings.	10±	80 to 90	2 to 9	3 to 5	2 to 3.5	2.58 to 2.70	1.5 to 2.5	23 to 29	Northwest, west-central, and north-central: Jackson, Ray, and Sullivan Counties.	Aggregate for asphaltic concrete, bituminous surfacing, base, and surfacing; riprap.
			Pawnee Fm.: Myrick Station Ls. Mbr.	Limestone; thin bedded; shaly in northern outcrop area.	5 to 10	-----	-----	-----	-----	2.58	1.6 to 1.8	-----	West-central and north-central: Bates, Johnson, Lafayette, Henry, and Randolph Counties.	Aggregate for portland cement and asphaltic concrete, bituminous surfacing, base, and surfacing.

Pennsylvanian	Desmoinesian	Pd	Higginsville Fm	Limestone; thick and wavy-bedded to south; thin in northern area.	5 to 15	85 to 95	0.5 to 5	5 to 9*	------	2.50 to 2.67	0.5 to 3.5	22 to 35	West-central and north-central: Bates, Cass, Henry, Johnson, Linn, Putnam, Lafayette, Randolph, and Vernon Counties.	Aggregate for portland cement and asphaltic concrete, bituminous surfacing, base, and surfacing; aglime.
			Blackjack Creek Fm	Limestone and dolomitic limestone; medium to massive beds with shale partings.	5 to 10	85.3	5.9	4.12*	------	2.50 to 2.60	0.5 to 1.5	27 to 31	West-central: Bates, Henry and Vernon Counties.	Aggregate for asphaltic concrete, bituminous surfacing, base, and surfacing; riprap.
			Verdigris Fm.: Ardmore Ls. Mbr.	Limestone; one or two massive layers with shale partings.	3 to 10	------	------	------	------	------	------	------	West-central: Johnson and Henry Counties.	Aggregate for surfacing.
Mississippian	Chesterian	M	Golconda Fm	Upper: oolitic limestone. Middle: shale and limestone. Lower: limestone------	40 to 50 60 to 90 5 to 20	90.35	2.03	4.78	------	------	------	------	Southeast: Perry County---	
	Meramecian	M	Ste. Genevieve Fm	Limestone, oolitic, chert, thin sandstone beds and disseminated quartz sand grains.	80 to 100	90 to 96	1.5 to 2.0	0.3 to 6.0	0.3 to 1.0	------	------	------	Southeast: Perry and Ste. Genevieve Counties.	
			St. Louis Ls	Limestone, shaly and dolomitic in part; interbedded dolomite.	50 to 175	70 to 98 45 to 62	0.5 to 20 26 to 39	0.2 to 11 5 to 16	0.1 to 5.0 0.1 to 5.0	2.15 to 2.68	0.3 to 10	21 to 46	East and southwest: Clark, Scotland, Lewis, St. Charles, St. Louis, Ste. Genevieve, Dade, Cedar, and Barton Counties.	Portland cement; metallurigcal limestone; aggregate for portland cement and asphaltic concrete, bituminous surfacing, base and surfacing; aglime; riprap; flagging and rubble; rough building stone.
			Salem Fm	Limestone, oolitic; chert and dolomitic in St. Louis area; dolomitic and shaly in northeast; limestone in southwest.	50 to 150	60 to 99	0.1 to 36	0.1 to 5.0	0.0 to 5.0	2.20 to 2.70	1.0 to 11	27 to 55	East-central and southwest: St. Charles, St. Louis, Ste. Genevieve, Dade, and Jasper Conties.	Lime; metallurical limestone; aggregate for asphaltic concrete, bituminous surfacing, base, and surfacing; aglime; riprap.

See footnotes at end of table.

TABLE 15.—*Principal carbonate rock units in Missouri*—Continued

System	Series	Map designation	Unit	Character of unit	Generalized ranges								Area(s) of principal outcrop	Principal uses
					Thickness (feet)	Chemical composition (percent)				Physical properties [1]				
						$CaCO_3$	$MgCO_3$	SiO_2 [2]	Al_2O_3 Fe_2O_3	Specific gravity	Absorption (percent)	Wear [3] (percent)		
Mississippian	Meramecian		Warsaw Fm	Limestone, cherty; shaly and shale units in eastern and central Mo.; cherty limestone in southwest.	20 to 150	75 to 98	0.5 to 6.5	------	------	2.38 to 2.65	0.2 to 6.0	30 to 37	East-central and southwest: St. Charles, St. Louis, Ste. Genevieve, Barton, Cedar, Dade, Jasper, Lawrence, and Newton Counties.	Marble; aggregate for portland cement (southwest only) and asphaltic concrete, bituminous surfacing, base, and surfacing; aglime; riprap.
	Osagean	M	Keokuk Ls	Limestone, high percentage chert.	50 to 100	95 to 98	0.0 to 2.0	0.1 to 0.5	0.1 to 0.3	2.53 to 2.66	0.4 to 3.0	30 to 49	Widely distributed throughout the Mississippian outcrop area from northeast (Clark Co.) to southwest (Newton Co.).	Marble; aggregate for portland cement and asphaltic concrete, bituminous surfacing, base, and surfacing; aglime; riprap.
			Burlington Ls	Limestone, high percentage chert; basal 10 to 30 feet low chert content; local dolomitization.	50 to 100	90 to 99 / 55 to 70	0.0 to 1.5 / 30 to 45	0.2 to 2.0 / 0.0 to 2.0	0.2 to 1.0 / 0.5 to 1.5	2.33 to 2.69	0.4 to 8.0	24 to 80	Widely distributed throughout the Mississippian outcrop area from northeast (Lewis Co.) to southwest (McDonald Co.).	Marble; lime; cement; aggregate for portland cement and asphaltic concrete, bituminous surfacing, base, and surfacing; aglime; riprap.
			Pierson Fm	Cherty limestone, dolomitic limestone and dolomite.	20 to 50	------	------	------	------	2.68	0.5	27	Southwest: Greene, Stone, Barry, Christian, Taney, McDonald, Lawrence, and Polk Counties.	Aggregate for asphaltic concrete, bituminous surfacing, base, and surfacing; riprap.
	Kinderhookian		Chouteau Group (undifferentiated).	Limestone and dolomitic limestone; chert nodules; shale partings.	60 to 100	60 to 90	1.0 to 20	------	------	2.25 to 2.63	1.3 to 6.0	28 to 47	Central and northeast: Saline, Howard, Boone, Callaway, Montgomery, Warren, Lincoln, Pike, Ralls, Shelby, Knox, and Marion Counties.	Aggregate for asphaltic concrete, bituminous surfacing, base and surfacing; aglime; riprap.
		M	"Upper Sedalia"	Dolomite, dolomitic limestone.	10 to 30	20 to 85	7 to 33	6 to 51	1.2 to 3.5	2.33 to 2.53	3.1 to 5.9	33 to 38	Central: Boone, Moniteau, and Cooper Counties.	Aggregate for bituminous surfacing, base, and surfacing; used in past for rock wool.

			Sedalia Fm	Limestone, dolomitic limestone and dolomite; chert, argillaceous to silty.	20 to 50					2.53 to 2.62	2.0 to 3.0	28 to 37	West Central: Pettis, Polk, Benton, Hickory, and Cooper Counties.	Aggregate for bituminous surfacing, base and surfacing: aglime; riprap.
			Compton Fm	Limestone, argillaceous: shale partings; minor amount of chert.	10 to 20	80 to 90	1 to 4			2.58 to 2.67	1.0 to 3.0	24 to 30	Southwest: Cooper, Pettis, Benton, Hickory, Polk, Stone, Greene, Christian, Barry, Lawrence, McDonald, and Taney Counties.	Aggregate for asphaltic concrete, bituminous surfacing, base, and surfacing; aglime; riprap.
Devonian		DS	Callaway Fm	Limestone, variable in texture, thickness, and purity; locally contains dolomitic sandstone and conglomerate.	5 to 60	60 to 98	0.5 to 22	0.4 to 13	0.2 to 1.0	2.59 to 2.69	0.1 to 1.6	22 to 36	Central and northeast: Boone, Callaway, Cooper, Saline, Pettis, Moniteau, Marion, and Ralls Counties.	Aggregate for portland cement and asphaltic concrete, bituminous surfacing, base, and surfacing; aglime; riprap.
			Bailey Ls	Limestone, argillaceous, shaly; and dolomitic limestone.	100 to 300								Southeast: Cape Girardeau and Perry Counties.	Riprap.
Silurian		DS	Edgewood Fm.: Bowling Green Dol. Mbr.	Dolomite and dolomitic limestone; small amount of chert.	10 to 40	47 to 53	27 to 35	10 to 14	1 to 3	2.38 to 2.40	4.0 to 6.0	38 to 43	Northeast: Pike and Lincoln Counties.	Aggregate for base and surfacing; aglime.
Ordovician	Champlainian	Occ	Kimmswick Fm	Limestone; minor amount of chert; locally dolomitic.	25 to 120	95 to 99	0.1 to 2.5	0.1 to 3.0	0.1 to 2.0	2.40 to 2.68	0.3 to 4.0	28 to 65	East: Ralls, Pike, Lincoln, St. Charles, St. Louis, Jefferson, Ste. Genevieve, Perry, Cape Girardeau, and Scott Counties.	Cement; marble; aggregate for portland cement and asphaltic concrete, bituminous surfacing, base, and surfacing; riprap; aglime.
			Plattin Fm	Limestone; interbedded dolomitic limestone and shale partings; chert.	50 to 400	70 to 98	0.2 to 15	0.4 to 15	0.2 to 10	2.40 to 2.80	0.1 to 3.0	20 to 46	East: Ralls, Pike, Lincoln, Montgomery, Warren, St. Charles, Franklin, St. Louis, Jefferson, Ste. Genevieve, Perry, Cape Girardeau, and Scott Counties.	Cement; terrazzo chips; aggregate for portland cement and asphaltic concrete, bituminous surfacing, base, and surfacing; riprap; aglime.
			Rock Levee Fm. and Joachim Dol.	Dolomite in central and northeast; dolomite, dolomitic limestone and limestone in southeast. Interbedded sandstone and shale in lower part.	50 to 450	45 to 75	12 to 40	1.0 to 15	0.3 to 12	2.10 to 2.67	0.7 to 10	21 to 30	East: Lincoln, Montgomery, Warren, St. Charles, Franklin, St. Louis, Jefferson, Ste. Genevieve, Perry, Cape Girardeau, and Scott Counties.	Dimension stone; aggregate for asphaltic concrete, bituminous surfacing, base, and surfacing; riprap; aglime.

See footnotes at end of table, p. 133.

TABLE 15.—*Principal carbonate rock units in Missouri*—Continued

System	Series	Map designation	Unit	Character of unit	Generalized ranges								Area(s) of principal outcrop	Principal uses
					Thickness (feet)	Chemical composition (percent)				Physical properties [1]				
						$CaCO_3$	$MgCO_3$	SiO_2 [2]	Al_2O_3 Fe_2O_3	Specific gravity	Absorption (percent)	Wear [3] (percent)		
Ordovician	Canadian	Oc	Cotter and Jefferson City Dol.	Dolomite; argillaceous and siliceous; shaly, chert; thin sandstones.	300 to 800	30 to 60	30 to 45	0.1 to 20	0.5 to 13	2.29 to 2.80	0.5 to 7.5	19 to 46	Ozarks: Salem Plateau	Dimension stone; aggregate for asphaltic concrete, bituminous surfacing, base, and surfacing: riprap; aglime.
			Gasconade Dol. (upper part of formation only).	Dolomite, massive: minor amount of chert.	40 to 60	47 to 57	37 to 44	1 to 7	0.4 to 4	2.38 to 2.75	0.9 to 4.5	20 to 40	Ozarks: Salem Plateau, principally along the major drainage.	Aggregate for asphaltic concrete, bituminous surfacing, base, and surfacing; aglime.
Cambrian		Cpe	Eminence Dol.	Dolomite; massive; varying amounts of chert.	200 to 250	51 to 58	40 to 46	0.1 to 5.0	0.2 to 2.0	2.53 to 2.74	0.7 to 3.5	26 to 48	Ozarks: Salem Plateau; Camden, Morgan, Shannon, Carter, Reynolds, Wayne, Madison, Iron, Washington, and Crawford Counties.	Aglime.
			Potosi Dol.	Dolomite; massive quartz druse.	200 to 250	50 to 58	40 to 46	0.4 to 4.0	0.2 to 1.0	2.70 to 2.78	0.4 to 1.0	27 to 33	Ozarks: Salem Plateau: Shannon, Reynolds, Madison, Iron, Wayne, Crawford, and Washington Counties.	Aggregate for asphaltic concrete, bituminous surfacing, base, and surfacing; aglime; locally used for portland cement concrete aggregate.
			Derby-Doerun Dol.	Dolomite, argillaceous; varying minor amounts of intercalated siltstone and shale.	100	44 to 53	35 to 42	4 to 18*	0.5 to 4.0	2.40 to 2.75	1.0 to 5.5	24 to 36	Southeast Ozarks: St. Francois Mts. area: Iron, St. Francois, Ste. Genevieve, and Madison Counties.	Aggregate for asphaltic concrete, bituminous surfacing, base, and surfacing.

	Cl be	Bonneterre Fm.	Dolomite, relatively pure; dolomitic limestone and limestone in some areas.	300	47 to 55	34 to 44	0.5 to 8.0	0.5 to 7.0	2.50 to 2.80	0.2 to 2.3	20 to 30	Southeast Ozarks: St. Francois Mts. area—peripheral to the Precambrian· Iron, St. Francois, Ste. Genevieve, and Madison Counties.	Dead-burned dolomite; refractory dolomite; aggregate for portland cement and asphaltic concrete, bituminous surfacing, base and surfacing; agline.
		NOTE.—Gray to pink limestone facies in the Bonneterre; locally developed and restricted in extent; extremely variable shale and clay content.		0 to 50	80 to 98	0.5 to 15	0.3 to 4.0	1 to 5.0	------	------	------	Iron and Madison Counties.	Terrazzo chips; aglime.

[1] Ranges based on tests made by the Materials and Research Division, Missouri State Highway Department. Courtesy MSHD District geologists.

[2] * Denotes total insolubles.

[3] Percentage of wear based on Los Angeles Abrasion Test (AASHO T96-58(c)).

CRUSHED AND BROKEN STONE

(By James A. Martin, Missouri Geological Survey and Water Resources, Rolla, Mo.)

The production of crushed and broken limestone and dolomite exceeds all other types of stone produced in Missouri, having averaged more than 95 percent of the total stone tonnage and 93 percent of the value for the past 10 years. Physical properties and chemical quality are the determining factors for the majority of uses. In order of importance, the principal consumer categories are: construction and maintenance aggregate, the manufacture of cement and lime, agricultural liming, and riprap. Essentially all of the carbonate rock units present in the State are or have been quarried. The largest percentage of stone presently produced is from limestones in the Pennsylvanian, Mississippian, and Ordovician Systems (table 15). For general discussion, the term limestone is used to include both limestone and dolomite.

As one of the major basic industrial minerals, the yearly tonnages of crushed limestone produced are a barometer of both economic conditions and population growth. With the exception of minor declines, the crushed limestone industry has grown steadily since 1920. In 1964, Missouri ranked sixth nationally in tonnage of crushed limestone produced. Of the neighboring States, only Illinois production exceeds that of Missouri. The 1965 production of nearly 35 million tons with a value of $49 million accounted for 22 percent of the total value of mineral production in the State for that year. Production and value of crushed limestone, exclusive of stone used in the manufacture of cement and lime, for the period from 1917 to 1965 is shown in figure 25.

Crushed and broken limestone was reported in 1965 by 203 commercial producers from 76 of the State's 114 counties (figure 26). Noncommercial stone (stone produced by or under contract for a Federal, State, or municipal agency) was reported from 10 counties. Over 1 million tons of crushed limestone were produced in seven counties with the largest production in St. Louis and Jackson Counties. Movement of crushed stone to the market by truck amounted to nearly 31 million tons or about 85 percent of the total stone produced in 1965. Rail and water transportation accounted for about 1.8 and 1.5 million tons each. The largest percentage of crushed stone shipments terminate within the State. However, stone is transported to adjoining States particularly by barge for revetment work on the Mississippi River, and in a few areas, stone is brought into bordering counties from adjoining States. The use of portable crushing and screening plants has become increasingly important in recent years, especially with the expanded highway construction program. By using portable equipment many stone producers crush and stockpile at several permanent quarry locations within their market area. Other quarries are opened for a single project and then abandoned.

The principal markets for crushed limestone and dolomite produced in Missouri in 1965 were: (1) concrete aggregate, roadstone, and screenings, (2) in the manufacture of cement, (3) agricultural limestone, (4) riprap, and (5) in the manufacture of lime and dead-burned

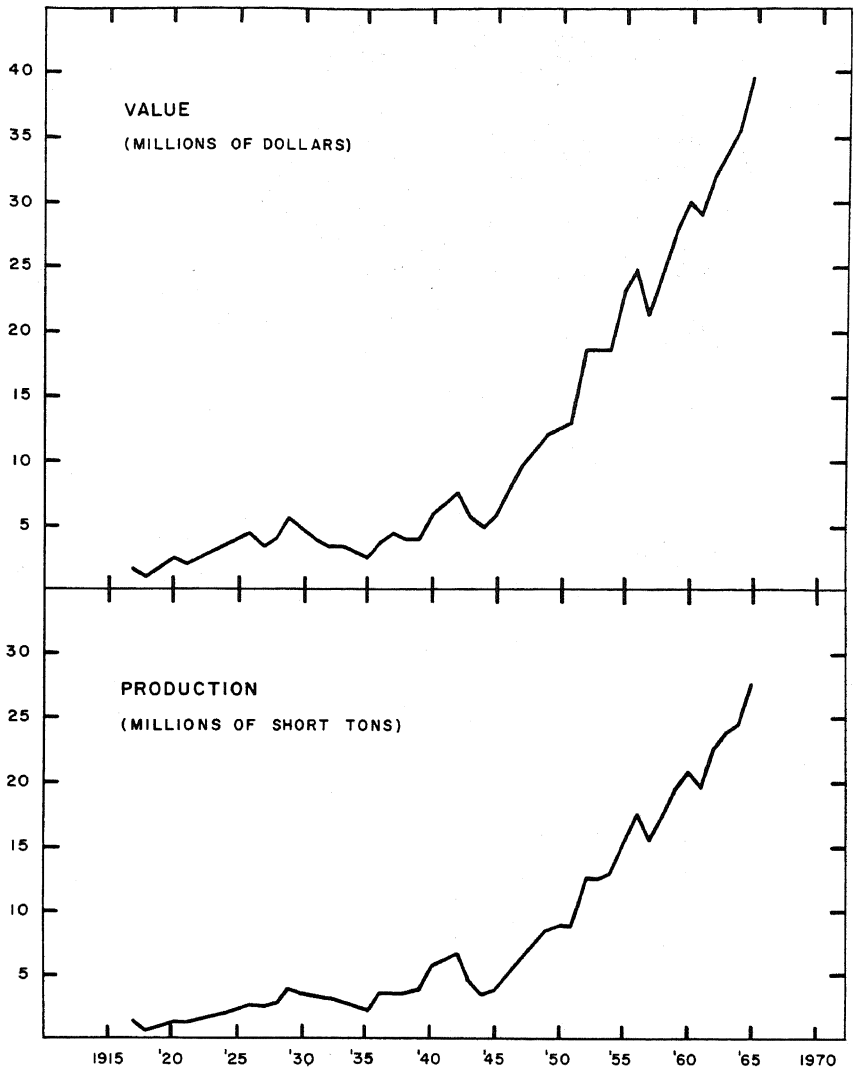


FIGURE 25.—Missouri production and value of crushed limestone and dolomite, 1917–65 (exclusive of stone used in the manufacture of cement and lime, and crushed limestone termed marble by the trade). Source: Bishop (1949) 1917–47; U.S. Bureau of Mines, 1948 to date.

dolomite. Production for miscellaneous uses amounted to slightly over 1 million tons and included such items as railroad ballast, flux and refractory stone, and mineral filler. Crushed stone production for the five major uses listed above during the period 1954 to 1965 is shown on figure 27. Stone used in the manufacture of cement, lime, and dead-burned dolomite are totaled together and estimates, based on

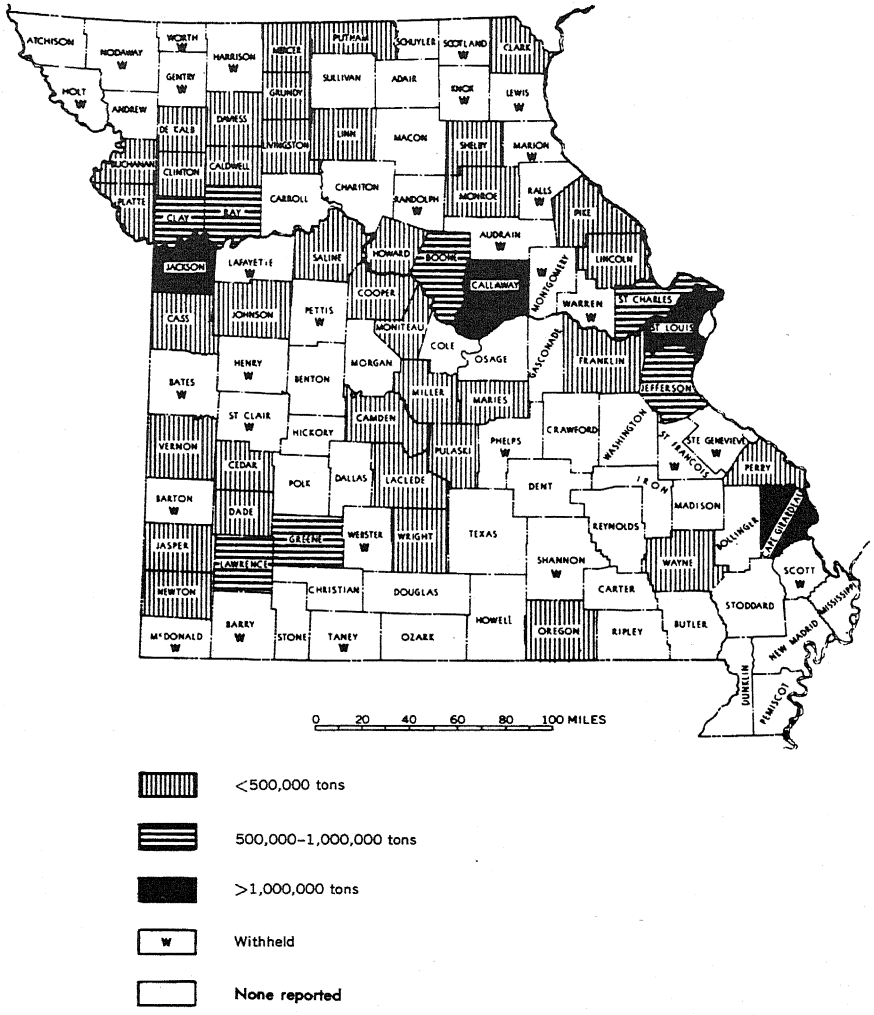


FIGURE 26.—Counties in Missouri that produced crushed limestone and dolomite in 1965. Source: U.S. Bureau of Mines.

the production of the finished product, are made for the years 1955, 1963, and 1965 when crushed stone figures were not available. Figure 28 shows the percentage breakdown in value and tonnage by major consumers in 1964.

By far the most important single market for crushed limestone and dolomite in Missouri is highway base and subbase, surfacing, and aggregate for portland cement concrete, asphaltic concrete, and bituminous surfaces. In this category alone, the use of crushed stone has increased from slightly over 5 million tons in 1950 to an unprecedented high of 20.6 million tons in 1965 and amounted to 57 percent of the

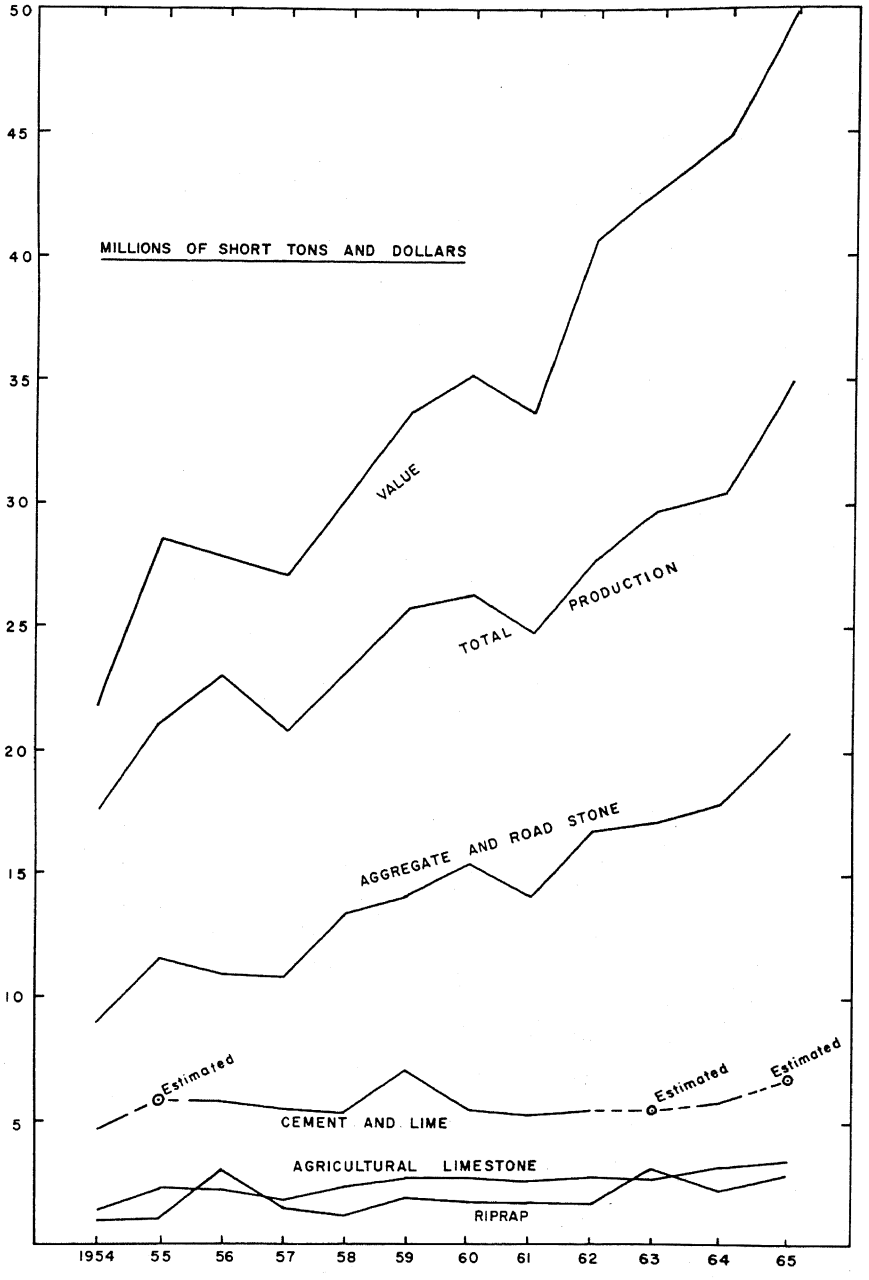


FIGURE 27.—Production for major uses, and total production and value of crushed and broken limestone and dolomite in Missouri, 1954–65. Source: U.S. Bureau of Mines.

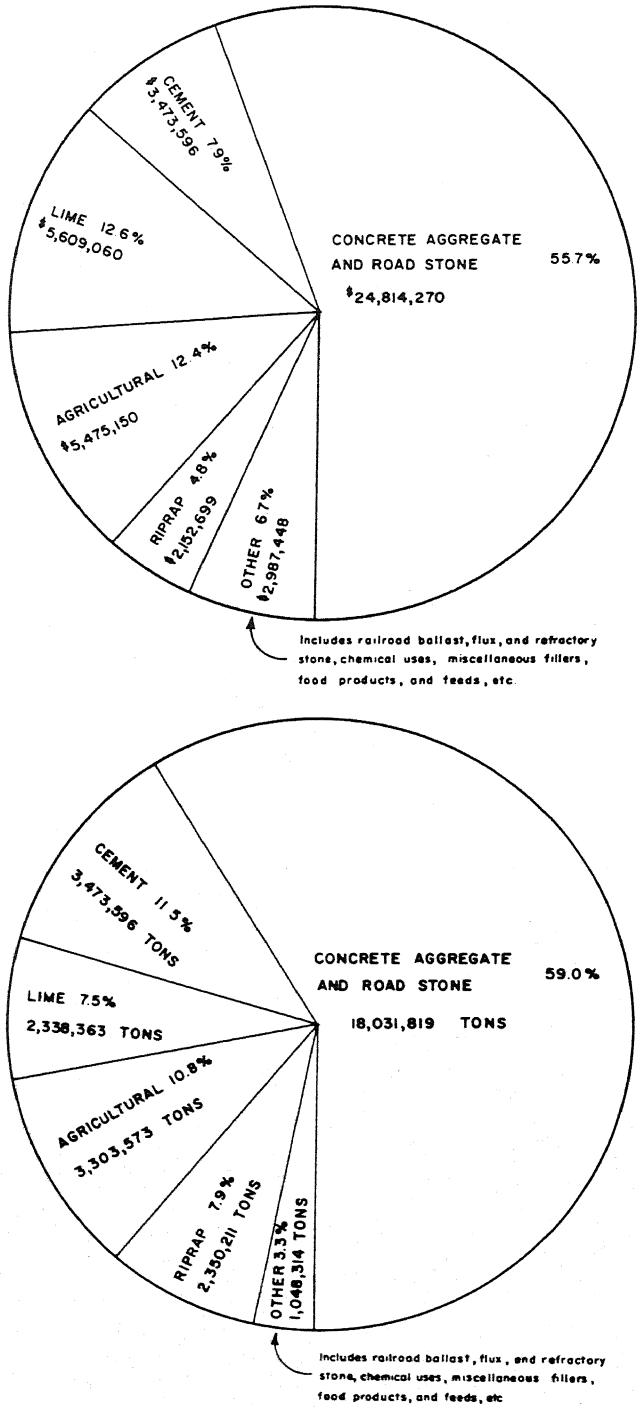


FIGURE 28.—Consumption and value by major uses in Missouri of crushed and broken limestone and dolomite (1964). Source: U.S. Bureau of Mines.

total stone produced in the State during that year. In 1964, Missouri ranked seventh nationally among States producing crushed limestone for concrete and roadstone use. Physical factors, in addition to location and thickness, that govern the use of a particular deposit of limestone or dolomite for concrete aggregate and other construction purposes are: resistance to wear (abrasion tests), soundness or resistance to weathering (freeze-thaw tests), specific gravity, absorption (porosity), and the percentages of deleterious material (shale, clay, soft stone, etc.) and chert ("flint"). The chemical reactivity between the aggregate particle and cement (alkali-carbonate and alkali-silicate reactions) which causes excessive expansion and cracking of concrete, has become increasingly important in evaluating stone to be used in concrete paving. Competitive with crushed stone are lightweight aggregate, blast furnace slag and stream gravels. Under present specifications, limestone and dolomite will remain the most important raw materials for these uses in the State. Production should continue to increase at a healthy rate parallel to the anticipated expanding highway programs (especially the Interstate Highway System), urban renewal, and residential and other building construction requirements.

During the period 1955–65, the cement and lime industries used an average of about 5.5 million tons of crushed limestone and dolomite annually. The 1965 production for cement alone amounted to a record high of slightly over 4 million tons. The chief requirements of rock used in the manufacture of lime and cement are those relating to chemical characteristics: high calcium for lime; high magnesia for dead-burned dolomite and dolomitic lime; and low magnesia for cement. Requirements and resources for these commodities are discussed in detail elsewhere in this report (Cement, p. 172; Lime, p. 183). Limestone production in this category is expected to increase an additional 2 to 2½ million tons per year with the expansion of the cement industry in the State.

The use of finely crushed limestone or dolomite to neutralize or "sweeten" the soil, to add calcium, magnesium, and trace elements as plant nutrients, and in general, to improve soil conditions has increased in Missouri under the very active programs of the U.S. Department of Agriculture and the University of Missouri Extension Service. Between 1.5 and 3.0 million tons of agricultural limestone and dolomite (also referred to as aglime, agstone and "lime") were used annually during the period 1947–63. The 1965 production reached an all-time high of 3.5 million tons. Nationally, Missouri ranks second, following Illinois, in aglime production. However, present production is only slightly over 60 percent of the annual "lime need" in the State, according to the National Limestone Institute. Under the 1966 Agricultural Stabilization and Conservation Service (A.S.C.S.) program, which is based on calcium carbonate equivalent (CCE), both dolomites and limestones are used for agricultural liming with the high-magnesium limestones and dolomites being competitive to, or having a slight edge over, the high-calcium limestones. From 1958 to 1966, the A.S.C.S. cost-share program was based on pounds of effective calcium and magnesium per ton with the higher rate paid for calcium. While this program was in effect, high-calcium aglime was often shipped into the dolomite areas of the State, such as the Ozarks.

77–278 O—67——10

Substantial quantities of aglime will continue to be used in the State as farming practices improve and with the increased use of nitrate fertilizer. The anticipated annual use will be in the range of 5 to 6 million tons per year—the present "need" figure—but may eventually surpass that amount. As a relatively low priced commodity, the location of agricultural limestone quarries is dependent on market demands and transportation costs. In most cases, aglime is a coproduct of crushed stone quarried for other uses; however, a few quarries produce only agstone. In addition to in-State use, aglime is shipped from Missouri to many Southern States. Nearly all limestones and dolomites in the State, with the exception of a few very cherty or siliceous and shaly units, are satisfactory for aglime.

Large tonnages of broken stone are produced annually in many of the counties bordering the Mississippi and Missouri Rivers for revetment, dike, and wing-dam projects by the Corps of Engineers. Such stone, termed riprap, generally consists of large irregularly shaped blocks; however, graded crushed stone is also used. Whether shovel-run or crushed gradations are utilized depends upon specifications for each particular use. In addition to river bank protection, riprap is also used as facing on dams to protect against wave erosion, spillways, road and bridge embankments, foundations, and fill. The stone should be durable and free of such features as fractures and shale partings which would permit breaking, splitting, or deterioration. Tests made on stone for riprap are specific gravity, absorption, soundness, and for certain specific uses, wear and toughness. In practice, the specifications are frequently controlled by the types of rock available within economic haul distances, the type of structure being built, and the costs of repair and maintenance. Since 1954, the production of riprap in Missouri has exceeded 1 million tons annually with over 3 million tons produced in 1956 and 1963. The 1965 production, 2.873 million tons, was about 8 percent of the total stone produced in the State. In recent years, large quantities of stone have been barged from Missouri quarries to projects on the lower Mississippi River. Future production will fluctuate primarily with the number of new projects undertaken by the Corps of Engineers and requirements for the maintenance of existing structures.

Miscellaneous uses of crushed limestone and dolomite, exclusive of stone used in the manufacture of cement and lime, have accounted for slightly over 1 million tons (2 to 3 percent of the total) annually during the past 3-year period (1963 to 1965). Yearly tonnages from 1950 to 1963 ranged between 500,000 and 1 million tons. The 1965 production in the miscellaneous use category was 1.193 million tons (slightly over 3 percent of the total crushed stone production) with a value of $3.231 million. Chief among these minor industrial uses were:

Asphalt filler	Glass	Poultry grit
Railroad ballast	Putty	Fertilizer filler
Chemical uses	Paper	Coal-dust abatement
Filter beds	Whiting	Paint filler
Flux	Mineral feeds and food	

The largest tonnages were used in glass manufacturing, asphalt filler, whiting, mineral feeds, poultry grit, and railroad ballast. Chemical quality or purity of the stone is the prime factor for the majority

of these uses; however, for some, such as railroad ballast, physical characteristics are important. Summaries of industrial limestone and dolomite uses and specifications are given by Lamar and Willman (1938), Colby (1941), Bowles and Jensen (1947), Bowles (1956), and Lamar (1961). Overall production of crushed stone for miscellaneous uses will probably continue to increase gradually; however, individual market demands will vary from year to year.

Resources

The carbonate rock resources of Missouri are in the three major areas shown on figure 29. Pennsylvanian strata underlie all of Area 1. Area 2 outlines the outcrop of Mississippian, Devonian, and Ordovician (Champlainian Series) limestones. Area 3, essentially the Ozarks, is underlain by a thick sequence of Ordovician (Canadian Series) and Cambrian dolomites. With the exception of a few small areas in northern Scott and Stoddard Counties, bedrock is deeply

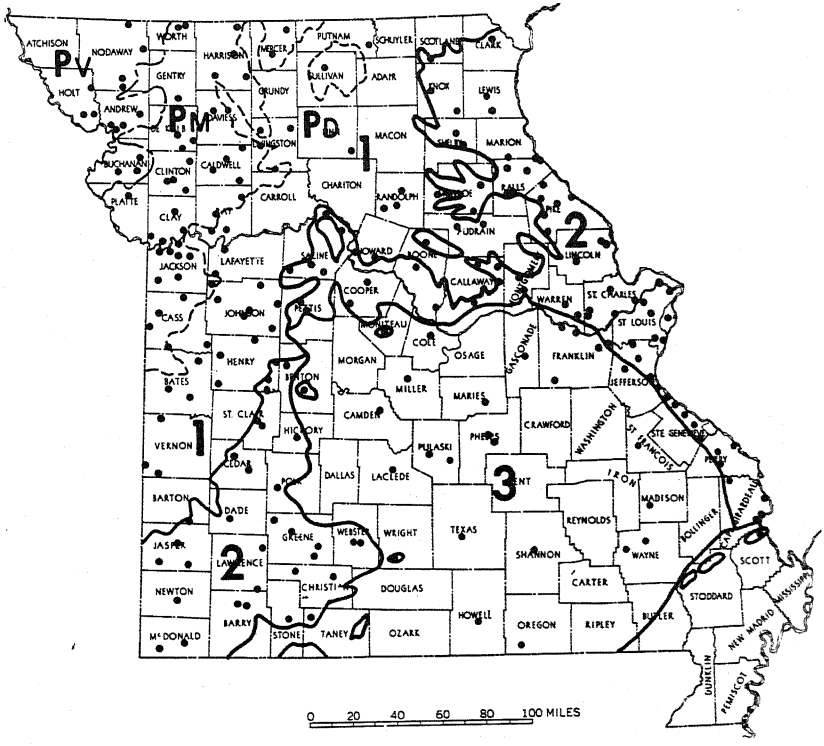


FIGURE 29.—Major carbonate rock areas in Missouri and approximate location of quarries active in 1965. 1: Pennsylvanian rocks; Pv, Virgilian; Pm, Missourian; Pd, Desmoinesian; thin (5 to 35 feet) limestone units interbedded with sandstone, shale, clay, and coal. 2: Mississippian, Devonian, Silurian, and Middle Ordovician; predominately thick (25 to 200 feet plus) limestone units; a few dolomite units. 3: Lower Ordovician and Cambrian; predominantly thick (50 to 300 feet plus) dolomite units; minor amount of limestone in restricted areas.

buried in the Southeast Lowlands. Table 15 lists the main uses and general ranges of thickness, chemical quality, physical properties, and distribution of the principal limestone and dolomite units in the State. A formation or member designated in the table as being suitable for a particular use, such as aggregate for portland cement concrete, may not pass specifications in all areas. Likewise, the chemical and physical ranges that are listed are typical but may not apply to all outcrops.

Area 1.—Pennsylvanian strata, underlying the western and northern parts of the State, consist of interbedded sandstone, shale, limestone, clay, and coal. The area is subdivided on the basis of the three major Series; Virgilian (Pv), Missourian (Pm) and Desmoinesian (Pd) which underlie this portion of Missouri. Limestones seldom exceed 15 to 30 feet in thickness and units 2 to 5 feet thick are most common. Quarries have been operated in nearly all of the limestone units in the area, including some only a foot or two in thickness. In much of the area north of the Missouri River, bedrock may be buried by several hundred feet of glacial deposits and near-surface sources of stone having economic potential are virtually absent in many of these counties. South of the Missouri River, bedrock is exposed at the surface but much of the area is underlain by thick sandstones and shales. In general, the carbonate rock resources are deficient in many of the counties. An exception is the greater Kansas City area where the major limestone units in the Pennsylvanian crop out. Unfortunately, however, competition for land use is making much of the limestone unavailable for this prime market area.

In the northwest corner of the State, the area of Virgilian bedrock, limestone is quarried from the Deer Creek, Oread, Lawrence and Iatan Formations (table 15). The Ervine Creek Member of the Deer Creek is the uppermost limestone suitable for quarrying. Above this unit, the limestone beds seldom exceed 4 feet in thickness. Outcrops are restricted to the valleys of the major streams—Platte, Nodaway, and Hundred and Two Rivers—and the Missouri River bluff. In the outcrop area of Missourian strata, the Bethany Falls Member of the Swope Formation is the principal limestone quarried, and it contributes the largest tonnage to the total stone being produced in Area 1. Other important units are in the Stanton, Plattsburg, and Dennis Formations. The Higginsville and Blackjack Creek Formations of the Fort Scott Subgroup are the main limestone sources in the Desmoinesian outcrop area, chiefly south of the Missouri River. Northward, the Fort Scott limestones thin but have been quarried in counties where thicker units are absent.

Throughout the greater part of the area of Pennsylvanian rocks north of the Missouri River, near-surface sources of limestones are inadequate and virtually every outcrop has been worked at one time or another. Stone is trucked into many of these counties when large supplies are required for a particular use; however, except for aglime the present demand for crushed stone is not great. A general evaluation of the subsurface resources of the northern counties is necessary to delimit those areas where deep pit or underground mining by slope or shaft would be feasible. South of the Missouri River adequate re-

sources are present in most counties and where absent, stone from Area 2 is available within relatively short distances.

Area 2.—Paralleling the Mississippi River in the east, continuing westward along the north side of the Missouri River, and extending into the southwest corner of the State is a belt of carbonate rocks containing the principal limestone resources in Missouri. The largest tonnages of stone produced annually in the State are quarried from this large area. Mississippian strata are present throughout; the main Devonian outcrop area is in the central and northeast counties; Silurian formations are restricted to two small areas in the northeast and southeast; and Ordovician rocks crop out along the Mississippi and eastern part of the Missouri Rivers (fig. 2 and table 15). Thickness of individual units ranges from 25 to more than 200 feet.

High-calcium limestone is present in the St. Louis, Salem, Burlington, and Kimmswick in eastern Missouri and in the Warsaw, Keokuk, and Burlington in the southwest. Stone suitable for higher type aggregate, such as portland cement concrete, is quarried mainly from the St. Louis, Burlington, Callaway, Kimmswick, and Plattin in eastern and central Missouri and from the Warsaw, Keokuk, and Burlington in the southwest. The Burlington Limestone is by far the most widely quarried unit in the State. The major drawback to even more extensive utilization of the Keokuk and Burlington limestones is the high percentage of chert present throughout both formations. The resources of the area are more than adequate for the majority of crushed stone uses. Chemically pure high-calcium stone is restricted both stratigraphically and geographically. Such resources are not inexhaustible but are ample for long-range future needs.

Area 3.—The carbonate rocks of this area, which covers over one-third of the State and is the main area of the Ozarks, are predominantly dolomite. The principal stone resources are in the Cotter, Jefferson City, and Gasconade Dolomites of the Ordovician and the Eminence, Potosi, Derby-Doerun, and Bonneterre Formations of the Cambrian System (table 15). The majority of quarries produce stone from the Cotter and Jefferson City Dolomites. Limestones are essentially absent in the area; however, dolomitic limestone and limestone are present in certain areas in the Bonneterre. Chert is present in all of the Ordovician formations. Over parts of the southern and southeastern Ozarks, a thick residual cover of clay, with chert and sandstone rubble, blankets much of the bedrock. Production of aggregate for portland cement concrete has been limited to that from the Potosi and Bonneterre formations at a few localities. Nearly all of the dolomites are satisfactory for aggregate in asphaltic concrete and bituminous surfacing, base stone, surfacing, aglime, and riprap. The resources of this area for crushed and broken stone uses, other than portland cement concrete, are far in excess of any anticipated demands and may be considered virtually inexhaustible.

In the Southeast Lowlands region of the State, carbonate rocks are restricted to the northern flank of Crowley's Ridge and a few isolated hills in northern Scott (Everton, Dutchtown, Joachim, Plattin and Kimmswick formations) and northern Stoddard (Jefferson City and Cotter Dolomites) Counties. Elsewhere in this area, the Paleozoic strata are covered by thick deposits of Cretaceous, Tertiary, and Quaternary clay, silt, sand, and gravel.

Outlook

Judging from the annual increase in production during the past 5 years, the statement "Crushed stone—Soaring in the sixties" (Rock Products, January 1964) does not seem too optimistic for this industry in Missouri. Reserves present throughout the greater part of the State will meet any foreseeable demands and additional resources are available. In some areas, notably the northern two-thirds of the State where near-surface supplies are being depleted, deep pit or shaft mining will be necessary to utilize local deposits. In parts of this area, coal strip pits are also serving as quarries with the tandem production of stone and coal. With the possible exception of Kansas City and St. Joseph, adequate supplies of carbonate rock are present adjacent to the major population centers. However, further detailed geologic investigations will be required to evaluate completely the tonnage and quality of the limestone and dolomite resources of the State.

DIMENSION STONE

(By L. D. Fellows, Missouri Geological Survey & Water Resources, Rolla, Mo.)

Rock that is broken, split, or sawed into blocks or slabs is known as dimension stone. Dimension limestone and dolomite, used principally as building stone, are sold as rubble, rough construction stone, rough architectural stone, and finished (cut or sawed) stone, depending on the type of finish given. Rubble is the least finished type.

Although limestone and dolomite are present at or near the surface in many parts of the State, few formations meet the requirements for use as dimension stone. In general, rock to be used cannot have fractures or joints that prevent it from being quarried or cut into blocks of desired size, yet it must be easy to split. The rock must be durable, that is it must resist weathering, atmospheric acids, abrasion, and cleaning solutions. Its color must be attractive, long lasting, and currently in demand. Minerals that oxidize and make stains (e.g. pyrite, marcasite, and sphalerite) cannot be present. Texture and grain size should be uniform. Color and uniformity of texture and grain size are largely esthetic properties and change in importance. The physical properties of some of the limestone and dolomite used for dimension stone in Missouri were described in more detail by Buckley and Buehler (1904).

Limestone and dolomite have been quarried in Missouri since settlement began. Many of the first houses had stone foundations and chimneys and some were built entirely of stone. Slabs of limestone and dolomite were also commonly used for sidewalks, curbing, paving blocks, and monuments. Dimension limestone and dolomite have considerably different uses today than they did in the early 1900's for, whereas they were originally used to support the weight of an entire building, today they are used almost exclusively as exterior and interior veneer. Dimension limestone and dolomite are used most commonly for floor, walls, steps, window sills, wainscoting, and baseboards.

The total domestic output of dimension limestone in 1964 was 779,236 tons valued at $18,943,710. Of this, Missouri produced 21,380 tons valued at $73,923. (fig. 30). Missouri ranked fifth in tonnage produced but was eighth in value of output because most of its dimen-

sion limestone is sold as rubble. The above figures do not include the value of stone that was purchased from the quarryman, finished, and resold. Output was at an alltime high around 1910 but has declined greatly since then, largely because of the increased use of concrete.

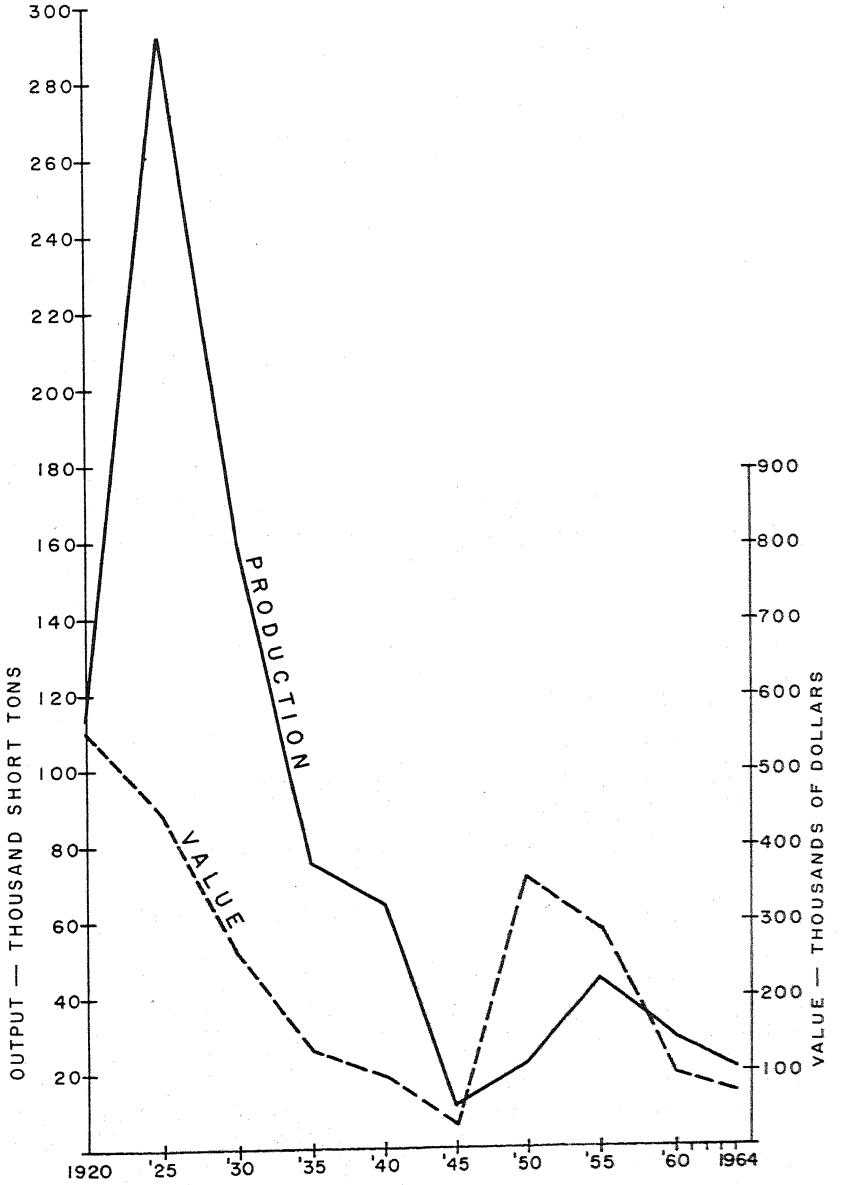
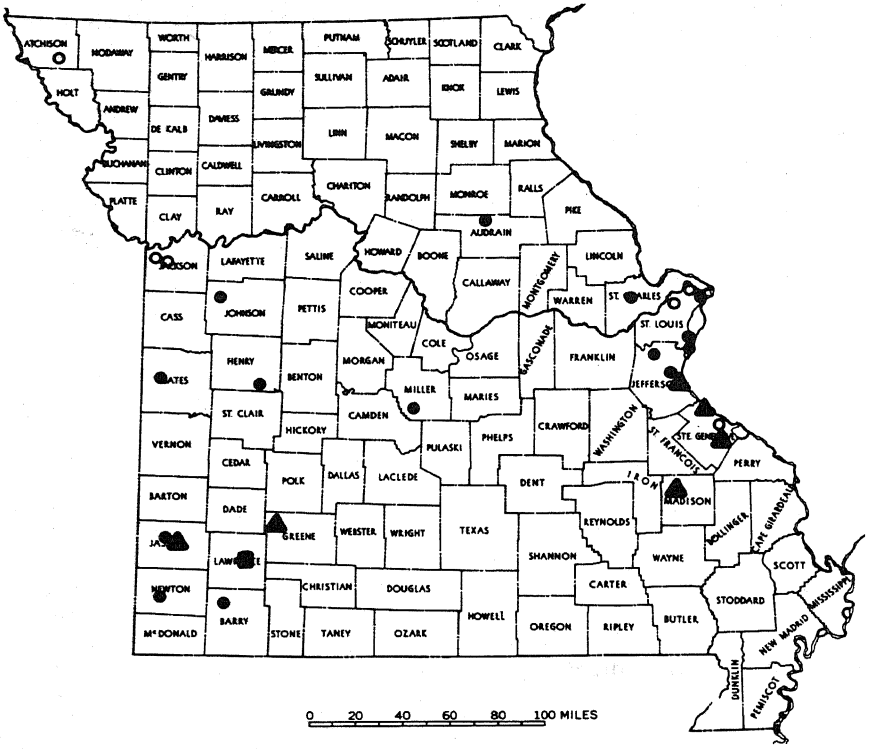


FIGURE 30.—Production and value of dimension limestone and dolomite in Missouri, 1920–64.

Dimension limestone or dolomite was quarried in Jackson, Lawrence, Ste. Genevieve, and St. Louis Counties in 1964 (fig. 31). Formations



—LEGEND—

- ● QUARRY FROM WHICH DIMENSION LIMESTONE WAS PRODUCED IN 1964.
- ■ QUARRY FROM WHICH DIMENSION DOLOMITE WAS PRODUCED IN 1964.
- o QUARRY FROM WHICH DIMENSION LIMESTONE OR DOLOMITE HAS BEEN PRODUCED SINCE 1950 BUT WHICH IS NOT CURRENTLY IN USE.
- ▲ QUARRY FROM WHICH DIMENSION AND/OR CRUSHED MARBLE WERE PRODUCED IN 1964.

FIGURE 31.—Quarries in Missouri that produce dimension limestone, dolomite, and marble.

currently being quarried include the Cotter Dolomite, Plattin Formation, St. Louis Limestone, and Westerville Limestone Member of the Cherryvale Formation (table 16). Generalized descriptions of the formations may be found in Howe and Koenig (1961). (See also table 15.)

Rock units formerly quarried for local use include the Derby-Doerun Dolomite, Bonneterre Formation, Jefferson City Dolomite, Kimmswick Formation, Edgewood Formation, Little Saline Limestone, Grand Tower Limestone, Burlington Limestone, Keokuk Lime-

stone, Salem Formation, Higginsville Formation, Raytown Limestone Member of the Iola Formation and the Argentine Limestone Member of the Wyandotte Formation. Some of these units did not furnish high-quality dimension stone but had extensive use because they were available locally and were relatively inexpensive. For example, the Argentine, which is thin bedded and weathers to an unattractive color, has been used widely in Kansas City in building and retaining walls and as curbing and flagging.

TABLE 16.—*Summary of dimension limestone quarrying in Missouri*

Company	Location [1]	County	Units quarried	Geologic age
George & Clark Stone Contractors.	48N-32W:6	Jackson	Westerville Ls. Mbr., Cherryvale Fm.	Pennsylvanian
Gerald Hodgins Building Rock Quarry.	48N-32W:6	do	do	Do.
Republic Stone Co	28N-25W:27	Lawrence	Cotter Dol	Ordovician.
Riverview Stone & Material Co.	48N-6W:34	St. Louis	St. Louis Ls	Mississippian.
West Lake Quarry & Material Co.	46N-5E:3	do	do	Do.
Roth Building Stone Co	38N-8E	Ste. Genevieve	Plattin Fm	Ordovician.

[1] Township, range, and section shown by abbreviated notation used by Missouri Geological Survey and Water Resources.

Missouri has an almost inexhaustible supply of the rock currently being quarried as dimension limestone and dolomite as well as that which has been quarried in the past. The future of the industry is dependent on the amount of competition provided by concrete and synthetic veneers, the ability of the industry to meet competition and, to some extent, changes in architectural styles.

MARBLE

(By L. D. Fellows, Missouri Geological Survey and Water Resources, Rolla, Mo.)

As defined by the dimension stone industry, marble includes four kinds of rock: (1) metamorphosed limestone and dolomite (the marble of technical definition), (2) limestone and dolomite that take a high polish but that have not been metamorphosed, (3) onyx marble, and (4) serpentine marble (Bowles, 1960, p. 330). Onyx marble, also called Mexican onyx or cave onyx, is calcium carbonate that precipitated from cold-water springs. Travertine, calcium carbonate that precipitated from hot springs, is also included with the onyx marbles. Serpentine is a metamorphic rock that is not high in calcium carbonate. Rocks included in this commercial definition of marble have little in common except their use.

Marble quarried in Missouri and described below is limestone that has not been metamorphosed. Cave onyx was sold in Missouri at one time but is no longer being mined. Both crushed marble and dimension marble, that which is shaped into blocks or slabs, are produced in Missouri. Dimension marble is used for building stone, memorials, statuary, and novelties. As building stone, it is commonly used for walls, floors, stairs, balusters, baseboards, toilet compartments, window stools, and columns. Crushed marble is used for terrazzo, aglime, as-

phalt filler, concrete aggregate, roadstone, poultry grit, roofing, stone sand, stucco, and whiting.

Marble from Missouri has been used on the interior of buildings throughout the United States, including the National Art Gallery, the National Academy of Sciences Building, the Interstate Commerce Commission Building, the Department of Commerce Building, and the National Archives Building in Washington, D.C., and in Rockefeller Center, the New York Stock Exchange Building, the American Telephone & Telegraph Building, the Bank of America Building, and the Standard Oil Co. Building in New York. These are but a few of the buildings containing Missouri marble that were included in the list by Hinchey (1946).

Missouri ranked third in tonnage of crushed marble and fifth in value of dimension marble produced in the United States in 1964. Production and values of dimension marble and crushed marble sold or used by producers in Missouri during representative years from 1920 to 1964 are listed in table 17. Values of rough dimension stone that has been finished and resold are not included in the totals.

TABLE 17.—*Production and value of dimension and crushed marble sold or used by producers in Missouri during representative years from 1920–64*

Year	Dimension marble		Crushed marble	
	Short tons	Value	Short tons	Value
1920		[1] $616,550		
1925	59,880	1,439,604	2,400	$2,963
1930	31,070	839,616	17,630	11,721
1935	7,320	175,985	6,420	3,827
1940	14,180	375,209	12,860	17,553
1945	3,840	282,616	960	1,810
1950	5,170	639,335	8,000	103,800
1955	[2]	[2]	8,500	102,000
1960	[2]	[2]	[2]	[2]
1964	[2]	[2]	[2]	[2]

[1] Total value of dimension and crushed marble.
[2] Withheld to avoid disclosing individual company confidential data.

Rock to be quarried as dimension marble cannot have fractures or joints that prevent it from being cut into blocks of desired size. Its color must be attractive and long lasting and its texture should be uniform. The rock must be resistant to weathering, atmospheric acids, cleaning solutions, and abrasion. Minerals that oxidize and stain the rock (e.g., pyrite, marcasite, and sphalerite) cannot be present. Finally, the rock must be of sufficient density to take a high polish. The latter property is important in determining whether the limestone in Missouri can be classed as dimension limestone or marble. The composition and physical properties of Missouri marble were described more fully by Hinchey (1946).

In 1964, marble was quarried by the Carthage Marble Corp. in Jasper and Greene Counties, by the Marble Products Co. of Georgia in Jefferson and Madison Counties, and by the Tennessee Marble Co. and the Weiler Marble Co. in Ste. Genevieve County (fig. 31 and table 18). Dimension marble was produced from three quarries, crushed marble from two quarries, and both dimension and crushed marble from one quarry.

Rock formations currently being quarried are the Bonneterre, Plattin, Kimmswick, Little Saline, Grand Tower, Keokuk, and the Warsaw. Howe and Koenig (1961) described these formations and their areal distribution more fully. (See also table 15.)

TABLE 18.—*Summary of marble quarrying in Missouri*

Company	Location [1]	County	Stone produced	Formations quarried	Geologic age
Carthage Marble Corp.	29N-31W:33.	Jasper	Dimension, crushed	Warsaw Fm.	Mississippian.
Do.	31N-24W:35.	Greene	Dimension	Keokuk and Burlington Ls.	Do.
Marble Products of Georgia.	41N-6E:19.	Jefferson	Crushed	Plattin Fm.	Ordovician.
Do.	33N-5E:36.	Madison	do.	Bonneterre Fm.	Cambrian.
Tennessee Marble Co.	36N-9E:5.	Ste. Genevieve.	Dimension	Little Saline and Grand Tower Ls.	Devonian.
Weiler Marble Co.	39N-7E:24.	do.	do.	Kimmswick Fm.	Ordovician.

[1] Township, range, and section shown by abbreviated notation used by Missouri Geological Survey and Water Resources.

Dimension marble is sold as rough building stone, dressed (cut or sawed) building stone, and rough monument stone. As much as 80 to 90 percent of the rock in a dimension marble quarry cannot be cut into blocks and is commonly crushed and sold.

Although only a few rock formations can be used for marble, Missouri has a supply that will last for many years. No estimates of reserves are available. Future production will depend on the amount or competition provided by synthetics and other types of stone as well as the ability of the industry to meet competition. Competition from foreign stone is increasing.

METALLURGICAL LIMESTONE

(By Eva B. Kisvarsanyi, Missouri Geological Survey and Water Resources, Rolla, Mo.)

A considerable amount of limestone is used as a flux in extractive metallurgy in the process of recovering metals from their ores and in steelmaking. The widest use of limestone flux is in blast- and basic open-hearth furnaces, but it has found application in nonferrous metallurgy as well, such as in the smelting of copper, lead, zinc, and antimony ores (Bowles, 1929).

The purpose of adding fluxing stone to the blast-furnace charge is that its constituents will combine with the impurities in the iron ore, chiefly silica and alumina, to form a liquid slag that floats on the surface of the molten iron and can be easily removed. It also forms a slag with the ash produced by the blast-furnace fuel, and removes sulfur from the metal. In basic open-hearth furnaces the chief function of flux is to remove phosphorus and sulfur from the melt.

The chemical properties of the stone used for flux are of prime importance. Generally, it should be low in iron, alumina, sulfur, phosphorus, and other deleterious impurities, and should be easily calcined

in the furnace. Required physical properties are fineness of grain size and strength. It should be crushed to meet certain size distribution requirements and the fines should be removed. Most manufactures require a rock that holds its lump form until consumed in the melt. Table 19 summarizes the specifications of fluxing stone by the major types of consuming plants.

In 1964, sales of fluxing limestone in the United States amounted to 31,454,000 short tons valued at $44,511,000. About 71 percent of the total amount was sold for blast-furnace use, 17 percent for open-hearth use, and the remaining 12 percent for use in copper, lead, and zinc smelters, foundries, and in cupola and electric furnaces. Sales of fluxing limestone in the United States for the period between 1954 and 1964 is shown in table 20.

The amount of fluxing limestone sold to blast furnaces declined from an average of 77 percent of the total sales in the period 1954-58 to about 57 percent in 1962, but increased to 68 percent in 1963 and to 71 percent in 1964. The decrease of sales is partly a reflection of the decline in the pig-iron production during the years 1957–60. Sales to open-hearth plants remained relatively stable during the same period in spite of the increased proportion of steel output by the basic oxygen process that uses lime as the fluxing agent. In 1964, blast furnaces consumed an average of 0.274 ton of fluxstone for each ton of pig iron produced, compared with 0.284 ton of limestone in 1963. This decrease was caused by the improved grade of iron ore agglomerates used in the charge.

TABLE 19.—*Specifications of limestone for use as a flux by the principal types of consuming plants*

Use	Minimum required percentage	Maximum allowed percentages					Size range (inches)	Remarks
	$CaCO_3$	MgO	SiO_2	Al_2O_3	P_2O_5	S		
Blast furnace	70.0–80.0	4.0–15.0	5.0	2.0	0.005	Trace	2 x ½ (minimum) 6 x 3 (maximum)	Limestone and magnesian limestone are both acceptable Some plants use dolomite
Open-hearth furnace	90.0+	5.0	1.0–2.0	1.5	0.005	Trace	5 x 8 (minimum) 5½ x 11 (maximum)	High calcium limestone is required
Other smelters	High		Low				Smaller than above	

Source: Gault and Ames, 1960.

TABLE 20.—*Sales of fluxing limestone in the United States*

Year	Quantity (thousand short tons)	Value (thousand dollars)
1954–58 (average)	35,204	47,795
1959	28,206	40,442
1960	31,415	45,082
1961	27,198	39,725
1962	26,081	36,821
1963	27,185	39,322
1964	31,454	44,511

Source: U.S. Bureau of Mines Minerals Yearbooks.

Fluxing stone was produced by two operators in Missouri during 1964, one each in St. Louis and Ste. Genevieve Counties. West Lake Quarry and Materials Co. quarried the St. Louis Limestone of Mississippian age in northern St. Louis County. The formation occurs at the surface in the city of St. Louis and in parts of St. Louis, Lincoln, St. Charles, Jefferson, and Ste. Genevieve Counties in thicknesses exceeding 100 feet. It is a gray, dense, commonly lithographic limestone that is generally free of chert. It is exposed over parts of northeastern and southwestern Missouri (Dade County) and is encountered in the subsurface beneath Pennsylvanian sedimentary rocks as well, but its thickness there is generally not more than 50 feet and the limestone is frequently brecciated.

In east-central Missouri, the St. Louis Limestone is quarried for the manufacture of cement, for dimension limestone, concrete aggregate, riprap, fluxing stone, and for agricultural use. Chemical analyses of representative sections of the formation were published in 1947 (Hinchey, et al.). These indicate several tens of feet of rock running about 95 percent $CaCO_3$ and low in iron and alumina. The amount of silica varies from less than 1 percent to as much as 3 percent.

The major product of Mississippi Lime Co.'s plant in Ste. Genevieve County is lime, but fluxing stone, agricultural limestone, and crushed stone for concrete aggregate were also produced during 1964. The Salem Formation of Mississippian age is mined at the plant site. Inasmuch as this formation contains economically significant beds of high-calcium limestone, its areal distribution and characteristics are discussed in the section on lime.

MINERAL WOOL

(By Eva B. Kisvarsanyi, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Mineral wool is a general term designating insulating materials composed of silicates in the form of fine glassy fibers. This all-inclusive term includes rock wool made from rock, slag wool made from blast-furnace slag, and glass wool. Dolomite, limestone, calcareous shale, and sandstone have been used in the manufacture of rock wool in the United States. The industry got its start in Indiana during the early 1900's where siliceous limestones were first utilized. Until World War II, siliceous rocks were the major source of raw material, but since 1946, the use of slag has largely replaced natural wool rock in almost all plants.

In the usual methods of manufacture of mineral wool from natural rock material, the quarried rock is crushed to particles of 1 inch size or smaller. Further steps include melting, fiber forming, collecting, and in some instances, fabricating. Melting takes place in a cupola cooled by water jacket and lined with slag. During melting, the carbon dioxide content of the rock is expelled, and the calcium and magnesium oxides combine with the silica present to form an impure molten slag. The molten mass is poured from the cupola into a blast of air or steam where a light fluffy mass, minutely hairlike or fibrous in nature, is formed.

Mineral wool products must meet certain specifications set up by the ASTM, the General Services Administration, and the U.S. Department of Defense regarding conductivity, density, and compressive strength. Its thermal conductivity must be below 0.40 Btu per square foot per hour per degree F. at 1 inch thickness. Density requirements vary from one-half to 20 pounds per cubic foot depending on the product. Compressive strength must be enough to resist deflection at 500 pounds per square foot.

The principal use for mineral wool is as heat and sound insulation for the building industry. The wool is marketed loose, granulated, in batts, blankets, felts, boards, and blocks. In loose, granulated or batt form, the wool is used for fill in hollow spaces in frame houses and buildings. Blankets of wool are used to insulate railway cars and trucks. Felts are used for thermal insulation in a variety of equipment such as ovens and refrigerators. Boards and blocks are of high density, resulting from mixing the wool with clay or organic binders, and they are used in a manner similar to felts. Mineral wool is also formed into strips for use as pipe insulation. Insulating cements are manufactured from wool granules, clay, and powdered binders. Refractory wool products for application at temperatures above 2000° F. are made by mixing a highly siliceous wool rock with alumina before blowing it into fibers.

Natural wool rock not requiring the addition of other materials to yield mineral wool must contain 40 to 65 percent calcium carbonate (or calcium-magnesium carbonate) and 60 to 35 percent silica and alumina. It should yield a minimum of fines upon crushing so as to allow free passage of air and gas through the cupola during manufacture. A natural wool rock occurs in the Easley area, Boone County, where the dolomitic Sedalia Formation of Mississippian age has been used to produce mineral wool. The Sedalia Formation is typically an argillaceous, magnesian limestone or dolomite, brownish or bluish gray in color. It occurs in massive beds which weather into smooth, rounded surfaces; chert nodules are present locally. The Sedalia is exposed throughout southern Boone County, northeastern Moniteau County, western Cooper County, and eastern Pettis County. The thickness of the formation in these areas varies from 13 to 27 feet.

McQueen and Aid (1937) obtained 92 chemical analyses of the Sedalia Formation from 14 localities in Boone, Moniteau, and Cooper Counties to evaluate its suitability as a natural wool rock. They found that the carbon dioxide (CO_2) content constitutes a simple and convenient method for classifying the rock. Limestone having a CO_2 content between 20 and 30 percent makes a satisfactory wool rock. Limestones with 15 to 20 and 30 to 38 percent CO_2 are classified as

"sub-wool-rock," indicating they are composed predominantly of wool rock, but require the addition of moderate quantities of other rock materials to produce mineral wool. The 92 analyses from the Sedalia Formation range from 20.81 to 38.40 percent CO_2.

Commercial tests from quarries at Sweeney, Cooper County, and at Easley indicated that a good grade of mineral wool could be produced from the Sedalia Formation at these localities, and, in the late 1930's, the Columbia Rock Wool Sales Corp. constructed the Easley plant. Mineral wool was produced for several years, but the plant was destroyed by fire in 1943 and operations were not resumed until after the war. Statistical data are not available for the early years; the State Division of Mine Inspection in its annual report for 1949 reported 1,700 tons of limestone products, valued at $63,000, produced at the Easley plant. In 1950, production amounted to only 600 tons valued at $1,500. Since 1950, no mineral wool has been produced from natural wool rock in Missouri.

Rockwool was produced in the Kansas City area (Jackson County) between 1930 and 1942 by the Federal Rock Wool Co. A mixture of unspecified limestone and residuum was used. Production amounted to about 12 to 15 tons of wool per day.

The Eagle Picher Co. at Joplin, Jasper County, has for years produced mineral wool from smelter slag and mill chats from lead-zinc operations in the Tri-State District. However, as production statistics for mineral wool have not been compiled by the U.S. Bureau of Mines in recent years, no figures are available.

The natural wool rock and subwool rock resources of central Missouri are very extensive. But, as these raw materials must compete with byproduct slags of existing operations, they are at an economic disadvantage in most areas. It is, therefore, unlikely that Missouri limestones and dolomites will be utilized as mineral wool raw materials in the foreseeable future.

SANDSTONE

DIMENSION AND BROKEN

(By L. D. Fellows, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Sandstone is a sedimentary rock composed of mineral grains ranging in size from 1/400th to 1/12th inch in diameter. Most Missouri sandstones are composed of quartz grains cemented by a carbonate mineral or quartz. Dimension sandstone is that which is shaped into blocks or slabs rather than being broken or crushed.

Good quality dimension stone must be durable but must not be too hard to work. In other words, sandstone that is poorly cemented cannot be used, whereas that composed of grains of quartz cemented together with quartz may be too hard to be profitably cut into blocks. Some sandstone in Missouri is well cemented near the surface but poorly cemented below. This phenomenon, known as case-hardening, is the result of repeated wetting and drying, which causes minerals to precipitate from solution in water and cement the sand grains together more firmly. Although color should be attractive and long lasting, sandstone of unattractive color has been used because it was available locally.

Dimension sandstone has been used for foundations, chimneys, retaining walls, bridge abutments, culverts, sidewalks, patios, and veneer on houses, garages, and small stores. Sandstone broken into large chunks has had extensive use as riprap, particularly along the Missouri River. Sandstone quarried in Missouri has been used in the Eads Bridge and many buildings in St. Louis, the Iowa State Capitol at Des Moines, and a number of county courthouses in Missouri, Iowa, Kansas, and Nebraska (Buckley and Buehler, 1904, p. 277).

The most productive years for the dimension sandstone industry were prior to 1910. During the early 1900's, it had extensive use as veneer for houses and other small buildings. By the late 1920's very little dimension stone was used, but the production of sandstone for use as riprap had increased greatly. Many small quarries have been developed, used, and abandoned through the years. In 1964, 2,208 short tons of dimension sandstone valued at $29,239 was produced in Missouri. Missouri ranked tenth in the Nation in tonnage but produced only 1/200th of the total U.S. output.

In 1964, dimension sandstone was produced by Ozark Stone Products, Inc. in Shannon County (Roubidoux Formation) and by the Missouri Native Stone Corp. in Vernon County (Warner Formation). Sandstone broken for use as riprap was produced by the Mid-Continent Stone & Construction Co. in Platte County (Tonganoxie Sandstone Member of the Stranger Formation) in 1964 and Saline County (Lagonda Formation) in 1963. Other rock units that have been used as dimension stone in Missouri include the Gunter Sandstone Member of the Gasconade Dolomite, the Aux Vases Sandstone, and the Warrensburg Sandstone. Figure 32 shows the locations of the above quarries as well as others that have been worked since 1950 but are now abandoned.

Missouri has an almost inexhaustible supply of sandstone. Future demand for dimension sandstone will depend on architectural styles and on the competition from concrete and dimension limestone and dolomite. Only local use for dimension sandstone in Missouri can be predicted.

The Roubidoux Formation probably has more potential for use as dimension sandstone than any other formation in the State. However, in 1964 dimension sandstone was produced from only one quarry in the Roubidoux in spite of its large outcrop area. In the past, dimension stone has been obtained from many small quarries in it. Conceivably the Roubidoux might have increased use as dimension sandstone within or adjacent to its outcrop area.

ASPHALTIC

(By W. V. Searight, Missouri Geological Survey and Water Resources, Rolla, Mo.)

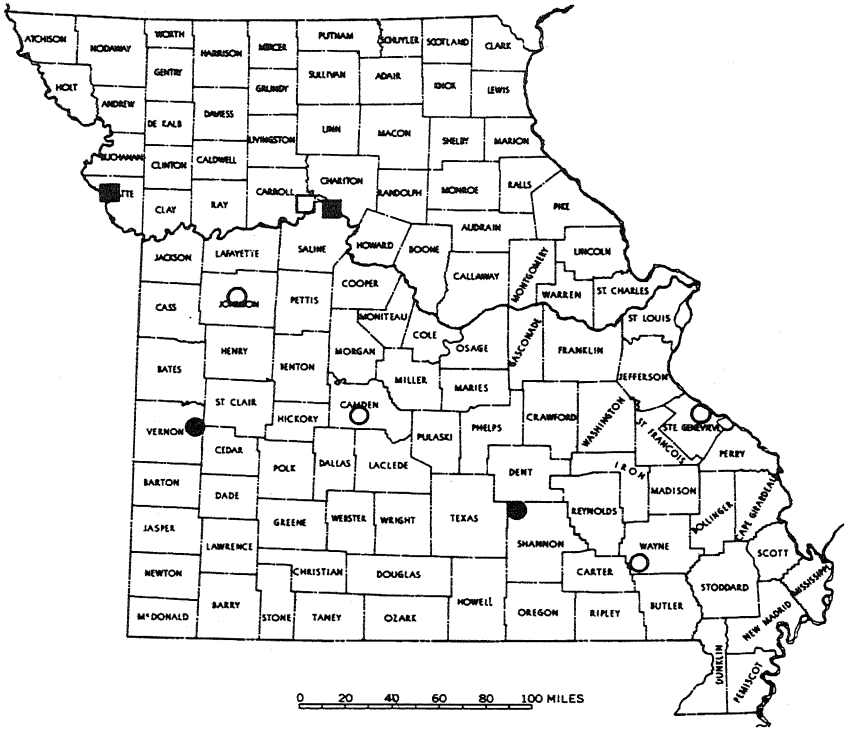
Sandstones and limestones impregnated with more or less bituminous matter lie at or near the surface in 21 or more counties in western Missouri. (Searight, 1957.) (See fig. 56, p. 249 for the general distribution.)

The bituminous matter is a residue derived from petroleum which has lost most of the volatile aromatics by evaporation and chemical change. The bituminous content of the sandstone is as much as 15.2

77-278 O—67——11

percent by volume or 6.4 percent by weight. The actual asphaltic constituents are less than 25 percent of the total bituminous matter.

The sandstones of the Krebs Subgroup of the Cherokee Group (table 1, p. 16) are the best known, and the most readily available, particularly the sandstone of the Bluejacket Formation, in Vernon and Barton Counties.



—LEGEND—

● QUARRY FROM WHICH DIMENSION SANDSTONE WAS PRODUCED IN 1964.

○ ABANDONED DIMENSION SANDSTONE QUARRY.

■ QUARRY FROM WHICH SANDSTONE WAS PRODUCED FOR USE AS RIPRAP IN 1963-1964.

□ ABANDONED SANDSTONE QUARRY FROM WHICH RIPRAP WAS PRODUCED.

FIGURE 32.—Quarries in Missouri that produce dimension sandstone.

One plant has operated on a small scale in processing asphaltic Bluejacket sandstone in Barton County as paving material. The sandstone is crushed and heated and more asphalt is added as binder. A new plant is in operation in eastern Vernon County near Sheldon.

Continuity of sands from area to area has not been established, but several areas in Vernon and Barton Counties are underlain by as much as 30 feet of the rock. Millions of tons are doubtless available if the demand develops.

GRANITE AND FELSITE

DIMENSION

(By L. D. Fellows, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Granite and felsite are rocks of igneous origin, that is, they cooled and solidified from a molten state. Both are composed largely of the minerals orthoclase and quartz, although other minerals are present in variable amounts. The rock types differ mainly in the size of the constituent mineral grains. Most mineral grains in granite, although not necessarily of uniform size, can be identified without the use of a microscope; those of felsite, however, generally cannot. Granite and felsite of Precambrian age crop out in and adjacent to the St. Francois Mountains in a nine-county area in southeastern Missouri (fig. 33).

Only a small percentage of granite meets the requirements for use as dimension stone, that which is shaped into slabs or blocks rather than being crushed. Dimension stone must have pleasing color and uniform texture. Inclusions, "knots" of dark minerals, and dikes are detrimental to polished surfaces. Pyrite, which oxidizes and stains the rock, is undesirable. The rock must not have fractures or joints that are spaced so closely that large blocks cannot be quarried.

Granite quarried in Missouri is red, has uniform texture and color, and takes an excellent polish. Gray, pink, and deep red granites are also present but are not being quarried. Buckley and Buehler (1904, pp. 60–85) described the properties of Missouri granite in detail.

Granite quarrying began in southeastern Missouri before 1869. Both gray and red granite were quarried. According to Buckley and Buehler, 15 quarries were active in 1904 or shortly before. Most of them were small and were abandoned in the early 1900's.

From 1900 to 1930, large quantities of gray and red granite paving blocks were shipped to St. Louis, where many are still in use. The demand for paving blocks decreased steadily because of the increase in use of concrete; such blocks have not been produced since about 1940.

Red granite from Missouri has been used as monument stone in every part of the United States, including Vermont, which is one of the leading producers of granite in the Nation (Bishop, 1949, p. 77). Red Missouri granite and gray Vermont granite make an attractive combination when used together.

Red granite also has had considerable use as building stone. Some of the buildings in which it was used were listed by Buckley and Buehler (1904, pp. 74–75). Gray granite had local use as building stone in the early 1900's. Although dimension granite was originally used to support the entire weight of buildings, today it is used largely as decorative veneer in prestige buildings. This change is largely the result of the increased use of concrete and structural steel.

Small quantities of granite have been sold as dressed monument stone, dressed construction stone, and rubble. Spalls and imperfect blocks have been used as riprap or have been crushed and used for concrete aggregate or roadstone.

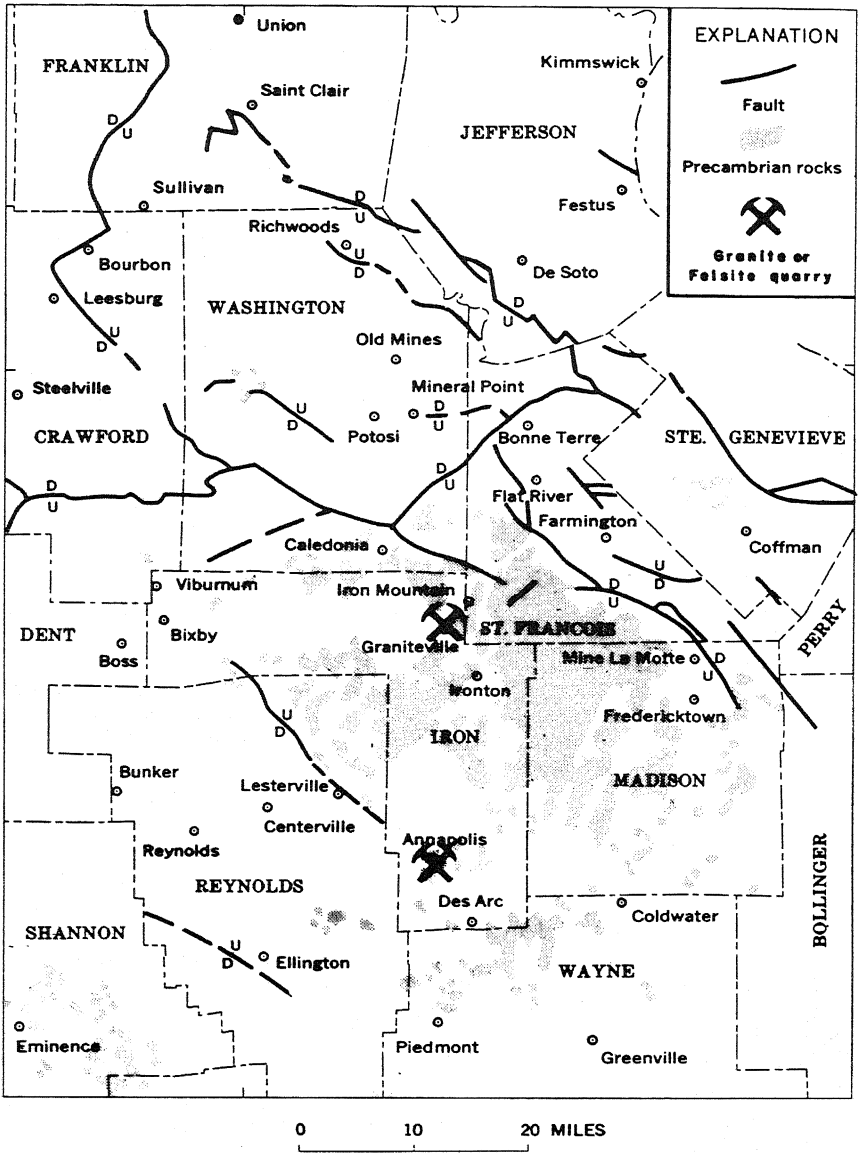


FIGURE 33.—Granite and felsite in Missouri.

In 1965, granite was produced from two quarries, both of which are at Graniteville in Iron County (fig. 33). One of them has been in continuous operation since 1884. Both crushed and dimension stone are produced.

Production and value of dimension granite, which includes building and monumental stone, sold or used by producers in Missouri from

1935 to 1965 are shown in figure 34. The maximum production of dimension granite was attained from 1900 to 1930 when both monumental stone and paving blocks were in demand. For example, in 1925 producers in Missouri sold or used 10,750 short tons valued at $131,748 compared with 3,226 short tons valued at $292,228 in 1964. Missouri ranked 12th in tonnage and 10th in value of domestic output in 1964. Values of stone purchased from quarrymen, finished, and resold are not included in figure 34.

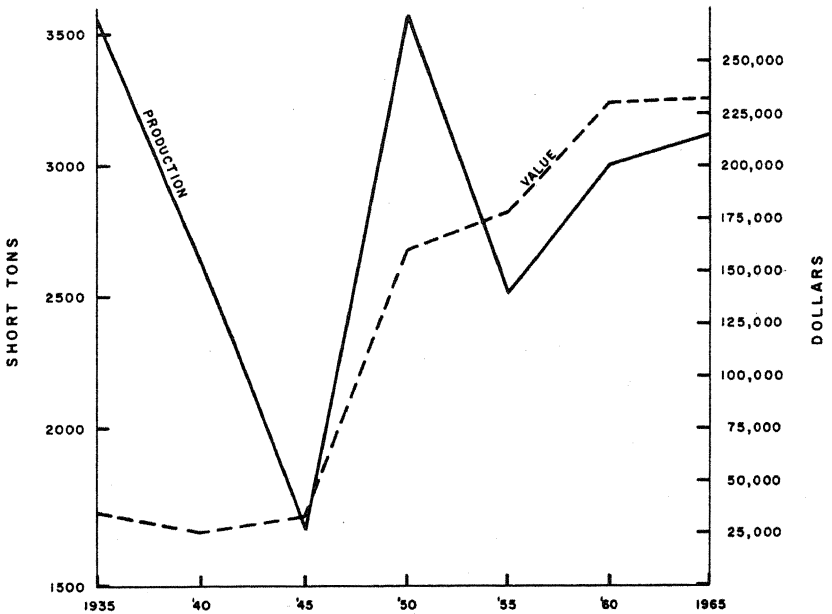


FIGURE 34.—Production and value of dimension granite in Missouri, 1935–65.

Until recently, felsite has had little use as either dimension or crushed stone. Although it has pleasing colors that range from black and dark purple through chocolate brown and red to pink, it is so thoroughly fractured or jointed that large blocks cannot be obtained. Much of the rock is porphyritic, containing visible crystals of feldspar and quartz. The rock is commonly iron-stained along joints.

Buckley and Buehler (1904, p. 83–84) described three felsite quarries near Piedmont in Wayne County that were in operation around 1900. Small quantities of felsite have had local use as building stone and paving blocks. Felsite, a finer grained rock than granite, wears to a smooth surface and therefore was less desirable for paving blocks.

Missouri red granite has been used for almost one hundred years, and has an excellent reputation as monument stone. Although no estimate of reserves is available, one can safely say that at the present rate of production, the State has enough to last for many years. Areas of gray or pink granite, which have had little use as either dimension or crushed stone, could be developed.

ROOFING GRANULES

(By D. M. Larrabee, U.S. Geological Survey, Washington, D.C.)

Introduction.—Roofing granules are stone particles that have been crushed and screened, commonly to between 10 and 35 mesh (Tyler standard screens, see table 29, page 200), and the sized particles carefully blended to give maximum coverage of the asphalt that binds them to asphalt-impregnated "felt" (Brown, 1960). This kind of roofing is often referred to as "mineral surfaced" roofing, and is applied in either strip shingle or roll form. The chief purposes of the stone are to prevent ultraviolet light from breaking down the asphalt with resultant failure of the roofing material, and to fireproof the exposed roof surface. Theoretically any rock that meets rather rigid requirements, regardless of color, might be used.

In contrast to granules, and often confused with them, are roofing "gravels" or roofing "chips." These terms apply to naturally colored, coarsely crushed (one-fourth inch and larger) gravel or stone that is rolled or pressed into the top dressing of hot asphalt on built-up roofing commonly used on flat or exceptionally low-pitched roofs. The purposes of "gravel" primarily are the same as those of granules—to protect and fireproof the asphalt that provides a waterproof roof. White is the predominant color used today to reflect light and reduce heat absorption. Marble, dolomite, limestone, quartzite, chert, gravel, slag, and some varieties of coquina are used for "gravel." Natural white, buff, brown, red, and green "gravels" are marketed locally, especially in parts of California where a variety of such colored rock is available.

In order to brighten the appearance of roofs, certain naturally colored rocks were used in the early days of the roofing granule industry; these rocks were chiefly red, green, and purple slates, greenstone, purplish aporhyolite, and buff chert. Black slate granules also were used because of the prevalence of black slate shingles on many buildings since the 1800's. Colored slag and crushed brick have been used; granules also were made from common clay or fire clay baked in multiple hearth (vertical) furnaces. Slate was preferred by many roofing manufacturers, not only for its natural color but also for the flat particles resulting from its cleavage; this shape was believed to provide better coverage for the asphalt. This rock was preferred also because of the long association of the term "slate" with roofs in the minds of homeowners; many roofers continue to refer to all granules as "slate," regardless of their true nature. The fact that a ton of flat slate granules covered more square feet of roofing than a ton of equidimensional granules, at a consequent lower cost per square (100 square feet of roof surface), was not overlooked by the manufacturers of the finished roofing product.

Slate is no longer used in quantity as a granule on the exposed part of roofing, partly because of the accentuated tendency to form "rights and lefts" or "shading", especially in natural black slate, where strip shingles are not properly applied on the roof. Most slate particles, having a strong tendency toward flatness, are rolled onto the asphalt base facing slightly in one direction; when the shingles are cut, the granules on different shingles may face in opposite directions. Improper application results in a "patchwork" roof, some sharply defined

areas appearing to be of a shade of color different from the rest of the roof, although the colors are identical. A second reason that fewer slate granules are used now is that under some circumstances they are less firmly imbedded in the asphalt than are more angular or equidimensional granules, resulting in more shedding, i.e., a higher proportion of "drop-outs," after which the asphalt is exposed directly to the sun.

In the last 30 years, brighter colors were demanded with the result that artificially colored granules were manufactured and marketed widely; today most granules are of this type. In recent years the preference has changed from roofing of a single or "solid" artificial dark color to blends of pastel colors, white, and single light colors. Solid green, gray, black, red, brown, buff, and a few darker blends are also made. Blue is now used only in blends. White is of special importance for modern roofs of low pitch where the attic spaces are smaller and become heated in a shorter time. Today, although most roofing granules are artificially colored, some natural granules are used beneath the overlay ("headlap") of some shingles to reduce the cost, and in blends of different artificial colors.

To be suitable for artificially colored granules, rock should be hard and tough but preferably not excessively abrasive to manufacturing equipment, of uniform color, of fine to medium grain, preferably opaque or nearly so, essentially nonporous, nondisintegrating under weathering conditions, chemically compatible with the coloring process, the mineral content and texture of individual granules physically compatible with the temperature used in the coloring process, and on crushing should yield roughly equidimensional rather than flat particles. A minimum of —35 mesh fines (waste) should be produced during crushing and screening. This involves factors of hardness, toughness, grain size, nature of fracture, and efficiency of crushing and screening methods. Large quantities of any rock selected must be present in a single deposit—normally at least a 20-year supply of finished granules—and the chemical and physical properties of all rock quarried should be as uniform as possible. A light color usually is preferred over dark because less pigment normally is required to produce the popular white granules from the former. Other factors being equal, a low free-silica content is desirable to reduce the silicosis hazard to workers.

At present, the rocks generally considered best for artifically colored roofing granules are fine-grained volcanic rocks, such as some felsites and the lighter colored greenstones; coarser but entirely acceptable rocks include various porphyritic volcanic rocks, diabase, and some nepheline syenite. A few dark rocks, such as basalt, have been used. Fine-grained, light-gray or impure quartzite has proved acceptable when properly pigmented in spite of a strong trade prejudice against certain coarse-grained pure quartzites based upon the reported transmission of ultraviolet light through pigmented granules. Of the above rocks, most rhyolite, diabase, and quartzite are unusually abrasive. Massive, non-schistose rocks other than those listed above can be used but the granules may be inferior, or high-quality granules may be produced only at an increased cost. However, under certain conditions of location preference, less satisfactory base rock can be used successfully with an overall economy to the producer.

Selection of a colored roofing granule plant location requires a careful study of deposits of rock meeting the aforementioned requirements, in addition to several necessary favorable operating conditions. Such deposits are not common within a reasonable transportation distance of most large market areas by established routes, including railroads. Few areas that furnish a choice of such deposits contain locations available for quarry and mill sites, which include ample water, large areas necessary for disposal of the overburden, waste rock necessarily quarried, and fines produced during milling; this last item alone may be as much as 50 percent of the rock milled. As such rock deposits are uncommon, and reserves are governed by manmade boundaries such as railroads, highways, property lines and zoning codes, as well as by geology and topography, the search for and testing of additional suitable rock as the known reserves at an operated deposit are depleted is an extensive and expensive project.

Roofing granules in Missouri.—The earliest roofing granule industry in Missouri was an outgrowth of the production of coarse roofing "gravel" or "chips," made as early as 1913 by crushing the buff to pale brown chert gravels of the Meramec and Osage Rivers (Dake, 1918). Such crushed gravels were produced at Valley Park, Pacific, Drake, and Jedburg (Sherman), all in St. Louis County.

In the 1920's, natural granules for mineral-surfaced roofing and brick-patterned siding were produced from the same gravels at Pacific, by the Pacific Roofing & Sand & Gravel Co.; and at Jedburg by the Missouri Portland Cement Co., which was purchased in about 1927 by the Staso Milling Division of the Central Commercial Co. This latter operation was closed in 1939, and the equipment removed. At various times the huge piles of chat—waste rock from the lead-zinc mines—were investigated as possible sources of base rock for artificially colored granules, especially in southwestern Missouri where the chat is chiefly chert. However, the disadvantages of this waste material outweighed the advantages of low cost and ready transportation, with the result that chat was rejected except for some small production of natural granules or "chips" for local use, which continues at Joplin (see p. 167).

The production of roofing "chips" was reported in 1960 at Carthage, Thayer, Webb City, and Whitebear (P. O. Hannibal) from limestone or chat (Pit and Quarry, 1960). They doubtless were made elsewhere in the State from the same rock types, the production of "chips" being hidden in other classifications of crushed rock; such production continues.

In 1960 the Roofing Granule Division of the Ruberoid Co. commenced core drilling a site in T. 30 N., R. 3 E., sec. 22, about three-fourths mile southwest of Annapolis, Iron County. This preliminary drilling, completed in 1963, led to the purchase of a deposit of suitable rock. A large modern plant for the production of artificially colored roofing granules was built in 1963–65 at a cost exceeding $5 million, and the plant was brought into production in August 1965.

The deposit is in felsite that ranges from gray to reddish brown, is well banded, and contains small phenocrysts of quartz and feldspar where presently quarried. It is quarried from a new open cut, trucked

downhill to the plant, crushed, and screened to the blend of sizes required. The granules are then artificially colored by a ceramic process.

Inasmuch as any appreciable change in color of the base rock requires adjustments in the coloring process, accurate color control of both raw and colored granules is necessary. Such control has been made possible by recently developed instruments, which are used in conjunction with other methods of testing as part of the complete quality control of finished products. These tests include granule grading, disintegration, opacity, color permanence, blistering, adhesion to asphalt, staining, efflorescence ("bloom"), and sooting. In addition to laboratory testing before shipment, shingles are prepared from representative samples of all products, and exposed to long-term weathering on "test decks" at the company's Granule Division laboratory and elsewhere. The finished granules are shipped in specially built hopper-bottom tank cars or in 100-pound paper bags.

Table 21 summarizes the most recent published data available on the production of granules. The value of domestic production for 1965 is estimated by the writer to exceed $46 million. Production by States is not given, in order to protect confidential information of the producing companies.

TABLE 21.—*Roofing granules sold or used in the United States, 1959–63* [1]

[Thousand short tons and thousand dollars]

Year	Natural		Artifically colored [2]		Total	
	Quantity	Value	Quantity	Value	Quantity	Value
1959	446	$4,264	1,447	$34,372	1,893	$38,636
1960	649	5,454	1,443	33,767	2,092	39,221
1961	663	5,544	1,534	35,654	2,197	41,198
1962	647	5,384	1,786	42,247	2,433	47,631
1963	696	5,856	1,667	38,352	2,363	44,208

[1] Manufactured from stone, slate, slag, broken ceramics, sand, gravel, diatomite, and pumice. (Believed to include some roofing "gravel" D.M.L.)
[2] A small quantity of brick granules is included with artifically colored granules.

Source: Key, 1966, p. 34.

Table 21 indicates an approximate average value of $24 per ton for artifically colored granules and $8 to $9 per ton for natural granules. From these figures it is plain that freight rates must be an important item in distribution. Part of the production from Missouri is used within the State but a considerable quantity is shipped elsewhere. The granule plant in Missouri, together with two in Arkansas, two in Georgia, and one in South Carolina are believed to meet that part of the demand in the Gulf Coast area and in the southeastern United States not met by shipments from the Northeast or from two plants in Wisconsin. The midwestern plants generally meet the needs of the Midwest and Rocky Mountain area. Most of the west coast requirement is met by producers within that area.

As the demand for colored granules expands in the area served chiefly by the plants in Missouri and Arkansas, the production faci-

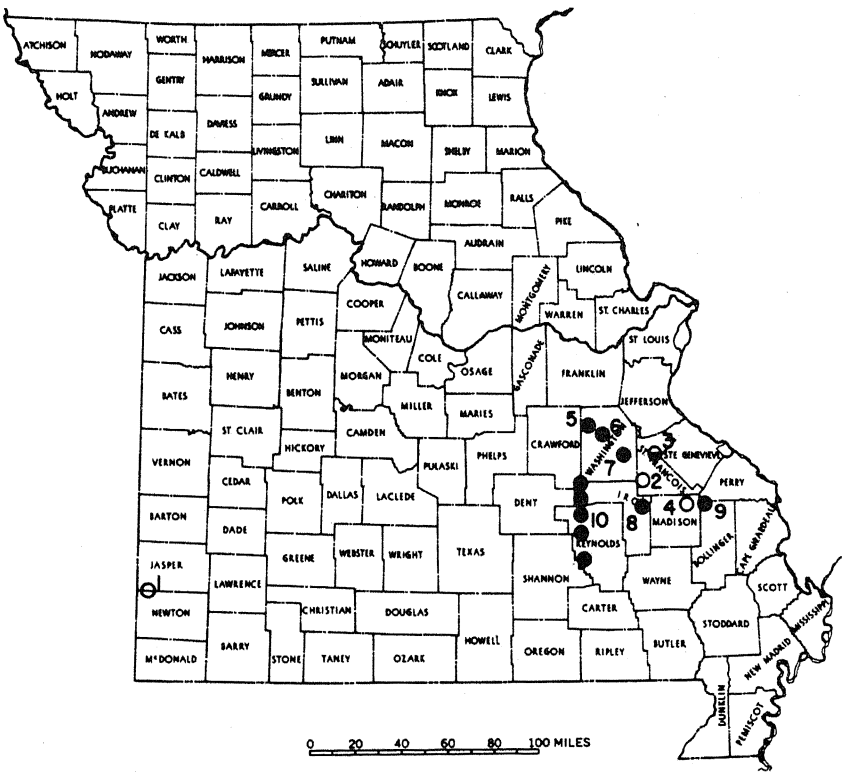
lities can be expanded at the Missouri plant and perhaps at the others as well. Because of the complicated and competitive market situation, involving location of granule plants and of roofing manufacturers using the granules, and certain trade preferences, there appears little likelihood that additional colored granule plants will be constructed in Missouri in the near future.

MINE AND MILL TAILING PRODUCTS

(By H. M. Wharton, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Most of the mine and mill tailings in Missouri that have had important commercial uses are called "chat" or "chats." It is believed by some that this is a colloquial contraction of chert, the dominant gangue mineral associated with the zinc-lead ores in the Tri-State district, where the term originated. It is usually restricted to the coarser waste piles produced in milling lead, zinc, and barite ores. The two areas in the State where the largest tonnages of chat have accumulated are around Joplin (Tri-State district) in Jasper and Newton Counties in the southwest corner of the State and in the Southeast Missouri Lead district, largely in St. Francois and Madison Counties. These are in fact the sites for most of the larger chat marketing operations. Locations are shown in figure 35. Despite their relatively small amounts, the mill tailings from the processing of iron ores at Iron Mountain in St. Francois County occasionally rank in importance in sales with the two latter areas. The felsitic waste rock formerly produced here, which is not chat in the strict sense, has been exploited for many years. It is referred to as "traprock" in the trade. Use is also made of "tiff" chat, chert-rich tailings from the processing of barite ores in Washington County.

Characteristics of the tailings.—All the important mine wastes now being exploited in the State are mill tailings that have been reduced to rather small size ranges by rock crushers. Some of them have been recrushed and milled two or more times at periods of high market prices for recovery of some of the remaining lead-zinc values. This is true for many of the chat piles around Joplin and in the Southeast Missouri Lead district. The result is that average fragment sizes are quite small and fines are abundant. Increasing amounts of material have been treated by flotation with resulting tailings being deposited as slimes or sludge in ponds. The sludges may include sizes up to 28 mesh, but in current practice over 50 percent is usually minus 200 mesh. (See table 29, p. 200.) Gravity recovery methods permit coarser sizes: up to 1¼ inch maximum for heavy media, three-fourths inch for jigs, and one-fourth to three-eighths inch for tables. Minimum sizes for efficient recovery of metallic values are estimated to be about one-fourth inch, 5 to 10 mesh, and 20 to 60 mesh, respectively. The main characteristics of tailings now being exploited in the State are given in table 22.



EXPLANATION

○

Center of past accumulations, chiefly coarse tailings (chat)

1. Joplin 2. Iron Mountain 3. Lead Belt 4. Fredericktown

●

Center of present and future accumulations, chiefly fines

5. Pea Ridge 6. Indian Creek 7. Potosi 8. Pilot Knob 9. Higdon 10. Viburnum Trend

⊖

Center where both the above categories fit

3. Lead Belt (Flat River)

FIGURE 35.—Principal centers of mine and mill tailing accumulations in Missouri, exclusive of coal mine and washer plant refuse.

TABLE 22.—*Main characteristics and uses of mine and mill tailings now being exploited in Missouri*

	Lead Belt and Fredericktown area	Joplin area, Jasper and Newton Cos.	Iron Mountain, St. Francois County [a]	"Tiff" chats, Washington County
Rock type	Dolomite	Cherty limestone	"Traprock": mineralized felsite porphyry	Red clay residuum with chert, limonite, and drusy quartz
Mineralogy	Dolomite	Chert and jasperoid	Feldspar, hematite, chlorite-epidote-serpentine	As above
Estimated composition	50% $CaCO_3$·36% $MgCO_3$ 90% $CaCO_3$ equivalent	Predominantly silica; some piles have limestone and other impurities	[a] SiO_2—58% MgO—6% Fe_2O_3—21% CaO—6% Al_2O_3—8% $Na_2O+K_2O<1\%$	High in silica and iron oxides
Color	Gray	White to buff	Dark gray	Red clay, rusty white chert, brown Fe oxides
Hardness (Mohs' scale)	3–4	5–7	6–7	Varied
Estimated toughness (Deval)	9	12	19+	Chert around 10
Particle size range	½" and less	½" and less	¾" and less	Gravel to fines, mostly minus 1"
Average size	100 mesh ±	¼" to ½"	¼" to ½"	Chats: ¼"± Fines: 325 mesh
Estimated reserves in short tons	Multimillions	1 million ±	2–3 years' supply ±	Chats: very small Fines: multimillions
Main uses in order of importance in 1965	Aglime, concrete aggregate and roadstone, RR ballast, flux	Sandblasting, grinding & polishing, roof granules, RR ballast, concrete aggregate & roadstone, rockwool	Concrete aggregate & roadstone, RR ballast	Chats: mine roads, tailings pond dams, State & County roads, RR ballast, planters Fines: barite potential
Remarks	No chats since 1960, sludges only; applies also to Indian Ck. mine, Washington County	No Zn-Pb ore (or chats) produced in Missouri Tri-State since 1957	Iron ore operations suspended indefinitely in August 1966	Mud ponds considered to contain millions of tons of barite

[a] From sales brochure (1954) on Iron Mountain "traprock" prepared for Trap Rock Material & Engineering Company.

In the Joplin area, "flint" chats are most abundant because the gangue minerals making up the tailings are mostly jasperoid and chert, both forms of silica. Host rocks of the zinc-lead deposits are altered Mississippian carbonate formations. The chats are very hard, brittle, and abrasive but may contain varying amounts of limestone, dolomite, and other ingredients which alter the physical properties. Only about 10 percent of Tri-State ores was put through flotation cells. The other 90 percent, treated by gravity methods, yielded the coarser tailings that accumulated in chat piles.

Mill tailings in the Southeast Missouri Lead district in the vicinity of Flat River and Fredericktown are composed of dolomite from the Cambrian Bonneterre Formation. The dolomite chats and sludges have, in accepted aglime usage, an average calcium carbonate equivalent of about 90 percent. Early mill practice used jigs and tables for recovery methods so that some fairly coarse sizes were produced in the waste piles. The existing chat piles in the district were built up mostly before 1930, when the use of jigs in the mills was generally discontinued (Coghill and O'Meara, 1932). By 1960, mill recovery was entirely by flotation, which had been first introduced in the district in 1914. Sizes up to one-fourth inch are fairly common in the chat piles, whereas sludges in the tailing ponds are over 95 percent minus 48 mesh.

A Precambrian felsite porphyry is the host rock of the hematite and magnetite iron deposits at Iron Mountain in St. Francois County. Jigs and tables were used for ore concentration in the mill; the rejects, known as "traprock", are very hard and abrasive.

The "tiff" chats produced in Washington County by washing, crushing, and jigging residual barite ores consist mostly of chert with lesser quartz druse and limonite. The chats include breaker-screen oversize and jig tailings which are minus ¾ inch. A very large quantity of fines have accumulated in the mud ponds over the years from washing and concentrating the barite ores. These sludges are made up of small fragments of chert, limonite, quartz, dolomite sand, and barite in a red clay matrix.

Uses and marketing.—Commercial uses of mine and mill tailings in Missouri generally conform with those peculiar to crushed and broken stone, a commodity of low unit value. Tailings have cost advantages in being already crushed to small sizes and located in readily movable stacks or ponds often containing very large tonnages. Furthermore, good roads and railroad services are usually available because of preexisting or current large-scale mine and mill operations.

Principal uses of chats and other mill tailings in Missouri during 1965, in order of dollar value, were as (1) aglime (agricultural limestone), (2) blast sand, (3) roadstone and concrete aggregate combined, (4) railroad ballast, (5) grinding and polishing agents, and (6) roofing materials. The order has varied somewhat over the years, but from 1955 to the present time, the above ranking has been the dominant one. Uses of tailings in the principal marketing areas in order of importance during 1965 are given in table 22.

Crushed and broken stone, including chats, are a basic raw material in the construction, chemical, and metallurgical industries. Increased highway, industrial, and residential construction since World War II

have been key factors in maintaining a high level of consumption (Cotter, 1965b, pp. 884–886). Requirements for particular uses have tended to become more strict. In order to meet specifications, close attention must often be given to physical and chemical properties such as the mineralogy, size range, hardness, toughness, and the presence of objectionable impurities (Severinghaus, 1960, p. 285–289). By 1953 the chats' share of the crushed and broken stone market had begun to level off and decrease, probably because of the stricter specifications for aggregate, roadstone, and ballast usage. In 1965 it constituted about 3 percent by tonnage and 2.6 by value of the total crushed and broken stone used in Missouri.

Joplin chats have become increasingly important as a raw material for industrial sands, which have a considerably higher unit value than unprocessed tailings. Thus, the sales value of blast sand and material for grinding and polishing marble often exceeds that for construction uses in the Joplin area. Other special uses of importance have been as roof granules and for furnace, molding, filter, engine, and glass sands (Reynolds, 1940, pp. 68–70).

The U.S. Bureau of Mines compiles production statistics for the nonmetals by commodity type and usage. Information on the consumption of mine and mill tailing products in Missouri is included in appropriate fashion under the headings of miscellaneous stone, sand and gravel, and crushed and broken limestone.

The tonnage and value of mine and mill tailings marketed since 1915 are given in figure 36. Consumption in 1965 was about 1,090,000 short tons valued at about $1,320,000. Overall value per ton has, amid great fluctuations, gradually increased. A low of about 15 cents per ton occurred in 1916. By contrast, mine and mill tailings have commanded an average price of about $1.25 a ton during the past 2 or 3 years. Consistent producers over the years have been: (1) the Independent Gravel Co. and American Zinc Co. in Jasper and Newton Counties in the Joplin section of the Tri-State district; (2) the St. Joseph Lead Co. in the Southeast Missouri Lead district in St. Francois County; and (3) the Trap Rock Material and Engineering Co. at Iron Mountain in St. Francois County. The latter company purchases mill tailings from The Hanna Mining Co.

Outlook.—It does not appear likely that the consumption rate of chats and other mine and mill tailings in Missouri will increase to any significant degree in the near future, unless some important new uses are developed for these materials. The cement reactive character and nonabsorptive nature in bituminous mixes of some of the "flint" chats are examples of important use restrictions in the aggregate field. The tendency for fines to be produced at the expense of larger sizes will curtail marketing of the tailings as crushed and broken stone for aggregate, roadstone, and ballast usage. Milling procedures at the new iron mines of the Meramec Mining Co. at Pea Ridge in Washington County and of the Pilot Knob Pellet Co. at Pilot Knob in Iron County are designed to produce dominantly fine tailings. The same is true for the modern lead ore concentrators now in operation at Flat River, Indian Creek, Viburnum, and Fletcher; and for those now under construction at Higdon and along the Viburnum trend. The reserves

of chats in the Joplin and Lead belt areas are a wasting resource as they are no longer being added to. However, many millions of tons remain, so it will be years before the existing supplies are exhausted (table 22).

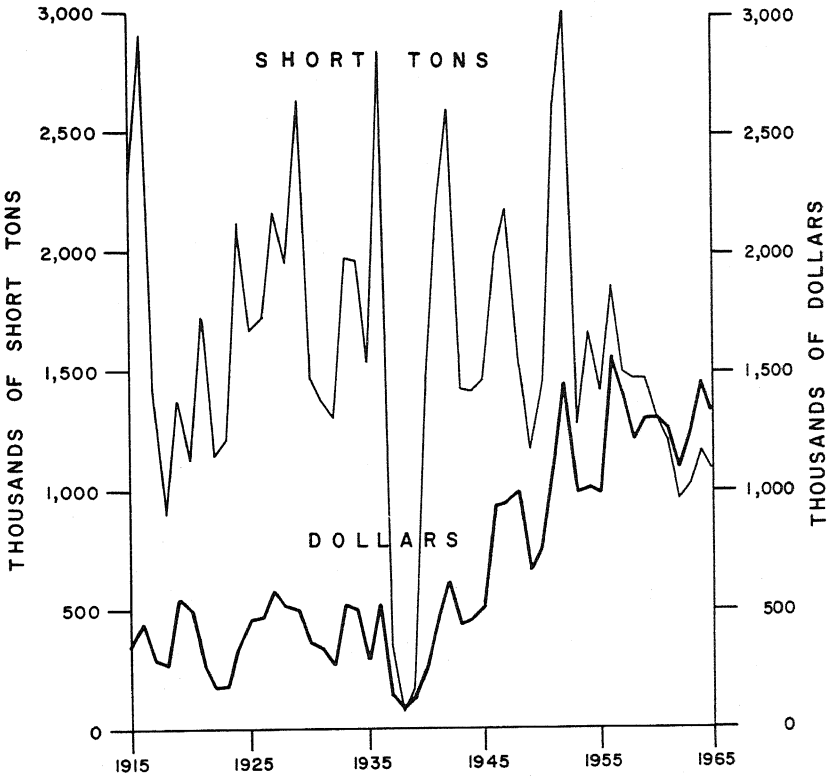


FIGURE 36.—Use of mine and mill tailings in Missouri, 1915–65.

There appear to be some favorable possibilities for marketing some of the finer mill tailings now or soon to be available in the State. The characteristics and potential uses for some major mine, mill, and furnace wastes in Missouri are given in table 23. The dolomite sludges from the Viburnum trend lead ore concentrators in southeast Missouri are well suited for use as agricultural limestone. Muilenburg (1957, pp. 10–12) reports that experimental work on the recovery of barite by retreating waste mud and sand from the washer plants in Washington County has been encouraging. Tabling, froth flotation, and spiral types of separators have all been tried with some success. Barite reserves in the mud ponds are probably measured in millions of tons since mill recoveries are believed to average only about 50 percent.

TABLE 23.—*Characteristics and potential uses for some major mine, mill, and furnace wastes in Missouri*

	Viburnum Trend lead mills	Meramec Mining Co. iron mine in Wash. Co.	Pilot Knob Pellet Co. iron mine in Iron Co.	Coal mine refuse	Brown iron ore tailings, southern Missouri	Iron and lead furnace slags
Rock type	Dolomite	Rhyolite porphyry	Felsite porphyry "trap-rock."	Mostly dark, carbonaceous shales.	Chert, limonite, pyrites, and clay residuum	Slags.
Mineralogy	Dolomite	Feldspar, quartz, skarn, etc.	Quartz and feldspar phenocrysts; fluorspar, sulfides.	Clay minerals, quartz, pyrites, carbon, phosphates, etc.	Chert, limonite, pyrites, and clays.	Glassy silicates.
Estimated composition.	51% $CaCO_3$·36% $MgCO_3$ ~90% c.c.c.	SiO_2—70% Al_2O_3—12% K_2O+Na_2O—8%	Not available	SiO_2—50–60% Al_2O_3—11–15% Fe_2O_3—3–8%	High in silica, alumina, iron sulfides, and oxides.	Iron:[a] SiO_2—36%. Al_2O_3—12% CaO—42% MgO—6%.
Color	Gray	Red and dark brown	Dark red-brown to dull purple-gray.	Dark gray to black	Brownish	Varied.
Hardness (Mohs' scale).	4±	6–7	6–7	2–5		5–6.
Estimated toughness (Deval).	9	19	19	5–6	Chert is around 10	10?
Particle size range	Minus 35 mesh, >50% minus 200 mesh.	(1) −⅝″+¼″ magnetic cobber reject. (2) Minus 200 mesh.	Minus 35 mesh	2″ and less	Fines to boulders	Unknown.
Average size	200 mesh	(1) ⅜″± (2) 325 mesh	100 mesh±	Coarse and fines often separated.	Mostly small	Unknown.
Estimated reserves (short tons).	By 1968, fines on the order of 5 million tpy will be produced.	On the order of 500,000 tpy.	About 800,000 tpy	Millions	Coarse: 100,000's Fines: millions	Iron: <1 million. Lead: Unknown.
Potential uses	Aglime, roadstone (fine aggregates) fillers, extenders.	Roadstone, rock wool, abrasives, fillers, extenders.	Roadstone, rock wool, abrasives, fillers, extenders.	Fuel, expanded shale, H_2SO_4, iron sinter, phosphate source.	Coarse: riprap, roadstone, RR ballast. Fines: iron ore and fill.	Mineral wool, roadstone, RR ballast, cement.
Remarks	Zinc and copper are coproducts.	Recovered apatite may be processed in the future for phosphate fertilizer manufacture.	Mill-mine startup scheduled for 1968.		Jig, heavy media, and other coarse tailings used for mine roads.	Lead:[a] SiO_2—26% Al_2O_3—7% CaO—14% FeO—40%.

[a] Richie (1960, p. 599).

Milling practice at Pea Ridge includes the recovery of apatite by flotation. This phosphate mineral is an objectionable impurity in the iron ore and must be removed. The apatite concentrate is currently being stockpiled at the plant. Consideration is being given to producing a phosphate fertilizer from the apatite using sulfuric acid produced at the Herculaneum smelter of the St. Joseph Lead Co. While no definite plans have been announced by the Meramec Mining Co., this byproduct possibility deserves mention. Rhyolite and felsite porphyries comprise the bulk of the fine wastes produced at the two new iron mines. Tremendous quantities of this material will be produced over the years. Some possible uses might be as roadstone, for rock wool preparation, abrasives, fillers, and extenders (table 23).

Three other accumulations of mine, mill, and furnace wastes in Missouri deserve attention. The first are those produced in coal mining operations in the northern and western sections of the State. The second are the mill tailings produced in cleaning and concentrating the brown iron ores mined in southern sections of Missouri, principally in Howell, Oregon, Wayne, and Butler Counties. Finally, there are the furnace slags produced in iron and lead smelting.

Herold and others (1958) have studied the bloating qualities of a variety of shales from Missouri, including some coal underclays. (See also section in this report by Bush, p. 119). Diamond and others (1964) have presented background information on marketing of lightweight aggregates in Missouri and adjacent States. Utley and Lovell (Utley and others, 1965) discuss some studies that have been carried out on coal refuse in Pennsylvania. Attempts were made to separate a readily combustible light fraction of this refuse from the heavier shaly fraction. The aim is to prepare a useful fuel and an expandable shale raw material for lightweight aggregate preparation. Research of this sort should be considered using samples of the coal refuse produced in large quantity in Missouri. Other potential byproducts of coal wastes include iron pyrites. Sulfuric acid and iron sinter for use in steel making can be derived from the pyrites. Phosphatic nodules containing appreciable P_2O_5 content occur in shales overlying many of the coal beds in Missouri. If suitable methods for separating the nodules from the shale could be developed, it might be possible to establish a small phospate fertilizer industry using the nodules as a raw material.

Log washers have been used for many years to clean and upgrade the brown iron ores of southern Missouri. Chert boulders and pebbles are scalped off by hand picking. This coarse material might average 3 or 4 inches in size. It is estimated, however, that less than 250,000 tons have accumulated in all the iron mining areas. Possible uses are as riprap, roadstone, and railroad ballast. The largest accumulations are fine wastes in tailing ponds that consist mostly of chert and limonite fragments mixed with clay. It is possible that this material will be re-treated at some future time to recover some of its remaining iron content.

The iron furnace slag dumps at Sligo in Dent County may be suitable for manufacture of rock wool (Beveridge, 1959). Main uses of rock wool are for heat and sound insulation in building construction. Satisfactory results were obtained from samples tested in 1946. The

77-278 O—67——12

dumps are estimated at over 300,000 tons. Reserves of iron slags in Missouri may not exceed a million tons, and no iron furnaces have operated in the State for many years. Ritchie (1960, p. 595–599) reports that "black" wool (rock wool with high iron content) is prepared from slags produced in refining lead and copper. This might be considered for the slags produced at Herculaneum and at the two lead smelters now under construction in Iron County, Mo.

CEMENT AND CEMENT RAW MATERIALS

(By James A. Martin, Missouri Geological Survey and Water Resources, Rolla, Mo.)

The word "cement" is used herein to designate the binder material known commercially as portland cement, which is the most important and widely used material in present-day construction. Portland cement is essentially a controlled mixture of lime, silica, and alumina-bearing raw materials which when calcined in a rotary kiln forms clinkers with special chemical compositions that give to cement its useful physical properties. To form the finished product, the clinkers are ground with gypsum (which retards setting) to a very fine powder. When mixed with sand, aggregate, and water and permitted to hydrate, concrete is formed. Five types of portland cement, designed for specific purposes and manufactured under uniform standards, are presently produced in the United States. In addition to these, other hydraulic cements being manufactured are: oil-well cement, high-alumina cements, portland pozzolan cement, white cement, and portland blast furnace slag cement. Masonry cement, used as mortar in brick laying and masonry work, is chiefly a mixture of portland cement, finely ground limestone or lime, and an additive to give it workability and plasticity.

The production of portland cement is reported in 376-pound barrels and of prepared masonry cement in 280-pound barrels. Total cement production is given in 376-pound barrels. In 1965 world production of all types of cement was estimated at 2.5 billion barrels, U.S. production was 388.8 million barrels and of this total, approximately 95.5 percent was portland cement, 4.4 percent prepared masonry cement and the remainder natural slag, and hydraulic-lime cements. Total U.S. exports for the year were slightly under 750,000 barrels while imports were 5.5 million barrels. It is doubtful that any Missouri-produced cement entered the foreign market. Production of portland cement in 1965 by Missouri plants reached an all-time high of 13.975 million barrels. Prepared masonry cement totaled 380,000 barrels.

In terms of value, cement is the second largest mineral industry in Missouri. The combined value of portland and masonry cement shipped from Missouri plants in 1965 amounted to $47.2 million or approximately 21 percent of the State's total value of mineral production for the year. State-based plants produced slightly more than 3½ percent of the total U.S. production in 1965, and Missouri ranked ninth among the producing States. By 1968, eastern Missouri will be the major cement-producing area on the Mississippi River. During 1965, 13.3 million barrels of portland cement valued at $46 million and 377,000 barrels of prepared masonry cement valued at $1.2 million were shipped from Missouri plants. The average prices per barrel

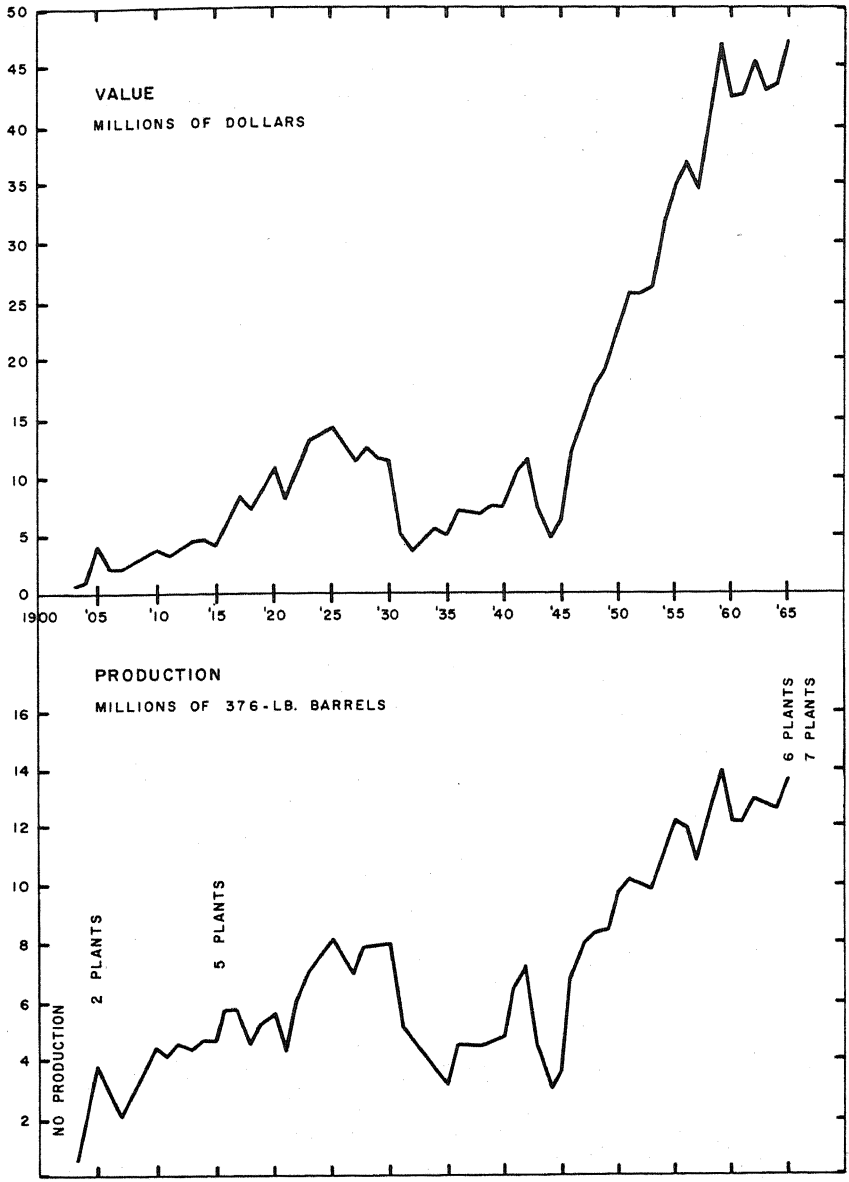


FIGURE 37.—Production and value of cement from Missouri plants, 1903–65 (includes masonry cement equated to 376-pound barrels except for the years 1955 through 1957). Source: Bishop (1949) 1903 to 1947; U.S. Bureau of Mines, 1948 to 1965.

were $3.45 and $3.11 for portland and masonry cements, respectively. Figure 37 shows the cement shipments and value in Missouri from 1903 to date. Since cement is a perishable product that is used shortly after manufacture, shipment figures are considered a valid measure

of both production and consumption. Portland cement used in Missouri, based on shipment destination, was 10.8 million barrels, which amounted to approximately 80 percent of the total shipped from Missouri plants. Figure 38 shows the major consumers of portland cement and the percentage used by each based on shipments from Missouri plants.

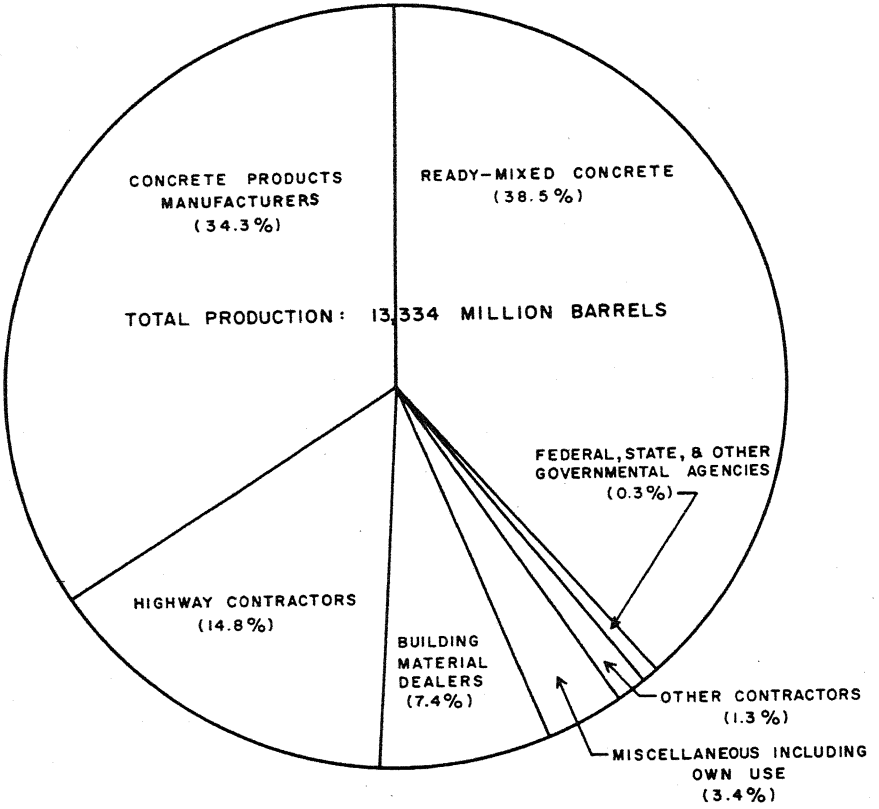


FIGURE 38.—Portland cement shipments from Missouri plants by types of customers, 1965. Source: U.S. Bureau of Mines.

Production of portland cement has, with the exception of major declines during the 1930's and the mid-1940's, increased steadily since 1900 when it surpassed the production of natural cement. Since 1957, total production of Missouri plants has averaged about 77 percent of total capacity. Should the cement industry in the State continue to operate at 75 percent of its effective capacity, production will reach 20 million barrels by 1969. With the increased demand in both residential and nonresidential building construction, highway uses such as concrete pavements and soil cements, plus the technological advances in the manufacturing of cement and specialty concrete uses,

the industry should continue to expand. Even though construction, both public and private, appears to be continuing to rise, excess overcapacity and lower prices can become major problems for the cement industry in the mid-Mississippi Valley region.

Six plants are presently producing portland and masonry cement in Missouri and a seventh is under construction. The location of plants in the State and the distribution of limestone suitable for the manufacture of cement are shown in figure 39. Table 24 lists the

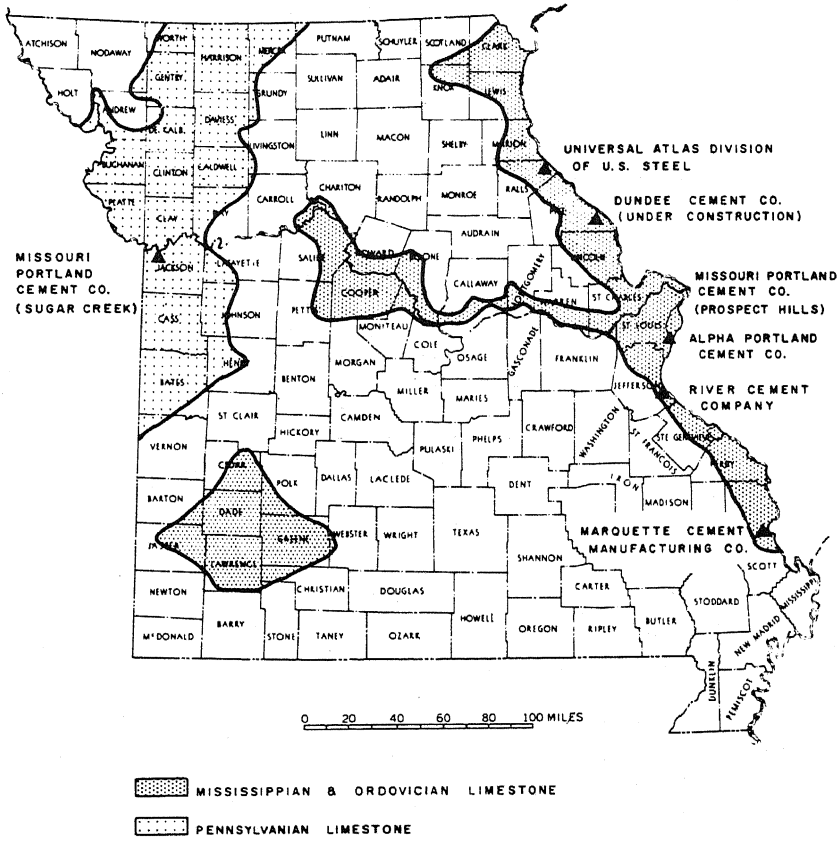


FIGURE 39.—Principal areas of limestone suitable for cement manufacture and location of plants in Missouri.

principal features of each plant. The prime factors determining location have been market, nearness to a limestone source, access to rail and river transportation, electric power, and fuel. At only one plant is limestone shipped to the plant by rail, and this is a distance of less than 10 miles. Three plants are in areas of urban encroachment which poses a threat to further development of potential stone reserves.

TABLE 24.—*Salient features of cement plants in Missouri*

Company	Annual capacity (million barrels)	No. of kilns	Process	Cement types produced	Shipment facilities	Raw materials
Alpha Portland Cement Co Home office: Easton, Pa. Plant: Lemay, St. Louis Co.	2.6	4	Wet	P.C. Types I, IA, II, IIA, III, IIIA, IVA. Masonry cement.	Rail and truck	St. Louis and Salem limestones and associated Pennsylvanian shale. Iron ore—Howell Co., Mo., and Minnesota. Gypsum—Iowa. Anhydrite—Louisiana.
Dundee Cement Co Home office: Dundee, Mich. Plant: Clarksville, Pike Co. (under construction).	7.0	1	do	P.C. Types I, IA, II, III. Masonry cement.	Rail, truck, and barge.	Kimmswick limestone. Maquoketa Shale.
Marquette Cement Co Home office: Chicago, Ill. Plant: Cape Girardeau, Cape Girardeau Co.	3.24	5	Wet and Dry	P.C. Types I, IA, II, II. Masonry cement and special cements.	do	Plattin limestone; Mississippi River alluvium. Iron ore—Howell Co., Mo., and Tennessee. Gypsum—Arkansas and Oklahoma.
Missouri Portland Cement Co Home office: St. Louis, Mo. Plant: Prospect Hills, St. Louis Co.	5.0	4	Wet	P.C. Types I, IA, II, III, IIIA, Masonry cement. Special cement-Bloxment.	do	St. Louis Limestone; Lagonda Shale. Iron ore—Howell Co., Mo., Gypsum and Anhydrite—Kansas and Oklahoma.
Plant: Sugar Creek, Jackson Co	3.0	2	Dry	P.C. Types I, IA, II, III, IIIA. Masonry cement. Special cement-Bloxment.	do	Bethany Falls and Winterset limestones and associated shales. Iron—mill scale (local). Gypsum—Kansas.
River Cement Co., Division of Stewart Concrete. & Materials Co. Home Office: St. Louis, Mo. Plant: Selma, Jefferson Co.	3.0	1	do	P.C. Types I, IA, II, III. Masonry cement.	do	Plattin limestone; St. Peter Sandstone; loess. Iron ore—Howell Co., Mo., Gypsum—Kansas and Oklahoma. Fly ash—Union Electric, St. Louis.
Universal Atlas Cement, Division of United States Steel. Home Office: New York, N.Y. Plant: Illasco, Pike Co.	(1)	1	Wet	P.C. Types I, IA, II, IIA, III. Block and Masonry cements.	do	Burlington Limestone; Grassy Creek and Saverton shales. Gypsum—Oklahoma.

[1] Not available.

The first production of portland cement in Missouri was in December 1902 at the St. Louis Portland Cement Co. (now Missouri Portland Cement Co.) plant at Prospect Hills, St. Louis County. Construction of the Atlas Portland Cement Co. (now Universal Atlas Cement, division of U.S. Steel), Ralls County, was begun in 1901 and completed in 1903. In that year an estimated 600,000 barrels of cement were produced by these two companies and in the following year over 1 million barrels were produced. In 1907 three companies were producing in the State—Atlas, St. Louis Portland Cement, and Kansas City Portland Cement (now Missouri Portland Cement Co.). Over 2 million barrels were produced. By 1913 five cement plants were operating and production was about 4.5 million barrels. These five plants—Universal Atlas Division of U.S. Steel, Alpha Portland Cement Co., Marquette Cement Manufacturing Co., and two plants of the Missouri Portland Cement Co.—are presently operating. During the period 1905–15 at least three additional plants were proposed, but plans were subsequently abandoned. In May 1965, River Cement Co.'s 3-million barrel plant in Jefferson County went on stream. The 560-foot-long kiln is the largest dry-process kiln presently in operation in the United States. In 1964 the Dundee Cement Co., Dundee, Mich., announced plans for the construction of a $55 million, 7 million-barrel wet-process plant near Clarksville, Pike County. The plant is presently under construction and scheduled to go on stream in early 1967. Aside from the large capacity of this plant, noteworthy features are the 760-foot-long rotary kiln, 15- by 54-foot raw mill, and two 15- by 49-foot finish mills, all of which will be the world's largest when completed. During 1965 the Universal Atlas plant near Hannibal installed a 620-foot wet-process kiln which went on stream in 1966. The total annual capacity of Missouri plants, when all are in production, will be nearly 28 million barrels, an increase of about 75 percent over the 1964 annual capacity when five plants were producing.

The manufacturing of portland and masonry cements is closely regulated by specifications recommended by the American Society for Testing Materials (ASTM), and the cement produced at any given plant is essentially the same as that produced at any other. This uniformity of product began early in the 20th century under Federal regulations and has been the rule since about 1917 when the ASTM specifications were accepted as standard by the industry.

The basic raw materials for cement are those that will supply the necessary amount of lime (CaO), silica (SiO_2), and alumina (Al_2O_3). Iron (Fe_2O_3) is required in cements having low heat of hydration (types II and IV). The principal sources of these compounds utilized by the cement industry in Missouri are:

Lime: Limestones low in magnesia (generally less than 5 percent).

Silica: Shale, sandstone, loess, river silts, fly ash.

Alumina: Shale, clay, fly ash.

Iron: Hematite, pyrite, mill scale.

The main limitations placed on the use of available raw materials are the percentages of magnesia, alkalies, sulfur, and phosphorus, which are not essential to the composition of the cement and if present in excess can be harmful to the finished product. A maximum of 5 per-

cent magnesia is placed on finished portland cement by ASTM specifications, and this controls the percentage that can be tolerated in the limestone to be used. Alkalies, sulfur, and other impurities should be 1 percent or less in the raw feed. Excess alkalies are harmful in finished cement because of reactions with certain types of aggregate that result in expansion and cracking of concrete.

Approximately 600 to 660 pounds of raw material are used in the manufacture of 1 barrel of cement. Of this total, limestone makes up from 500 to 550 pounds. Raw materials are crushed and blended to the proper chemical mix by one of two processes—"wet" or "dry". In the wet process, proportioned materials are mixed with water for grinding and blending and introduced into the kiln as a slurry. In the dry process, materials are dried prior to grinding and fed to the kiln dry. The wet or dry mix is fed into the upper end of an inclined rotary kiln. As the material moves slowly through the kiln it reaches a point of fusion (2,500°–3,000° F.) and clinkers, a complex of calcium-aluminum-silicates which give to cement its main characteristics, are formed. After cooling, the clinkers are mixed with 3- to 6-percent gypsum, pulverized to a fine powder, and stored for shipment. The modern cement plant is highly automated with computers, X-ray, and other refined techniques to provide rapid analyses for accurate quality control.

Five types of portland cement meeting specific chemical and physical requirements are presently produced under ASTM standards:

Type I: General purpose construction cement.

Type II: Similar to type I but generates less heat and is moderately resistant to sulfate attack.

Type III: High early strength. Gains strength and sets rapidly.

Type IV: Low heat of hydration and slow development of strength. Useful in massive concrete structures such as dams where volume changes might take place on cooling.

Type V: A special sulfate-resisting cement.

An "A" designation after the type, e.g., type IA, indicates that an air-entraining agent (resin or fatty acid) has been ground with the clinker to produce formation of numerous microscopic air bubbles in the concrete during mixing. The use of air-entrained cements in concrete prevent scaling caused by freezing and thawing action. Durability and workability are also increased.

RAW MATERIALS RESOURCES

Limestone

The main areas in Missouri where limestone suitable for the manufacture of cement occur are delineated in figure 39. The chief limestone resources and reserves are present in the Kansas City Group of the Pennsylvanian, the Meramecian and Osagean Series of the Mississippian, and the Champlainian Series of the Ordovician. Principal areas containing limestones with a low magnesium content are along the Mississippi River, both north and south of St. Louis; along portions of the Missouri River; in the southwest; and in the westcentral and northwestern parts of the State. The reader is referred to table 15, p. 127 for brief descriptions and general chemical ranges and the

State Geologic map (McCracken, 1961) for distribution of the various formations.

The *Upper Mississippi River Segment* is a belt some 10 to 15 miles wide and 120 to 140 miles long extending along the Mississippi River from Clark County at the north to St. Charles County at the south. Important limestone resources and reserves are in the St. Louis, Burlington, Kimmswick, and Plattin Formations. Outcrops of St. Louis Limestone are present along the Des Moines and Fox Rivers in Clark County; on the North Fabius and Wyaconda Rivers in central and northeastern Lewis County; and south of the Cap au Gres fault (fig. 3), in Lincoln and St. Charles Counties. The formation has a maximum thickness of about 50 feet in the northern counties and 150 feet in the southern area. The Burlington Limestone crops out from southern Knox and Lewis Counties southward to St. Charles County. Only the basal 15 to 40 feet of the Burlington is sufficiently low in chert (silica) to be considered desirable for the manufacure of cement. Above this lower unit the chert nodules and lenses increase to 25 percent or more of the total and the present economics of quarrying and benefication prohibits its use. The Kimmswick and Plattin Formations are exposed in Lincoln, Pike and Ralls Counties. The Kimmswick is relatively uniform in both chemical and physical properties throughout the area. Impurities are small amounts of iron oxide and disseminated sand- and silt-size quartz. Chert nodules are present at some horizons but minor in the overall total. Sinkholes, clay-filled joints, and local dolomitization may necessitate selective quarrying in some areas. Thickness of the formation ranges from 60 to 125 feet. The Plattin underlies the Kimmswick and is separated from it by 15 to 25 feet of shaly limestone (Decorah Formation). With the exception of a small area a few miles north of the Cap au Gres fault, the outcrop area lies some 10 to 15 miles west of the Mississippi River. Thin calcareous shale partings and chert are present throughout the Plattin. Thickness ranges from 40 to 100 feet with thinning to the north.

The *Lower Mississippi River Segment* parallels the river from St. Louis County southward to northern Scott County, a distance of some 130 miles, and varies from 3 to 15 miles in width. Limestone suitable for cement manufacture is present in the St. Louis, Kimmswick, and Plattin Formations.

The St. Louis and Salem outcrop areas are in St. Louis and Ste. Genevieve Counties. The St. Louis Limestone averages 150 feet in thickness in both areas. Some beds in the formation are dolomitic limestone or dolomite. The chert content and dolomitic beds appear to increase in the Ste. Genevieve area. The Salem Formation grades from a dolomitic limestone to dolomite in St. Louis County to a very pure high-calcium limestone in Ste. Genevieve County. Thickness ranges from 100 to 150 feet. The Kimmswick and Plattin Formations extend from the Missouri River in western St. Louis County southward to the Cape Girardeau area. From Jefferson County southward, the outcrop belt is adjacent to or from 5 to 8 miles west of the Mississippi River. The Kimmswick has an average maximum thickness of 125 feet but thins westward to 50 feet or less. It is relatively pure with only minor amounts of chert in the lower part. The Plattin varies in thickness from 125 feet in St. Louis County to over 400 feet

in Cape Girardeau and Scott Counties. Thin shale beds and partings and chert nodules are present. Parts of the formation are dolomitic. Zones having less than 5 percent magnesium carbonate can be found in aggregate thicknesses of 20 to 50 feet. Additional resources may be present in the Ste. Genevieve, Golconda, and Glen Dean Formations. The outcrop area of these units is limited to southeastern Ste. Genevieve and northeastern Perry Counties. The Ste. Genevieve Formation is an oolitic limestone with a maximum thickness of about 100 feet. Impurities are chert, disseminated quartz sand, and thin sandstone beds. The Golconda and Glen Dean are restricted to a small area in northeastern Perry County. The upper part of the Golconda is an oolitic, crossbedded limestone, 40 to 50 feet in thickness, which overlies a middle shale unit some 60 to 80 feet thick. The Glen Dean, about 60 feet thick, overlies the Golconda and is separated from it by 15 to 20 feet of sandstone (Hardinsburg Formation). The Glen Dean consists of limestone with interbedded shales.

The *Missouri River Area* can be divided into three segments: (1) from its confluence with the Mississippi River westward to the Warren-Montgomery County line, a distance of 70 to 80 miles; (2) an 80-mile reach between the Cole-Moniteau County line westward to central Saline County; and (3) a 95-mile stretch from western Lafayette County upstream to the vicinity of Andrew County. In the downstream segment resources are present in St. Louis and extreme northeastern Franklin County on the south bank of the river and in St. Charles, Warren, and Montgomery Counties on the north side. Important limestone units are in the St. Louis, Kimmswick, and Plattin Formations in St. Charles, St. Louis, and northeastern Franklin Counties. Only the Plattin Formation is present in Warren and Montgomery Counties, where the outcrop belt is some 2 to 6 miles north of the flood plain. The formations are essentially the same as described for the Mississippi River segment.

The high percentages of chert and local dolomitization are major drawbacks to utilization of much of the stone in the central segment of the Missouri River. The lower part of the Burlington and the upper part of the Keokuk(?) Limestones may be sufficiently low in these deleterious materials to be considered a possible resource. The lower part of the Burlington, some 20 to 30 feet thick, is relatively free of chert; however, dolomitization is sporadic throughout much of this lower unit. The outcrop of the lower Burlington is adjacent to the river bluffs in Moniteau and Cooper Counties on the south side and Howard and Boone Counties on the north. Dolomitization is not apparent in the upper part of the Keokuk(?) Limestone which crops out in Saline County. The chert content ranges from about 2 to 10 percent in the upper 30 to 40 feet. Along the west bluff of the Missouri River in eastern Saline County an isolated outlier of Kimmswick limestone is present on a structural high. The outcrop is only a few hundred feet long and about 20 feet thick. Nothing is known of its subareal extent beneath a thick loess cover. The Devonian Callaway Formation, present in parts of Boone, Callaway, Cooper, Montgomery, Moniteau, Pettis, and Saline Counties, contains limestone beds in aggregate thickness of 10 to 40 feet that would probably be suitable for the manufacture of cement. The thicker sections are principally in Callaway, Boone, and Montgomery Counties. The Cal-

laway contains two main limestone facies—fine-grained to sublithographic, and coarse crystalline to clastic. Both lithology and thickness vary in relatively short distances horizontally and vertically. Sandstone, shale, dolomite, chert, and conglomerate are interbedded with relatively pure limestone. Disseminated quartz sand grains and pyrite, in varying amounts, are present in many of the limestone beds.

The limestone resources in the western area are in the Fort Scott, Kansas City, Lansing, Pedee, Douglas, and Shawnee Groups of the Pennsylvanian System. With the exception of three or four units which have a maximum thickness of 25 to 35 feet, the limestones in these groups of rocks are thin and rarely exceed 15 feet (see table 15, p. 127). In addition to the upper Missouri River segment from Lafayette and Carroll Counties to southern Andrew County, Pennsylvanian limestones extend into the northwestern and west-central counties as shown on figure 39. In the counties north of the Missouri River, much of the area is overlain by glacial till. Acreages required to operate a modern large-capacity plant would be excessive throughout most of the area.

Potential limestone resources in the *Southwest Area* are principally in Barry, Cedar, Christian, Dade, Greene, Jasper, Lawrence, and Newton Counties. Relatively chert-free, high-calcium limestone units with thickness of from 30 to 75 feet are present in the Burlington, Keokuk, Warsaw, Salem, and St. Louis Formations. Associated with and separating the low-chert units are beds carrying 25 percent or more chert as nodules and lenses. In Greene County, two low-chert zones are present in the Burlington Limestone. The thickness of each varies from 25 to 50 feet, and they are separated by from 20 to 40 feet of cherty limestone. In Dade, Jasper, and Lawrence Counties, low-chert zones are present in the Salem and St. Louis, 50 to 75 feet; the middle Warsaw, 30 to 50 feet; and the upper Keokuk-lower Warsaw interval, 25 to 50 feet. Residue logs of well cuttings indicate that the low-chert zones in the Burlington, Keokuk, and Warsaw are local. In Newton County, the most favorable zone appears to be the upper Keokuk-lower Warsaw interval. In parts of this area, deep pit or shaft mining would be required to recover the most favorable stone. Chert in nodules and lenses is the major deleterious constituent. Dolomitization appears to be restricted to the immediate areas of faulting.

Suitable limestone resources are not a limiting factor to the extension or growth of the cement industry in Missouri. Should future technological advances permit the use of limestones with a higher magnesia content and the economic removal of chert, these resources can be greatly expanded. Unfortunately, much of the better quality stone, especially in St. Louis, St. Charles, Jefferson, Jackson, and Clay Counties, is in areas of expanding urbanization where restrictive zoning has removed much of these resources from future industrial use. The same applies to areas near the larger cities such as Springfield, St. Joseph, Cape Girardeau, and Hannibal.

Other raw materials

Principal sources of silica and alumina in Missouri are shale and clay, refractory clay, sandstone, loess, and alluvium. Iron ore (hematite and limonite) are mined in the southeast and east-central part of the State. For the distribution of these materials the reader is refer-

red to the appropriate commodity sections. Fly ash and blast-furnace slag are available in the St. Louis and Kansas City areas.

Shales presently utilized in northeastern Missouri are in the Devonian Grassy Creek and Saverton Formations and the Ordovician Maquoketa Shale. The Grassy Creek and Saverton shales range in thickness from 25 to 50 feet in the Hannibal area. The Maquoketa reaches a maximum thickness of nearly 120 feet in northern Pike and Ralls Counties. Thin shaly limestone and dolomite units are interbedded with the shale, especially in the lower part. In the northernmost counties, Warsaw shale underlies the St. Louis Limestone and is separated from it by 25 to 30 feet of interbedded limestone, dolomite, and shale. However, it is not known if the shale would be satisfactory for the manufacture of cement. Small outliers of Pennsylvanian shale and clay are present in St. Charles and southern Lincoln Counties. In the area from St. Louis southward, the only shales of appreciable thickness associated with potential limestone resources are in the Mississippian Golconda Formation in Ste. Genevieve and Perry Counties, and the Ordovician Maquoketa and Orchard Creek Shales in Cape Girardeau County. An outlier of Pennsylvanian shale, the Lagonda Formation, is present in St. Louis County. In northern and western Missouri (Pennsylvanian outcrop area) interbedded shales and clays and thick shale deposits are associated with the limestones. The St. Peter Sandstone outcrop parallels the limestone belt from southern Montgomery County to Cape Girardeau County. Several small outcrops are also present in Lincoln and southern Pike Counties (see fig. 47, p. 208). High-alumina refractory clays of Pennsylvanian age (Cheltenham Formation) are present in east-central Missouri, and Tertiary clay (Porters Creek Clay) crops out in Scott and Stoddard Counties in the Southeast Lowlands. A white-burning clay in the Lower Cretaceous is present in Butler County. Loess is present along both the Mississippi and Missouri Rivers, and thick alluvial deposits are also associated with these streams.

Hematite and limonite are present in south and central Missouri. Mines in Howell County furnish some of the iron ore used by Missouri cement plants; however, the supply is sporadic. Other potential sources are the Pea Ridge (Crawford County) and Pilot Knob (Iron County) iron mines (see section on Iron. p. 94).

Fly ash, a fine powder recovered by electrostatic precipitators or mechanical collectors from flue dust in coal-fired boiler plants, is presently being marketed by Union Electric and Kansas City Power & Light Co. The following analysis, supplied by P. D. Harrington of the Union Electric Co., is of fly ash from this company's Meramec plant, St. Louis County, Mo.:

	Maximum	Minimum	Average
SiO_2	50.9	39.0	46.9
Al_2O_3	28.1	18.2	23.6
Fe_2O_3	22.9	15.3	17.9
CaO	10.0	1.0	5.2
MgO	4.7	.1	1.4
Na_2O	1.03	.43	.74
K_2O	1.63	.51	1.21
SO_3	3.3	.2	1.4
Ign. loss	4.8	.8	2.6
Moist	.20	.20	.05
Sp. Gr	2.56	2.28	2.38

In summary, cement production in Missouri is on the increase with one new plant having gone into production in 1965, modernization of an old facility, and a second new plant to go on-stream early in 1967. Limestone, shale, clay and sandstone reserves are present for future expansion of existing plants, and raw material resources are available for future geographic expansion of this industry in the State.

LIME

(By James A. Martin, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Lime, the oxide of calcium, is manufactured by heating or calcining limestone or dolomite in a kiln to drive off carbon dioxide. The resulting product is quicklime. The addition of water forms calcium hydroxide, which is called hydrated lime. Both quick and hydrated lime are produced in Missouri and sold in bulk or bags.

The production of lime is probably the oldest of the mineral-industry manufacturing process. Although the term is generally associated with materials such as mortar and plaster or with agricultural liming for soil neutralization and plant nutrition, the major use for lime since World War I—more than 80 percent in 1964—has been in the chemical, metallurgical, and other industrial fields. In Missouri, three plants are presently producing high-calcium lime, and a fourth plans to produce dolomitic quicklime in 1967.

The U.S. production in 1965 of both captive and open-market lime and dead-burned dolomite was 16.794 million short tons with a value of $232.939 million. For the same year, Missouri's production of lime, including dead-burned dolomite, reached an alltime high of 1.442 million short tons with a value of $16.78 million. Nationally the State ranked third in tonnage and fourth in value. The production and value of lime manufactured in the State from 1900 to 1965 is shown in figure 40. Dead-burned dolomite statistics have been included with lime from 1939 to date. With the exception of major declines in 1915 and 1932 and some minor fluctuations since 1950, production has steadily increased. The lime industry presently accounts for nearly 7½ percent of the total value of mineral production in Missouri and ranks fifth in value following stone, cement, lead, and iron ore. Paralleling the national trend, the largest percentages of Missouri production went to chemical, metallurgical, refractory, and industrial uses. The greater percentage of output is shipped to out-of-state markets. A small percentage is shipped to foreign markets.

Limestone and dolomite have been burned for lime in Missouri since the earliest settlements, and mention is made of stone satisfactory for lime mortars in nearly all of the early geologic reports. Buehler (1907) states that lime manufacturing as an industry was well established in the State by 1880. At the time of his report, about 39 plants with a total of 114 kilns were producing lime from both limestone and dolomite in 21 counties. Greene County was the largest producer with five plants, and Missouri ranked fourth among the lime-producing States. A number of the plants operated intermittently and small field kilns for private use were sporadically operated throughout the State where suitable stone could be found. Ordovician limestones and dolomites and Mississippian limestones were utilized,

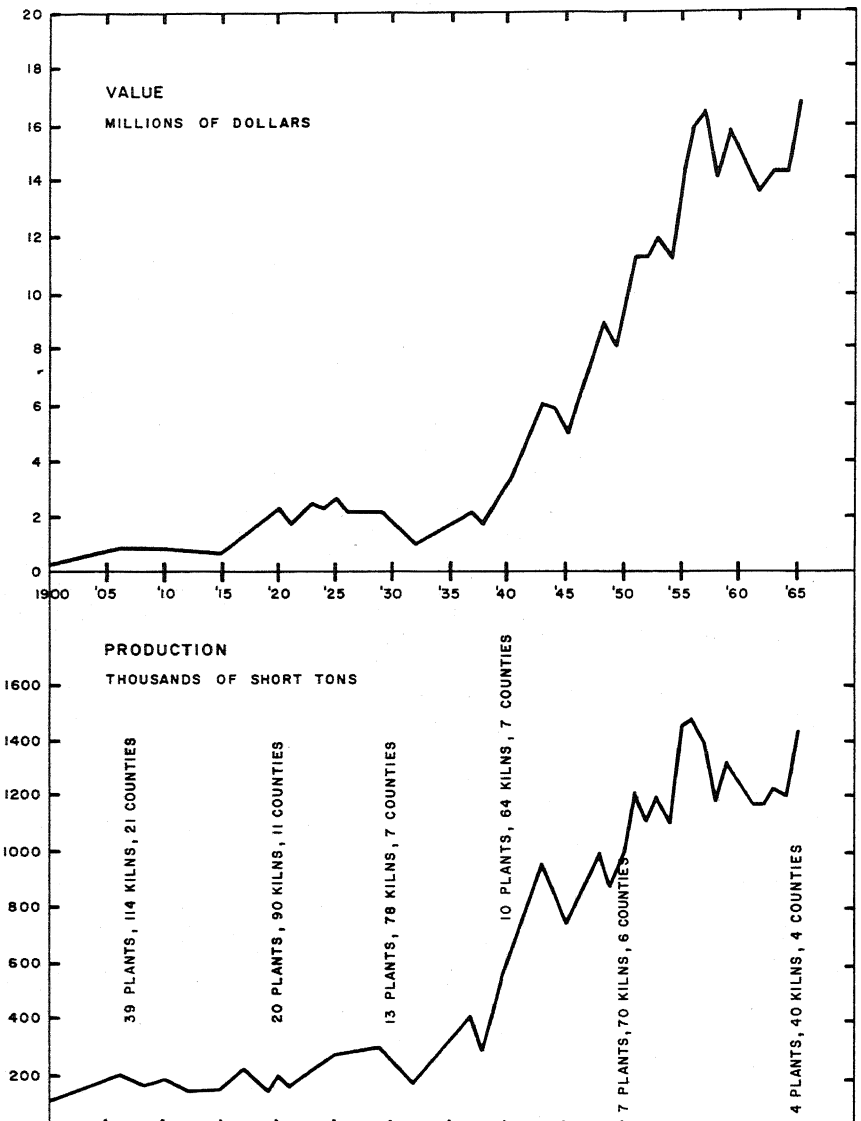


FIGURE 40.—Missouri production and value of quick and hydrated lime, 1900–65 (includes dead-burned dolomite, 1939 to date.) Source: Bishop (1949) 1900 to 1947; U.S. Bureau of Mines, 1948 to 1965.

with the bulk of production from the Mississippian Burlington Limestone. By 1940, the number of plants operating had decreased to 10 in seven counties but production had more than tripled. During the period 1950 to 1964, two companies ceased operations and another closed one of its plants. At present three companies (Ash Grove Lime and Portland Cement Company, Greene County; Marblehead Lime Company, Marion County; and Mississippi Lime Company, Ste. Genevieve County) are producing high-calcium lime in the State (table 25). Valley Dolomite Corp. presently produces dead-burned dolomite (see section on Refractory Dolomite) but plans to start production of dolomitic quicklime by mid-1967. The high-calcium plants are using limestone from the Mississipian Burlington and Salem formations. Dolomitic quicklime will be made from the Bonneterre Formation.

TABLE 25.—*Salient features of high-calcium lime plants in Missouri*

Company	Daily capacity	Kilns	Fuel	Products	Transportation facilities	Quarry	Formation
Ash Grove Lime & Portland Cement Co., Home Office: Kansas City, Mo., Plant: Springfield, Greene Co.	400 tons	2 vertical, 1 calcimatic.	Natural gas and oil.	Quicklime, hydrated lime, type S building lime, crushed stone.	Rail and truck	Open-pit	Burlington Ls.
Marblehead Lime Co., Division of General Dynamics Corp., Home Office: Chicago, Ill., Plant: Hannibal, Marion Co.	100 tons	2 vertical	Natural gas	Quicklime, hydrated lime, crushed stone, mineral feed.	do	Underground drive-in.	Do.
Mississippi Lime Co., Home Office: Alton, Ill., Plant: Ste. Genevieve County.	4,000 tons	10 rotary, 26 vertical.	Natural gas, standby coal.	Quicklime, hydrated lime, precipitated calciumcarbonate, crushed stone.	Rail, truck, and barge.	do	Salem Fm.

Calcination of limestone, essentially calcium carbonate ($CaCO_3$), consists of heating the crushed stone in a kiln to a temperature of between 2,000° and 2,500° F., with an average operating temperature of about 2,200° F. Carbon dioxide (CO_2) is driven off and calcium oxide (CaO), termed quicklime, is produced. The basic reactions are as follows:

(1) High-calcium limestone: $CaCO_3 + heat \rightarrow CO_2 + CaO$ (quicklime).

(2) Dolomite: $CaMg(CO_3)_2 + heat \rightarrow CO_2 + CaO \cdot MgO$ (dolomitic quicklime).

With 100 percent calcination, there is a theoretical weight loss of 44 percent for pure calcium carbonate (calcite) and 52.4 percent for pure magnesium carbonate (magnesite). For limestones and dolomites, the loss lies somewhere between 43 and 50 percent, depending upon the purity of the stone. Thus, about two tons of stone is required to produce one ton of quicklime. The size and shape of the crushed and broken stone fed to the kiln is not changed, but there is an increase in porosity with the removal of carbon dioxide.

Bowles (1952) lists three classifications of quicklime based on the chemical composition:

(1) High-calcium lime—not less than 90 percent CaO and 0 to 5 percent MgO.

(2) Dolomitic or high-magnesium lime—25 to 45 percent MgO.

(3) Low-magnesium lime—5 to 25 percent MgO.

The ranges for magnesium oxide given by the National Lime Association (1951) are as follows:

High-calcium quicklime—usually 0.5 to 2.5 percent MgO.
Dolomitic quicklime—usually 35 to 40 percent MgO.

Currently, only the high-calcium and high-magnesium (dolomitic) types are commercially important in the lime industry (Lamar, 1961). Only high-calcium lime is presently produced in the State; however, magnesium limes were produced until the early part of this century.

The National Lime Association (1951, p. 28) gives as typical analyses: 93.25 to 98 percent calcium oxide and 0.3 to 2.5 percent magnesium oxide for high-calcium quicklimes and 55.5 to 57.5 percent calcium oxide and 34.6 to 40.8 percent magnesium oxide for dolomitic quicklimes. Total impurities (silica, iron, and alumina) are generally less than 2 percent. The degree of purity of a lime depends largely on the stone being burned and the methods employed in calcining. Specifications and standards for physical and chemical testing and the uses of lime have been established by the American Society for Testing Materials (1965a).

Calcium oxide (quicklime) is an unstable compound in the presence of water and carbon dioxide. The absorption of water, which if added in quantity produces a rather violent reaction evolving a great deal of heat, is termed "slaking." When exposed to air (air-slaking),

77-278 O—67——13

moisture and carbon dioxide are absorbed and the lime eventually reverts to calcium carbonate. Because of its strong affinity for moisture and carbon dioxide, quicklime is a perishable product having handling, storage, and shipping problems. It is generally utilized within a few months after manufacturing.

Lime is manufactured in rotary, vertical (shaft), or one of the specialty patented kilns (Calcimatic, Fluo-solids, Ellernan). The largest percentage of lime is produced in rotary kilns both in the United States (80 percent plus) and Missouri. In the rotary kiln, crushed stone varying in size from ¼ to 2½ inches is used and the lime produced is referred to as "pebble lime." "Lump lime" is produced in the vertical or shaft kiln from feed stone generally ranging in size from four to eight inches, but a maximum size of 10 to 12 inches may be used. Lime is marketed as lump and pebble lime or as ground and pulverized to specified sizes. A Calcimatic kiln is presently in operation at the Ash Grove Lime and Portland Cement Co. plant in Greene County. In this kiln, lime is calcined on a rotating, circular hearth. The unique features of this kiln are the variable feed sizes (minus one-fourth to 8 inches) that can be utilized plus exact control of the temperature, time, production rate, and quality of lime produced. The Azbe Corp. of St. Louis has been instrumental in the design and modification of kilns for greater efficiency in lime production.

The addition of controlled amounts of water to quicklime produces dry hydrated lime ($Ca(OH)_2$). Slaking is done by crushing the quicklime to an average size of one-half inch or less and mixing with water in either a continuous or intermittent mechanical hydrator. The hydrated lime contains approximately 26 percent combined water.

The chief uses of lime can be placed in four categories: Chemical (37 percent), metallurgical (including dead-burned dolomite) (34 percent), industrial (18 percent), and construction (9 percent). The percentage figures are the approximate amounts used by each major group in 1964. In many chemical and industrial processes, lime is a basic chemical compound second in importance only to sulfuric acid. Table 26 lists some of the more important uses of lime. The largest increase in the usage of lime is expected in the steel industry as more plants convert to the basic oxygen furnace (BOF), which uses quicklime as the principal flux. Figures ranging from 120 to 175 pounds of quicklime per ingot ton of steel have been suggested for the BOF as opposed to 20 to 30 pounds of quicklime per ton of steel ingot in the open-hearth furnace. Soil stabilization (the mixing of hydrated lime with reactive soils or base materials to agglomerate and consolidate the soil) and sewage and water treatment are becoming important factors in lime utilization. Crushed limestone and dolomite have largely replaced lime for agricultural liming, and less than 2 percent of the lime produced in the United States in 1964 went into agricultural uses. In Missouri, production of agricultural lime has been negligible for a number of years.

TABLE 26.—*Uses of lime*

- Agricultural:
  - Fertilizers
  - Plant nutrients
  - Soil neutralization and conditioner
- Construction:
  - Asphalt paving
  - Concrete products
  - Insulation and acoustical material
  - Mortars, masonry cement, plasters, stucco
  - Sand-lime brick and artificial stone
  - Soil stabilization
  - Whitewash
- Metallurgical:
  - Dead-burned dolomite (furnace refractory linings)
  - Ferrous
    - Basic oxygen furnace
    - Casting
    - Electric furnace
    - Open hearth
    - Waste treatment
    - Wire drawing
  - Nonferrous
    - Alumina manufacturing
    - Magnesium manufacturing
    - Ore flotation
    - Smelting lead, zinc, copper
- Chemical and industrial:
  - Acetylene
  - Alcohols
  - Alkalies
  - Ammonia
  - Calcium carbide, cyanamide, and chloride
  - Calcium salts
  - Disinfectants
  - Dyes
  - Explosives
  - Food and food by-products
  - Glass
  - Glue
  - Grease
  - Industrial waste and sewage treatment
  - Insecticides and fungicides
  - Oil refining
  - Oil well drilling mud
  - Paint pigments
  - Paper
  - Pesticides
  - Petroleum refining
  - Pharmaceuticals
  - Rubber manufacturing
  - Soap
  - Sugar refining
  - Tanneries
  - Varnish
  - Water purification

The chemical purity of a lime depends primarily upon the purity of the raw material and the methods employed in its manufacture. Thus, in addition to reserves and economic factors, chemical impurities and physical reaction to calcination are the two main factors to be considered in evaluating a stone supply. High-calcium limes are most commonly produced from limestones with a calcium carbonate content in excess of 95 percent (often 97 to 98 percent). Minimum requirements for calcium carbonate have been given as low as 90 to 91 percent (Lamar, 1961; Lamar and Willman, 1938). Maximum magnesium carbonate content varies from a high of 6 to 3 percent or less. Missouri lime plants all utilize high-calcium stone (96 to 98 percent). Chief among the impurities present in limestone are silica, alumina, and iron. These are detrimental in that their relative percentage nearly doubles in calcining plus the fact that they combine during calcining with calcium to produce inert silicates and aluminates and thus reduce the percentage of available calcium oxide in the lime. Some of the minor impurities (generally present as trace elements) in limestone are: phosphorus, manganese, sulfur, sodium, fluorine, and arsenic. Standards for lime in certain uses specify allowable maxima for many impurities such as: sulfur in steel; arsenic and fluorine in food products; phosphorus in calcium carbide; and iron in glass.

Though the chemical composition is most often stressed in specifications for a potential rock source, the physical reaction of a particular stone to burning should not be overlooked. Limestones with comparable chemical analyses can react differently during calcining. Some stones crumble or decrepitate readily and are useless as feed for a shaft kiln. Others produce a low-reactive lime that will not

meet consumer specifications. Additional features to be considered are the texture (crystallinity or granularity), shale partings, chert zones, and facies changes. The ideal stone is one that holds its shape during calcination and produces under a variety of manufacturing procedures a lime that meets the chemical and physical demands of the market.

Resources.—The major resources for high-calcium lime are in the Salem, Warsaw, Keokuk, and Burlington Formations of the Mississippian System and in the Kimmswick Formation of the Ordovician System. High-magnesium resources are discussed in the section on Refractory Dolomite. Plants presently in operation utilize the Salem (Mississippi Lime Co.) and Burlington (Ash Grove Lime & Portland Cement Co. and Marblehead Lime Co.) limestones. High-calcium stone (95 to 99 percent $CaCO_3$) crops out in three main areas (fig. 41): (1) a belt paralleling the Mississippi River; (2) counties bordering the Missouri River in the east and central part of the State; and (3) a six-county area in the southwestern part of the State.

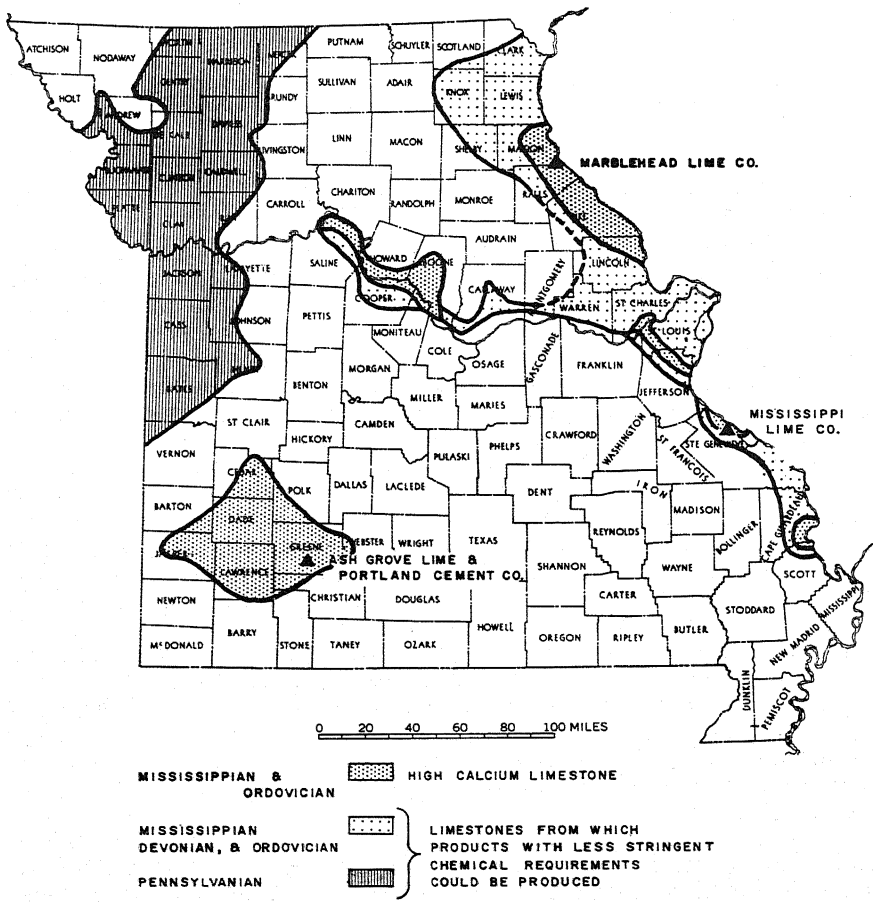


FIGURE 41.—Distribution of limestones suitable for the manufacture of lime and location of lime plants in Missouri.

The principal area of suitable stone in the Salem Formation is in Ste. Genevieve County where it is predominantly a light-gray, crystalline, oolitic limestone. Average thickness is about 160 feet. Chemical and industrial lime is produced from the high-grade oolitic units, which range from 10 to 30 feet in thickness. Interbedded with the chemically pure units are dolomitic limestones. A few chert zones are also present. Lime has been produced in the Ste. Genevieve area since about 1840. Elsewhere in eastern Missouri, the Salem is too dolomitic, shaly, and locally cherty for lime manufacturing. Approxmately 30 to 50 feet of relatively pure limestone has been tentatively identified as Salem in southwestern Missouri.

High-calcium limestone in the Warsaw Formation is present in southwestern Missouri, principally in Barton, Cedar, Dade, Jasper, and Newton Counties, where it consists of from 100 to 150 feet of crystalline limestone. Chert in certain intervals reduces the available thickness of stone that can be used for lime manufacturing. However, thicknesses of from 25 to 50 feet of low-chert stone are present.

The Burlington and Keokuk Limestones, averaging 175 to 200 feet in thickness, crop out in a broad belt through the northeastern, central, and southwestern parts of the State. Their lithology is relatively uniform throughout, consisting of light-gray to white, coarsely crystalline, crinoidal limestone. The chief deleterious material is chert nodules and lenses, which are present throughout most of the limestone, and locally dolomitized rock. In northeastern and central Missouri, the basal 10 to 25 feet of the Burlington is relatively low in chert. In southwestern Missouri, upward of 80 feet of suitable stone with interbedded cherty zones is present in the formation.

The Kimmswick Formation crops out in a belt paralleling the Mississippi River and along the Missouri River in St. Charles, St. Louis, and Franklin Counties. Lime was produced before 1900 from an outlier of the formation in Saline County; however, the total thickness and extent of this outcrop is not known. The Kimmswick is a medium to coarsely crystalline limestone. Minor amounts of chert are present but are generally restricted to definite horizons in the formation. Quartz sand is present locally as grains disseminated in the limestone, especially in the northern outcrop area. Thickness ranges from 50 to 125 feet. Lime produced from the Kimmswick in all but Cape Girardeau and Scott Counties was a dark gray or "black" lime.

The Mississippian St. Louis Limestone, the Devonian Callaway Formation, and the Ordovician Plattin Formation are of less importance but have beds of sufficient quality to produce lime, especially those types of lime that have a higher magnesia and in some cases silica tolerance. Several units in the Pennsylvanian System are considered as a minor resource.

The most favorable areas for suitable stone in the St. Louis Limestone are in the northeast, east-central, and the southwest parts of the State. The formation consists of gray, finely crystalline to lithographic limestone interbedded with dolomitic limestone and dolomite. Shale partings and beds are fairly common throughout the formation in eastern Missouri. Thickness ranges from 125 to 175 feet in the east-central area to 50 feet in the northeast and southwest. Lime was produced from the formation in the St. Louis area during the last century.

Limestone in the Callaway Formation is present in the central part of the State, particularly in Callaway and Cooper Counties. The lithology varies from finely crystalline to dense or lithographic. Vertical and lateral variations in thickness and purity take place in relatively short distances. Thickness varies from a few feet to as much as 60 feet in the aforementioned counties. Lime was manufactured from the Callaway Formation in the early 1900's.

Plattin limestone crops out in a belt contiguous with the Kimmswick Formation along the Mississippi and Missouri Rivers in eastern Missouri. Interbedded with the limestone are thin shale partings and dolomitic limestones. Chert nodules are present throughout but are concentrated in definite intervals. Thickness ranges from several hundred feet in the Cape Girardeau area to about 50 feet in Ralls and Montgomery Counties. There is no record of lime production from this formation.

Several of the limestone formations and members in the Pennsylvanian System contain from 90 to 97 percent calcium carbonate and from less than 1 to 5 percent magnesium carbonate. The chief deleterious materials are interbedded shales and a silica content commonly in the range of from 1 to 5 percent. Chert nodules are also present in several of the limestones. The limestone units are thin, rarely exceeding 20 feet. The most likely limestone units from the standpoint of thickness and calcium carbonate content are in the Higginsville, Swope, Wyandotte, Stanton, and Lawrence Formations. The outcrop area is in west-central and northwestern Missouri from Bates County northward to the Iowa State line.

Outlook.—High-calcium limestone resources for the existing industry and for future expansion are available in the State. Rock units having the greatest potential for further exploitation are present in the eastern, central, and southwestern parts of the State. In some areas, underground mining (either drive-in or shaft) will be required. The major drawback to present utilization of the purer limestone units in the Mississippian System is the high percentage of chert; however, with development of an economical means of removal by special crushing, screening, or perhaps flotation techniques, additional large tonnages of high-calcium stone would be available. Consumer specifications, especially for chemical and metallurgical uses, continue to call for higher purity lime. Limestones capable of meeting these demands are not present everywhere in an inexhaustible supply. Conservation of the high-purity resources could be realized by utilizing the less pure deposits for lime needs having more liberal tolerances.

REFRACTORY DOLOMITE

(By Eva B. Kisvarsanyi, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Basic refractory raw materials include rocks and minerals that contain significant amounts of magnesia (MgO) and that can be processed to yield brick or other products suitable for lining high-temperature furnaces and kilns. Dolomite is one of these used extensively by the steel industry either in its raw form, as calcined dolomite, or as dead-burned dolomite.

Raw dolomite is used for minor repair work and for patching the hearths of open-hearth furnaces. The rock is crushed to a minus

5-inch size and screened to remove the fines. The product is usually delivered directly to the iron and steel plants.

Calcined dolomite is prepared by heating the crushed rock to about 2,000° F. in suitable kilns. Water and most of the carbon dioxide are driven off in the process, leaving calcium oxide (CaO) and magnesium oxide (MgO) which sinter to an extent depending upon the impurities present. Because the chemical reaction involved in calcination is a reversible one, the product slakes readily in the presence of water and even to a certain extent under ordinary atmospheric conditions. Calcined dolomite, therefore, cannot be stored or transported over long distances and its use by the steel industry has been decreasing in recent years.

Dead-burned dolomite is produced by burning the crushed rock in rotary kilns at 3,000° to 3,200° F. The application of higher temperatures results in a dense sintered product that is more stable than calcined dolomite. Iron oxide is generally added before the charge goes to the kiln. It acts as a flux to produce a sintered, granular product, aids calcination, and helps stabilize the calcium oxide. Some manufacturers also add silica and alumina to the crushed rock. Some dolomite deposits contain these necessary ingredients in the right proportions to act as natural fluxes. Dead-burned dolomite is marketed in granular form and is used for patching and maintenance work in basic open-hearth furnaces (fettling), for electric furnace bottoms, in basic Bessemer converters, crucibles for lead blast furnaces, and in crucibles for melting metals (Lamar, 1961). Dolomite has also been used for the manufacture of refractory brick, but its major application is as a granular refractory.

The changing technology of steelmaking has reduced the market for dead-burned dolomite slightly in recent years. Before the introduction of the basic oxygen steelmaking process in 1954, basic open-hearth furnaces accounted for 91 percent of domestic steel production. This figure had dropped to 68 percent in 1965, when basic oxygen furnaces produced 22 percent of the total. Basic open-hearth furnaces consume an average of 42 pounds of dead-burned dolomite per ton of steel produced, and thus, a decline of production from this type furnace is reflected by a decrease in demand for this material. Basic oxygen furnaces will not compensate for this decline, as their refractory consumption is only about 15 pounds per ton of steel output, and this is generally material that does not contain dolomite.

The chemical properties of dolomite for refractories are summarized in table 27. The chemical specifications apply to high-grade dolomites to which the addition of fluxes is necessary. Naturally fluxing stones may contain silica, iron, and alumina in higher proportions, providing that their combined amount does not exceed 10 percent. Physical specifications also call for a stone that does not disintegrate when heated.

TABLE 27.—*Specifications of dolomite raw material for refractory uses*

Use	Minimum allowable percentages		Maximum allowable percentages				Size (inches)
	MgO	Total carbonates	SiO_2	Fe_2O_3	Al_2O_3	S	
Raw crushed	20.0	98.0	2.0	1.0	0.5	0.05	−5
Calcined	18.0–20.0	98.0	2.0	1.0	0.5	------	------
Dead-burned	21.0	98.0	1.0	1.0	0.5	------	½

Source: Lamar, 1961.

Approximately 2 million short tons of dead-burned dolomite have been produced annually in the United States during the past decade (Williams, 1965). Ohio accounted for about half of this production; the rest came from plants in California, Illinois, Mississippi, Missouri, Utah, and West Virginia. In 1963, the average value of dead-burned dolomite was $16.96 per short ton (Williams, 1965). Production data for refractory dolomite in Missouri are reported with the statistics for lime by the U.S. Bureau of Mines in order to avoid disclosing individual confidential figures.

Dolomite deposits occur throughout the entire Ozark region where Cambrian and Ordovician rocks are exposed at the surface (Figure 42). The chemical character of the major rock formations that are composed mostly if not entirely of dolomite are summarized in table 28.

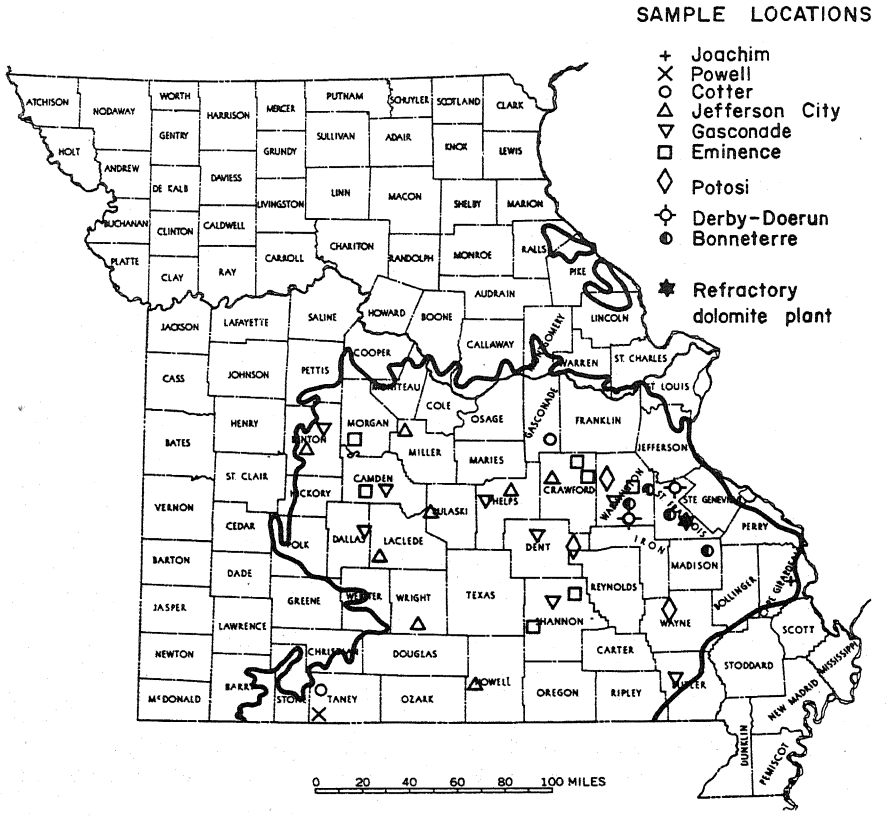


FIGURE 42.—Generalized outcrop areas of dolomite in Missouri and location of refractory dolomite plant. (Formation symbols show location of analyzed samples, Table 28.)

TABLE 28.—*Chemical character of the major Cambrian and Ordovician dolomite formations in Missouri*

Formation name	Locality [1]	$MgCO_3$	Total carbonates	SiO_2	Fe_2O_3	Al_2O_3	Insoluble	Remarks
Joachim Dol.[2]	Cape Girardeau	32.88	95.35	2.40	0.78	0.32	2.50	
Powell Dol.	Taney	34.05	76.00	16.22	11.02	4.18	(3)	Sandy, shaly.
Cotter Dol.[2]	Gasconade; Taney	35.0	89.0	5.0	1.0	1.0	11.0	Cherty.
Jefferson City Dol.[2]	Various	39.3	92.0	4.5	1.0	.4	8.0	Argillaceous.
Gasconade Dol.[2]	do	42.0	94.0	4.0	.3	1.5	5.0	Cherty except for the upper 50 feet.
Eminence Dol.[2]	do	43.5	98.2	.48	.24	.32	.5	Cherty in places.
Potosi Dol.[2]	Dent; Washington; Wayne	43.9	97.0	1.8	.3	.25	2.0	Drusy, cherty.
Derby-Doerun Dol.[2]	St. Francois; Washington	38.5	88.0	7.50	.5	1.5	12.0	Alternating beds of siltstone and shale, not uniformly dolomitic.
Bonneterre Fm.[2]	Madison; St. Francois; Washington	40.6	92.8	2.1	1.6	.9	3.1	

[1] Indicating counties where chemical analyses of a certain formation are available.
[2] Chemical data based on the average of 2 or more analyses, see fig. 42.
[3] No data.

Of the formations listed in table 28, only the Gasconade, the Eminence, and the Bonneterre may be considered as sources of high-grade dolomite. The Eminence is especially pure in Camden and Morgan Counties where it contains less than 2 percent impurities and over 42 percent magnesium carbonate. Good quality dolomite also occurs in the Eminence in Shannon and Washington Counties. The Potosi is generally too cherty to be of value.

The Bonneterre Formation contains zones of high-grade dolomite in the vicinity of Fredericktown, Madison County, and southeast of Bonne Terre, St. Francois County. At the former locality, light-gray, finely crystalline, compact dolomite occurs with a maximum thickness of 150 feet. It averages more than 42.50 percent $MgCO_3$ and less than 1 percent impurities. Analyses from the Bonne Terre area show a higher proportion of impurities, and a $MgCO_3$ content generally above 40 percent. Both these areas were considered as possible sources of dolomite for the production of magnesium metal in the early 1940's (Aid, 1942; McQueen, 1943).

Younger dolomites occur in places outside the Cambrian and Ordovician outcrops areas in the State, but these do not meet the chemical specifications required for refractory grade stone.

Refractory dolomite is produced in Missouri by Valley Dolomite Corp. of St. Louis. The company plant, located about 3 miles south of Bonne Terre in St. Francois County, has been in continuous production since 1930. Dolomite of the Bonneterre Formation is quarried near the plant site. This rock is unique in that its chemical composition permits dead burning without the addition of any fluxes. This is due primarily to the iron oxide content of the stone. Selective quarrying is employed so that only the stone that meets the company's chemical specifications is used for dead burning. During 35 years of operation, the total quarry output has been approximately 10 million tons. Most of this was dead burned. The fines from the crushing and screening plant have been sold as agricultural limestone. In recent years, rock from the quarry that did not meet required chemical specifications for dead burning has been approved by the State Highway Department for use as concrete aggregate.

SAND AND GRAVEL

(By James A. Martin, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Sand and gravel, as used here, are the unconsolidated alluvial and glacial deposits of rock and mineral fragments ranging in size from the No. 200 sieve (U.S. Standard) to 3 or 3½ inches in diameter. The principal use of sand and gravel is as aggregate in concrete construction. None is used in the manufacture of glass and only negligible quantities are used for industrial purposes (grinding and polishing, core and molding sands, blast sands, and so forth). The largest production of sand and gravel is from flood plain and in-channel deposits of the major streams; however, upland terrace and glacial deposits are important in the southeastern and northwestern parts of the State, respectively.

The production of sand and gravel is reported from every State and the annual national tonnage exceeds that of all other mineral commodities. Included with both National and State totals are quartz sand produced from indurated rock (see Silica Sand, p. 203) and mine

tailings marketed as sand and gravel. U.S. production for 1964 was nearly 870 million tons valued at $894 million. Missouri production for the same year was 11.5 million tons valued at $13.4 million, and the State ranked 28th nationally in tonnage. The 1965 State production reached an alltime high of 12.068 million tons valued at $13.7 million. Of the total production, about 90 percent was produced from alluvial sources. During 1965, 72 commercial producers reported from 40 counties and 127 noncommercial (government and contractor) plants were active in 46 counties. Noncommercial production is by a Federal, State, county, or other governmental agency or its contractor. Total production and value of sand and gravel in Missouri and the production of each for the period 1905 to 1965 is shown in figure 43. The alltime high

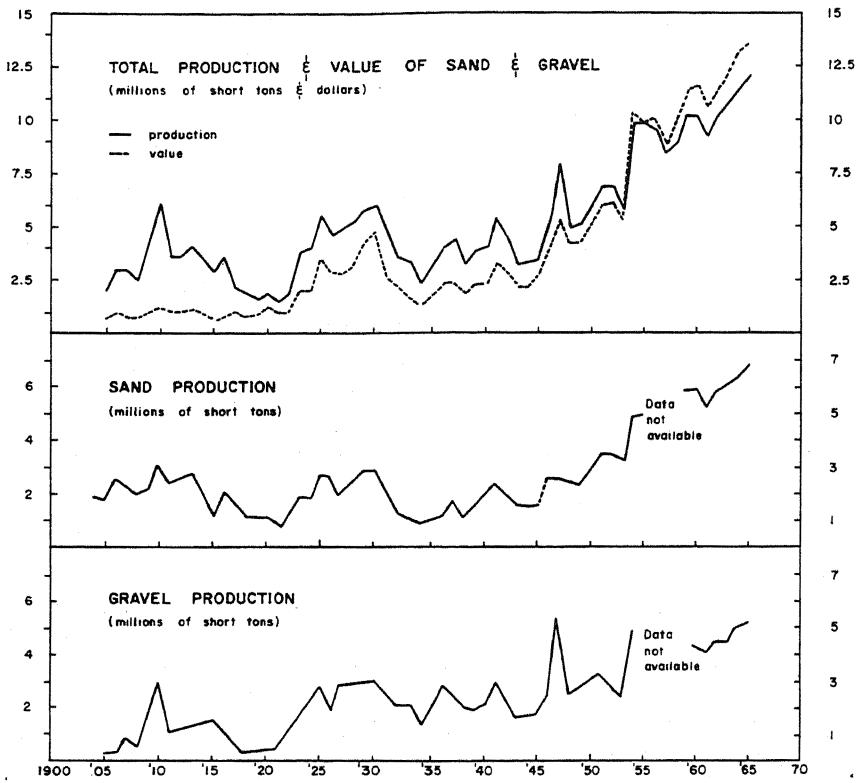


FIGURE 43.—Production and value of sand and gravel in Missouri, 1905–65 (includes silica sand, and mine tailings marketed as sand and gravel). Source: Bishop (1949) 1905 to 1947; U.S. Bureau of Mines, 1948 to 1965.

in gravel production in 1947 was caused by the nearly 3 million tons of gravel used in construction of Clearwater Dam. Counties with reported production for 1965 are shown in figure 44. The greatest production, about 5½ million tons, was from St. Louis County.

Among the mineral commodities produced in Missouri in 1965, sand and gravel ranked second, after stone, in tonnage and seventh in value. The unit value varies with demand, availability, and transportation costs. The average 1965 price of commercial sand and gravel used

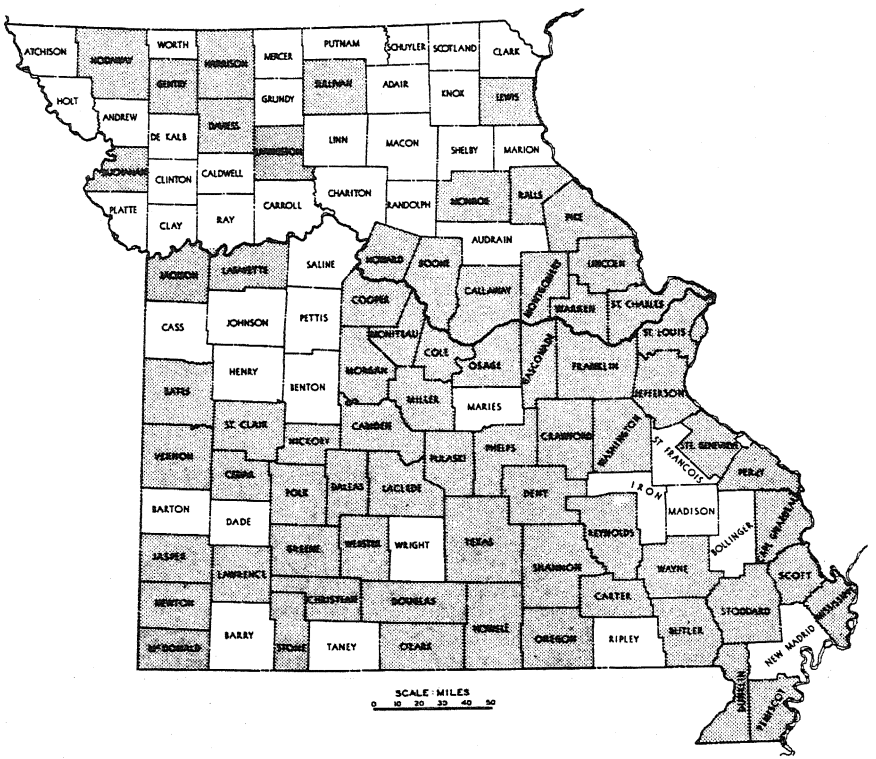


FIGURE 44.—Missouri counties with reported sand and gravel production in 1965. Source: U.S. Bureau of Mines.

in construction was about 90 cents per ton for sand and 97 cents per ton for gravel. As a low-value high-tonnage commodity, plant sites, where feasible, are generally located near the point of use and long-haul shipments are restricted to those areas with inadequate local supplies or for specialty uses. Truck transportation accounted for nearly 80 percent of the total shipments in 1965. The remaining 20 percent was by rail and waterway, or unspecified.

Under present construction specifications, essentially all sand and gravel produced in Missouri undergoes processing such as washing and grading. In 1964, about 3 percent of the total was marketed as unprocessed. Both sand and gravel are essential to most phases of construction and are the major aggregate in portland cement and asphaltic concrete, bituminous paving, surfacing material, mortars and plasters, and to a lesser extent are used as fill and ballast materials. Figure 45 shows the percentage breakdown by use of all sand and gravel, including silica sand and mine and mill tailings, produced in the State during 1965. Noncommercial sand and gravel were used only for paving and surfacing. To a large extent, crushed limestone has replaced stream gravels as the coarse aggregate in portland cement concrete for highway paving in Missouri. In addition to availability and transportation factors, some gravels have reacted adversely with cement and caused excessive cracking and "pop-outs" of the aggregate.

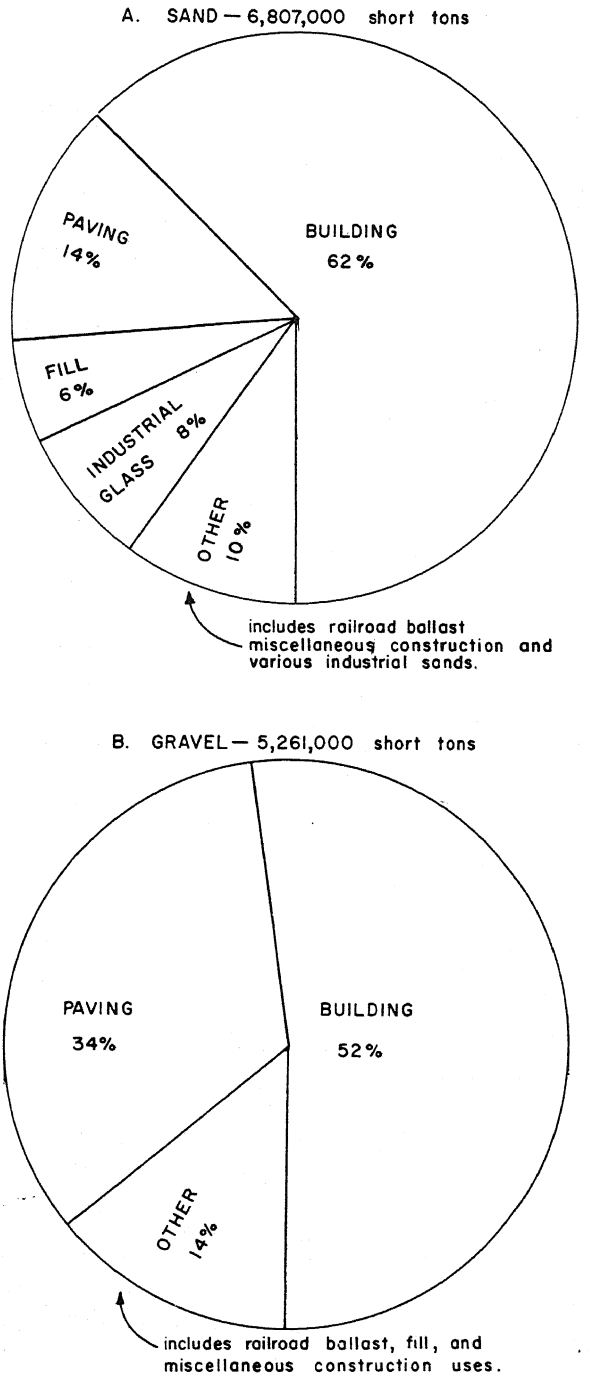


FIGURE 45.—Sand and gravel consumption in Missouri by use, 1965 (includes silica sand and mine tailings). Source: U.S. Bureau of Mines.

Sand and gravel result from the disintegration of bedrock by weathering, with reworking and deposition by water, wind, or glacial action. Deposits may be well sorted and consist of essentially the same types and sizes of material, or they may consist of heterogeneous materials of varying sizes. Shapes may range from smooth and rounded to angular and rough. The terms sand and gravel refer to particle size rather than a particular rock type or mineral, although "sand" is also used to denote quartz grains. Sieve designations, sizes, and various nomenclatures are shown in table 29. Commercial gravel ranges upward to 3 or 3½ inches. Above this size, stone is referred to as cobbles and boulders. In most classifications, the sand-gravel break is made at the No. 10 (2 mm) sieve and the lower limit on sand is made at the No. 200 (0.074 mm) sieve. Specifications for material gradations to be used in construction are given as percent passing and (or) retained on a particular screen.

TABLE 29.—*Particle size classification*

Wentworth (1922)	AASHO and ASTM	Corps of Engineers	U.S.D.A.	Size (Sieve opening) mm	Size (Sieve opening) Inches (approximate)	U.S. Standard Sieve Series (ASTM E-11-61) Sieve designation	Tyler Standard Screen Scale Mesh designation
Boulder gravel	Boulder	Cobbles	Cobbles	256.0	10		
Cobble gravel	Gravel (ASTM)			76.1	3	[1] 3	
Pebble gravel	Gravel	Gravel	Gravel	64.0	2.5	[1] 2½	
Granule gravel		Coarse sand		4.76	0.187	No. 4	4
				4.0	0.157	5	5
				2.0	0.0787	10	9
Very coarse sand	Coarse sand	Medium sand	Very coarse sand				
				1.0	0.0394	18	16
Coarse sand			Coarse sand				
				0.5	0.0197	35	32
Medium sand			Medium sand	0.42	0.0165	40	35
				0.25	0.0098	60	60
Fine sand	Fine sand		Fine sand				
				0.125	0.0049	120	115
				0.105	0.0041	140	150
Very fine sand			Very fine sand	0.074	0.0029	200	200
	Silt			0.0625	0.0024	[2] 230	[2] 250
				0.053	0.0021	270	270
Silt			Silt				

[1] Inches.
[2] Approximate.
AASHO—American Association of State Highway Officials.
ASTM—American Society for Testing Materials.
USDA—United States Department of Agriculture.

RESOURCES

The principal sources of sand and gravel in Missouri are the Recent alluvial deposits associated with the streams and their flood plains. In addition to these, important upland terrace deposits of Tertiary ("Lafayette") age are present in the Southeast Lowlands. In the northwestern part of the State, Pleistocene deposits of glacial outwash or interglacial alluvial origin are present but have limited areal extent. Chert is the predominant rock type present in nearly all gravel deposits in the State and generally comprises a large percentage of the coarser sand fraction. Igneous and metamorphic rocks—chiefly granites, basic rocks, and quartzites—are present in the glacial deposits. In the fine and medium sand range, quartz grains are the principal constituent. Coarser sands are generally an admixture of chert and quartz grains. In areas other than the Mississippi and Missouri Rivers, the distribution and occurrence of sand and gravel in Missouri are discussed by physiographic provinces as shown in figure 1, page 14.

Mississippi-Missouri Rivers.—Nearly 75 percent of the sand and 15 percent of the gravel produced in Missouri during 1964 were taken from the in-channel and floodplain deposits of these two streams. Essentially all of the gravel was produced from floodplain deposits along the Mississippi River. The sand fraction in both streams is chiefly quartz. The Missouri River sands are generally finer grained and the percentage of silt is higher. Lignite, a deleterious material in portland cement concrete aggregate if present in significant amounts, is reported from the Missouri River sands and the Mississippi River south of the confluence of the Missouri. Though chert gravels predominate in both streams, igneous and metamorphic gravels are more common to the Mississippi River. At present, the bulk of production from in-channel operations on both rivers is sand. Floodplain deposits of rounded to subangular admixtures of chert, igneous, metamorphic, and limestone gravels of probable glacial outwash origin are being worked along the Mississippi River north of St. Louis. Sand, predominantly quartz, is also produced from these deposits.

Ozarks Province.—Chert gravels derived from Mississippian and Ordovician limestone and dolomites predominate throughout this area. Quartz sand is present in streams which drain areas of Ordovician sandstone (Salem Plateau); however in the southwestern part (Springfield Plateau), where Mississippian limestones are present, the streams contain only a minor amount of quartz sand. In the St. Francois Mountains area the gravels contain a large percentage of felsite, granite, and basic igneous rocks. Sizes of both sand and gravel are quite variable throughout the Ozarks in all but the larger streams. Most smaller stream deposits contain considerable clay and silt. The chert gravel ranges from smooth, dense, waxy brown types to leached and porous particles. Sand, present as an admixture in the gravel or as relatively clean bars, is generally quartz but includes chert in varying amounts. Most of the streams in this area have the potential of producing large amounts of gravel for future needs, but critical examination and exploration will be required for locating sand and higher quality gravel deposits. In the past, residual upland and

colluvial slope deposits of chert containing relatively minor amounts of clay were worked for road metal. In Perry County, a deposit of bedded residual chert (Clear Creek Chert) was excavated for ballast and road surfacing during the first quarter of this century.

Osage Plains Province.—The alluvial deposits of this area consist predominantly of fine sand (minus 60 sieve), silt, and clay. Gravels are rare to absent in most streams, and the coarser fragments are commonly shale and sandstone particles. Small isolated terrace deposits of Tertiary sand and chert gravel are present in Bates, Henry, and Vernon Counties, chiefly along the Osage, South Grand, and Marmaton Rivers and their major tributaries. Crushed limestone is largely used for aggregate in the area because of the scarcity of gravel deposits. A detailed geologic examination of the area will be required to locate and evaluate the potential sand and gravel resources of the area.

Dissected Till Plains Province.—Glacial drift, ranging from a few to a maximum of 400 feet in thickness, blankets much of this area. Stratified outwash or interglacial alluvial deposits are associated with the drift. The gravels are mostly chert, limestone, quartzite, granite, and basic igneous rocks. Sand, principally quartz grains, ranges from coarse to fine with the largest percentage in the medium to coarse range. The majority of these deposits have a clay matrix, but washing will remove clay coatings from the sand and gravel particles. Deposits are located principally in the northwest and have been worked along their outcrop in Atchison, Holt, Livingston, and Nodaway Counties. Drawbacks to exploitation are rapid thickening and thinning over short distances, thick overburden of glacial drift, and spotty distribution of outcrops; however, a detailed evaluation of these deposits is warranted, especially in areas of limited limestone resources for aggregate. Incorporated in the drift itself are small pockets of sand and gravel which in general are too small for economic exploitation. Stream deposits in the western three-fourths of this area consist of fine to medium sand and contain considerable quantities of silt and clay. Gravel deposits are scarce; however, coarse sands and gravel are present at depth (25 to 50 feet) overlying bedrock in some of the stream valleys. In the eastern one-fourth, glacial drift is thin and the stream deposits are much like those in the Ozarks. Gravels consist predominantly of chert but also contain igneous material derived from the glacial drift. Sand, mostly quartz, is present in most streams, but the silt content is often higher than in the Ozarks.

Southeastern Lowlands Province.—The principal sand and gravel resources are the upland Tertiary ("Lafayette") deposits on Crowley's Ridge in Dunklin, Stoddard, and Scott Counties. Deposits consist of interbedded sands, gravel, and clay. Thickness and distribution are variable throughout the area. Maximum thickness ranges upwards to 60 feet but the average is about 25 feet. Overburden is loess which may attain a maximum thickness of 50 to 75 feet. The gravel is predominantly brown chert and quartz ranging in size from one-half to 3 inches. Black chert pebbles averaging one-fourth inch in diameter are fairly common in most deposits. Nearly all pebbles are waterworn and subangular to rounded in shape. The coarse and medium sand

fraction predominates and consists predominantly of quartz. Interbedded with the gravel are thin beds of red clay and sand. Deposits vary in thickness over short distances and grade from coarse gravel through fine sand and clay. Particles are generally coated with clay which can be removed by washing. Streams adjacent to Crowley's Ridge often contain deposits of reworked "Lafayette" gravel. Alluvial sand deposits, and in some areas gravels, are present over most of the lowland area. Sand sizes range from fine to coarse but within a particular lens the size is generally uniform. Coal "balls" are present in both the sand and gravel and in some areas are of such quantity as to preclude mining of the deposit. The Crowley's Ridge deposits will continue to be the main sand and gravel source for the area.

Outlook.—Overall, the production of sand and gravel in the State will continue to increase to keep pace with the anticipated rise in construction and maintenance demands. Crushed stone will remain the major competitor although inroads are being made by lightweight aggregate and slag. Stricter construction specifications on gradation limits, particle shapes, and deleterious materials will require tighter quality control by the producer. Restrictive mining and zoning regulations, particularly those relating to floodplain deposits, will hamper existing operations to some extent and if unrealistic will curtail production from undeveloped resources adjacent to the prime market areas. The potential sand and gravel production from the Missouri and Mississippi Rivers and the Ozark region is virtually unlimited. Almost inexhaustable supplies are present in these areas to supply demands far into the future. In the areas of the Springfield Plateau subprovince, the Osage Plains and the greater part of the Dissected Till Plains extensive and detailed exploration will be required to evaluate completely the availability and potential of the sand and gravel resources.

SILICA SAND

(By Eva B. Kisvarsanyi, Missouri Geological Survey and Water Resources, Rolla, Mo.)

The term silica or industrial sand is applied to sand and sandstone of exacting chemical and physical specifications that can be used for a number of industrial purposes other than aggregate, ballast, or fill. The prime requisite of a raw material suitable for industrial sand is that it be composed essentially of silica (SiO_2, silicon dioxide, quartz) and have a minimum of deleterious impurities. Deposits of gravel, conglomerate, quartzite, and quartz are also considered as sources of industrial sand if they meet this criterion, although the term "sand" may properly be used only if the grain size is within defined limits (see table 29, p. 200). For most uses these latter raw materials must be processed before they can be marketed as silica sand.

The uses of silica sand are numerous and varied. The bulk of production is consumed by the glass industry. Therefore, the raw material is often referred to as "glass sand." Other major uses are as abrasives (blasting sand, grinding and polishing sand); as metallurgical silica applied as a component in the preparation of silicon

77-278 O—67——14

alloys and as a flux; and as a refractory material (foundry sand, molding sand, core sand). Finely ground silica is used in the ceramic industry in the bodies of whiteware, earthenware, chinaware, and glazed wall tile. The chemical industry uses high-purity industrial sands in the manufacture of soluble silicates and silicon carbide. Miscellaneous minor uses include the application of silica sand as filter media, as engine sand, and in hydraulic fracturing (hydrafrac sand) to promote recovery from oil wells. It is used increasingly in the manufacture of silicones and for a number of other purposes.

The chemical and physical properties of the raw material used as industrial sand must meet rigorous specifications. As a rule chemical specifications call for a maximum amount of silica and a minimum of such impurities as iron, alumina, lime, magnesia, and alkalies. The presence of certain associated detrital minerals, such as ilmenite and chromite, may be detrimental for most uses. Therefore, a limit of their permissible amount is often also specified. Physical characteristics that play the most important role from the standpoint of use are grain size, degree of rounding, and uniformity of grain size or sorting. Primary grain size is important in natural sands and sandstones, but other silica raw materials, such as quartzite, may be crushed to any desired size and sold on the basis of numbered grades. This is the practice for silica used for abrasives. Table 30 summarizes the most important chemical and physical specifications for the major uses of silica.

TABLE 30.—*Specifications for silica sand by uses*

Use	Chemical specifications (oxides expressed in percentages)							Physical specifications			
	Minimum	Maximum allowable					Undesirable materials	Grain size (in mesh unless specified otherwise)	Degree of rounding	Uniformity of grain size	Other
	SiO_2	Fe_2O_3	Al_2O_3	CaO+MgO	Na_2O+K_2O	CO_2					
Glass:											
"Flint" quality	98.0+	0.04	0.02	0.05	0.01		Ilmenite, spinel, sillimanite, kyanite, Mn oxides	20–100	Immaterial	Important	
"Amber" quality	98.0+	0.05–0.10	Slightly higher								
Abrasives:											
Blasting	High						Clay Fe	Coarse 4–12, medium 12–30, fine 20–100		Important	Hardness, toughness, soundness.
Grinding	High							30–100	Immaterial	Important	
Stone sawing and rubbing	High						Clay, mica	12–100			
Metallurgical:											
Silicon alloy manufacture	High	0.2	0.4	Combined 0.3			Ti, P, As opaline silica	½ in.–6 in.			Mechanical breakdown into fines undesirable, ignition loss below 0.3 percent.
Flux	90.0+	1.5	1.5	0.2		1.5		1 in.–4. in.			
Refractory	96.0+										Bond, refractoriness, durability, permeability, size-frequency distribution.
Ceramics	95–99.8	0.05			Minimum		Feldspar, clay	200 (ground)			
Chemical:											
General	99.3–99.7		0.04					20–80			
Soluble silicates	98–99	0.05	0.7	Minimum				20–80	Angular		

Sources: Gay (1957) and Murphy (1960).

Sedimentary, igneous, and metamorphic processes have all produced deposits high in silica. Unconsolidated sedimentary deposits of sand and gravel may have attained a high degree of purity by the selective action of water and air currents. Depending on whether these processes occurred on ocean beaches, in rivers, in lakes, or on land, the deposits are designated as marine, alluvial, lacustrine, or aeolian, respectively. The consolidated equivalents of sand and gravel are sandstone and conglomerate. Primary igneous deposits that are high in silica occur as the quartz cores of pegmatites and as hydrothermal quartz veins. Metamorphism produces dense and massive quartzites of high purity by subjecting primary siliceous sedimentary or igneous rocks to great temperatures and pressures that result in recrystallization of the material.

Unconsolidated raw materials are easy to work and require very little preparation and expense. They do not generally attain the high degree of purity found in some sandstones and quartzites but may be suited for various industrial uses where purity is not a paramount factor. Recent beach and dune deposits in California, for instance, are widely used there as blasting and foundry sand although they contain considerable amounts of feldspar. In Missouri, alluvial sand and gravel deposits are found in the major stream valleys, but they are suited only for construction purposes.

When the source of silica is sandstone, quartzite, or vein quartz, the raw material must be crushed, washed, screened, and sometimes beneficiated in some way before it is used. The highest grade and most productive silica sand deposits in the United States are the Oriskany Sandstone of Early Devonian age and the St. Peter Sandstone of Middle Ordovician age. The former occurs in the Appalachian Highlands and is mined mainly in West Virginia, Pennsylvania, and Virginia. The latter is exploited in Illinois, Iowa, Missouri, and Arkansas.

Some silica deposits are suited for more than one use and others are especially valued for their adaptability to a single use and command high prices. It is very important to a glass manufacturer, for instance, to maintain the quality of his materials supply, as any departure from its standard composition causes expense and trouble.

Production of silica sand in the United States during 1964 was 23,283,000 short tons valued at $74,335,000. About 30 percent of the total production was reported as glass sand. Leading producers were California, Illinois, Missouri, New Jersey, Pennsylvania, Virginia, and West Virginia. Total silica sand production in Missouri from the St. Peter Sandstone during 1965 was 960,088 short tons with a value of $2,900,000. Figure 46 illustrates silica sand production in Missouri from 1930 to 1965.

DEPOSITS

St. Peter Sandstone.—Practically all the industrial sand production in Missouri comes from the St. Peter Sandstone. The formation crops out in a continuous belt ranging from less than a quarter of a mile to 10 miles in width roughly parallel to the Mississippi and Missouri Rivers in Cape Girardeau, Perry, Ste. Genevieve, Jefferson, St. Louis,

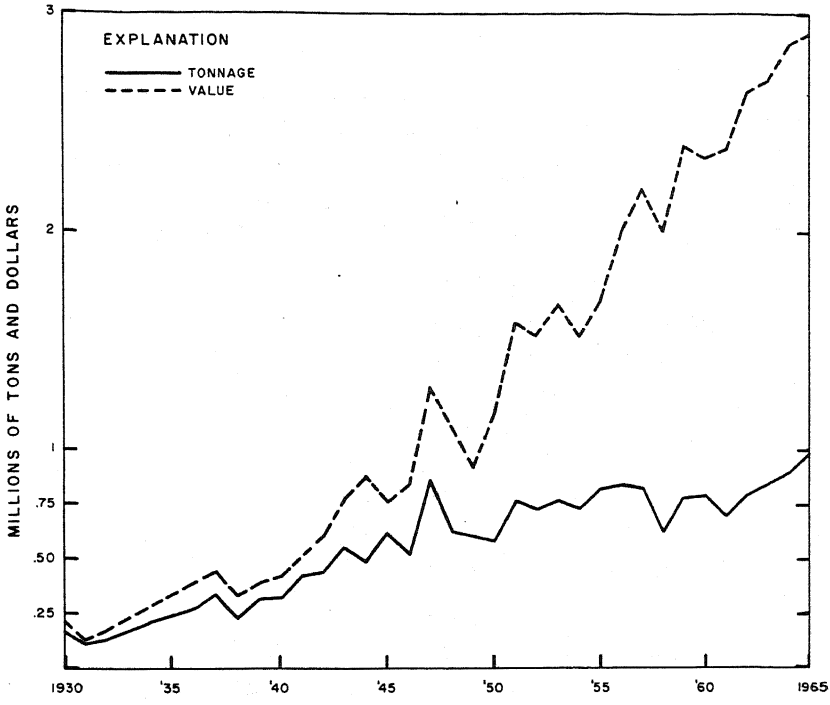


FIGURE 46.—Silica sand production in Missouri, 1930–65. Source: Missouri Division of Mine Inspection, Annual Reports.

Franklin, St. Charles, Warren, Montgomery, and Callaway Counties (fig. 47). Isolated smaller exposures occur in Lincoln and southern Pike Counties. The formation is absent to the west of its outcrop area and dips below the surface to the east and north where it has been encountered in numerous wells in the subsurface. The thickness of the formation varies from 10 to 100 feet, averaging between 60 and 80 feet in its outcrop area. In Perry and Cape Girardeau Counties, where the St. Peter rests conformably on sandstone members of the Everton Formation, the contact between them cannot be readily distinguished. The thickness of the Everton Formation decreases rapidly to the north and it is not known to occur in the State north of Jefferson County. In the central and northern reaches of its outcrop belt, the St. Peter Sandstone is underlain by the Jefferson City Dolomite of Ordovician age.

The St. Peter Sandstone outcrop area is on the northeast margin of the Ozark dome, a position that has given the formation gentle dips varying from one-half to 5° to the north, northeast, and east. Faulting has disturbed the St. Peter Sandstone in only a few places, the most marked of which is near the St. Genevieve-Perry County line. There the continuous belt is offset abruptly by an east-trending zone of complex faulting that has shifted the upthrown (south) side of the outcrop 5 or 6 miles to the east. (See fig. 2, p. 14, and fig. 3, p. 20.)

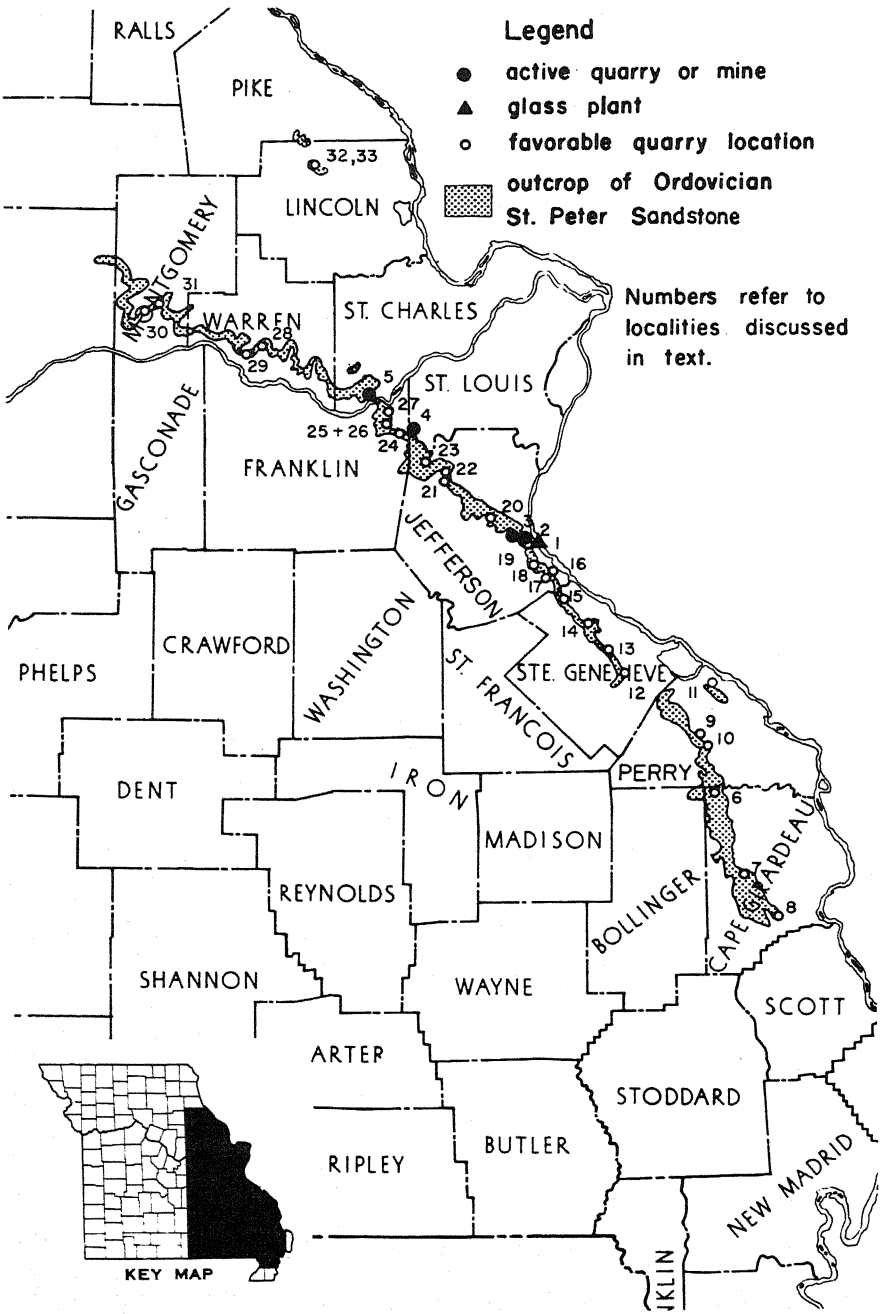


FIGURE 47.—Silica deposits in Missouri.

The St. Peter Sandstone in Missouri is a white, friable, fine- to medium-grained, remarkably pure quartz sandstone. Dake (1918) reported the average of 17 analyses as 99.44 percent silica and 0.078 percent iron. Alumina varies from 0.02 to 1.46 percent, the average being about 0.3 percent. The analyses were made of unwashed samples that were taken from the ferruginous as well as the pure phases of the formation to represent it in its entirety. The ferruginous layers give the rock a reddish or yellowish tint, but they grade into very pure and white sandstone within short distances. Occasionally a greenish tint caused by clay is seen on freshly exposed surfaces, but washing eliminates it entirely. Weathered surfaces are often discolored and case-hardened; however, removal of the crust reveals a clean white sandstone.

In addition to its high chemical quality, the St. Peter Sandstone is also remarkable for its uniformity of grain size. It is composed of well rounded, frosted and pitted sand grains which frequently show secondary crystal growth. The average size of the grains ranges from about 0.20 to 0.15 millimeter. In other words, most of it passes the 40 sieve and is retained on the 100. Typically, the rock is friable and crumbles easily, but locally it is cemented to an orthoquartzite by secondary silica. Throughout most of its outcrop area, the sandstone is massive, though locally it is crossbedded and ripplemarked.

Present producing areas.—The St. Peter Sandstone is mined in Missouri by both open pit and underground methods. In 1965, five operators from three counties reported production for the following uses: glass sand, molding sand, grinding and polishing sand, blast sand, engine sand, filtration sand, ground sand, and miscellaneous. Ground sand was used for abrasives, chemicals, filler, glass, pottery, porcelain, tile, in foundries, and for other unspecified purposes. Table 31 summarizes pertinent data on silica sand producers in the State; the locations of their operations are shown in figure 47.

Glass is manufactured by the Pittsburgh Plate Glass Co. at its Crystal City plant in Jefferson County (fig. 47, no. 1). Operations began here around 1874. The St. Peter Sandstone crops out here in a very narrow belt forming an escarpment toward Plattin Creek and mining is conducted underground by the room and pillar method. The overburden consists of the Joachim Dolomite and younger formations that thicken rapidly from a few feet to 200 feet. The sandstone is very friable and is eminently suited for plate glass manufacture. It is washed and screened but requires practically no crushing. The washed sand is reported to be 99.98 percent silica. The undersize after screening is used for abrasives (grinding and polishing sand). A study made of the workings in 1946 by the Missouri Geological Survey (unpublished manuscript) indicated the life expectancy of the mine to be about 200 years.

Two open pit mines operate at present in Jefferson County and produce silica sand from the St. Peter Sandstone. The Manley Sand Division of the Martin-Marietta Corp. of Rockton, Ill. has a quarry near Festus (fig. 47, no. 2). Glass sand and molding sand are produced for use outside of the State. Masters Brothers Silica Sand Co. opeates an open pit mine near Pevely (fig. 47, no. 3) and produces molding sand and ground sand for abrasives, glass, pottery, and for foundry uses. The rock at these localities is less friable than at the Crystal City workings and usually requires special crushing.

TABLE 31.—*Current producers of silica sand from the St. Peter Sandstone in Missouri*

Number [1]	Company and location	Location [2]	County	Type of operation	Use
1	Pittsburgh Plate Glass Co., Crystal City Plant, Crystal City.	40N–6E:9	Jefferson	Underground mining glass plant	Glass, abrasive.
2	Manley Sand Division, Martin-Marietta Corp., Missouri Plant, Festus.	41N–5E:36	do	Quarry	Glass, molding.
3	Masters Bros. Silica Sand Co., Pevely	41N–5E:27	do	do	Abrasives, molding, glass, foundry, pottery.
4	Pioneer Silica Products Co., Pacific Plant, Pacific.	43N–3E:7	St. Louis	Quarry and underground	Glass, molding, abrasives, chemical, foundry, ceramic.
5	Pennsylvania Glass Sand Corp., Klondike Plant, Augusta.	44N–2E:7	St. Charles	Quarry	Glass, molding.

[1] Locations shown in figure 47.

[2] Township, range and section shown by abbreviated notation used by Missouri Geological Survey and Water Resources.

The quarry of the Pioneer Silica Products Company is located at Pacific, in St. Louis County (fig. 47, no. 4). Operations are carried on by both underground and open pit methods. The overburden consists of Joachim Dolomite that is about 3 feet thick at the quarry face but thickens rapidly into the hill. A gray to white pure quartz sandstone that is moderately friable but requires crushing is quarried. Chemical analyses of the sandstone indicate 99.57 and 99.20 percent silica. The company produces unground sand for the glass industry, molding sands, and sand for miscellaneous uses; and ground sand for abrasive and chemical uses, foundry sand, glass sand, and for various ceramic uses such as pottery.

The Klondike quarry of the Pennsylvania Glass Sand Corporation (formerly Tavern Rock Sand Company) is near Augusta in St. Charles County (fig. 47, no. 5). All mining is by open pit methods. The sandstone is exposed in the bluffs on the north side of the Missouri River. Its thickness averages 100 feet and represents the entire section at this locality. In the quarry, the overburden varies from about 15 feet to 70 feet and consists both of the Joachim Dolomite and the Plattin Formation. Locally, the rock is an orthoquartzite composed of medium to fine quartz grains cemented by silica. Production is primarily for glass sand, but some molding sand is also reported.

Past and potential producing areas.—In the past, the St. Peter Sandstone has been mined at various other localities in Jefferson, St. Louis, and Franklin Counties. Most of these operations have been centered around the Crystal City-Festus, the Pacific, and the Gray Summit areas. These locations have been found most favorable both from the point of view of the quality of the rock and the proximity to cheap transportation facilities. There are various other places in the State, however, where the St. Peter Sandstone might be quarried. Its outcrop parallels closely for nearly 150 miles both the Missouri and Mississippi Rivers where cheap barge transportation is available. Good highways and railroads transect the belt at several places in a general east-west direction and the metropolitan St. Louis area provides a nearby market for industrial sands.

The localities where the St. Peter Sandstone might lend itself favorably to quarrying are listed in table 32; numbers refer to those in figure 47.

Other sources.—In addition to production from the St. Peter Sandstone, industrial sand is also reported from Jasper County in southwestern Missouri where the Independent Gravel Company operates a sandmill in the vicinity of Joplin. They produce silica for abrasives by grinding chats from extensive stockpiles of mine tailings (see Mine and mill tailing products Ch., p. 164) in the old Tri-State Zinc-Lead mining area. The chats consist mainly of chert, a dense, cryptocrystalline form of silica, that constituted much of the gangue in the ore. Production from this area is included in the data represented by figure 45.

A possible future source of silica in Missouri is the "Commerce quartzite" of the Cretaceous McNairy Formation. Its outcrop area is limited to Scott and Stoddard Counties in southeastern Missouri. It occurs as the silicified part of a sandstone member of the McNairy Formation that forms prominent bluffs on the Mississippi River and in Crowley's Ridge. Although the thickness of the quartzite is only about five feet, it is believed to be a persistent zone in the lower part

TABLE 32.—*Favorable quarry locations in the St. Peter Sandstone in Missouri*

Number [1]	Location [2]	County	Chemical composition			Exposed thickness in feet	Remarks
			SiO_2	Fe_2O_3	Al_2O_3		
6	33N–11E:2, 3, 4, 5	Cape Girardeau					Good cliffs, ferruginous on the surface.
7	31N–12E:15, 16	do	99.52	0.07	0.16		Do.
8	30N–13E:19	do	99.00	0.057	0.183		Loess overburden.
9	35N–10E:25	Perry	99.07	0.11	0.46	10–30	Most favorable locality in county.
10	34N–11E:5 35N–11E:32	do	99.34	0.043	0.297		Steep cliffs, ferruginous on the surface.
11	36N–11E:15	do	99.72	0.06	0.02		Quartzitic, brecciated, veined with quartz.
12	37N–8E:26	Ste. Genevieve	99.50	0.067	0.093		Everton formation.
13	38N–8E:32	do					Friable.
14	38N–7E:10	do	99.54	0.10	0.20		Do.
15	39N–7E:29	do					Do.
16	40N–6E:27	Jefferson	97.60	0.10	0.20		
17	40N–6E:33	do					
18	40N–6E:17, 20	do				70	Dominantly friable.
19	40N–6E:6 41N–6E:31	do					Quality of sandstone similar to that at Crystal City.
20	41–N5E:21	do					Former quarry sites.
21	42N–4E:18	do	99.32	0.07	0.12		
22	42N–4E:7	do				70	
23	43N–3E:34	do					
24	43N–2E:12	Franklin					Former quarry site.
25	43N–2E:4	do	99.68	Trace	0.18		Do.
26	43N–2E:4	do					Do.
27	44N–2E:15	do	99.40	0.05	0.08	75	10–40 feet of limestone and loess overburden.
28	46N–2W:32	Warren					
29	45N–3W:1	do	99.57	0.085	0.065		Friable.
30	46N–6W:2	Montgomery	99.64	0.097	0.063		Do.
31	47N–6W:36	do	99.54	0.07	0.13		Do.
32	51N–1W:28	Lincoln	99.26	0.11	0.07		
33	51N–1W:33	do	99.55	Trace	0.33	30	

[1] Locations shown in figure 47.

[2] Township, range, and section shown by abbreviated notation used by Missouri Geological Survey and Water Resources.

of the McNairy Formation. A chemical analysis of the quartzite near Commerce shows 99.50 percent silica, 0.12 percent iron, and 0.24 percent alumina.

SULFUR

(By Eva B. Kisvarsanyi, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Sulfur, a nonmetallic element that is one of the essential raw materials of industry, has many uses. L. B. Gittinger, Jr., in a talk before the Society of Mining Engineers, A.I.M.E., on March 1, 1966, gave the following use pattern for sulfur consumed in the United States in 1965:

Use:	*Percent of total*
As sulfuric acid for—	
Fertilizers:	
Phosphates	36
Other	9
Industrial products:	
Chemicals	18
Titanium and other pigments	7
Iron and steel	4
Rayon and film	4
Petroleum	2
Other	6
Total sulfuric acid	86
Nonacid applications for—	
Pulp	5
Carbon bisulfide	3
Ground and refined	3
Other	3
Total nonacid	14

Sulfur occurs in nature both in elemental form and combined with many other elements as sulfides, sulfates, and other mineral species. The largest and best known deposits of elemental sulfur are associated with the salt domes along the Gulf Coast, both in the United States and Mexico. Other deposits are associated with gypsum in evaporite sequences. Solfataric deposits in volcanic regions have been worked most extensively in Italy.

Sources of nonelemental sulfur are achieving increasing importance. These include deposits of metallic sulfides such as pyrites (the iron sulfides, pyrite, marcasite, and pyrrhotite) and various base-metal sulfides, from which sulfur dioxide is recovered during smelting; sulfates (gypsum and anhydrite); and sulfur in sour gas (particularly hydrogen sulfide). The sulfur content of various sulfur-bearing compounds is as follows:

	Weight percent sulfur
Pyrite and marcasite, FeS_2	51–53
Pyrrhotite, FeS	37–39
Chalcopyrite, $CuFeS_2$	35–36
Sphalerite, ZnS	31–33
Galena, PbS	13–14
Gypsum, $CaSO_4 \cdot 2H_2O$	18
Anhydrite, $CaSO_4$	23
Hydrogen sulfide, H_2S	94
Sulfur dioxide, SO_2	50
Sulfuric acid, H_2SO_4	32.6

The United States is the world's leading producer of sulfur. It is also the world's largest exporter, importer, and consumer of sulfur. In 1965, total free world production of sulfur in all forms was 22.6 million long tons of which the U.S. produced 35 percent or 7.9 million long tons and consumed 37 percent or 8.1 million long tons. Twenty-nine percent of our production was exported and 25 percent of our consumption was imported. Domestic sulfur consumption was equivalent to 93 pounds per capita in 1965, compared to an average of 60 pounds per capita for a group of 20 developed nations of the free world and an average of 23 pounds per capita for the free world as a whole. Free world and U.S. sulfur production in 1965 is shown below:

Millions of long tons, sulfur content

	Frasch sulfur	Sour gas	Pyrites	Smelter gases	Sulfate minerals
Free world	7.7	5.6	6.0	2.7	0.6
United States	6.2	1.3	0.3	(1)	(2)

[1] No data.
[2] None.

In the United States, Frasch sulfur was produced in Louisiana and Texas; pyrites were mined in Pennsylvania, Colorado, Arizona, and South Carolina; and in the production of sulfur recovered from sour natural and refinery gases, Texas, California, Delaware, Wyoming, and New Jersey were the leading States. The production of byproduct sulfuric acid (basis, 100 percent) at domestic copper, zinc, and lead smelters in 1964 amounted to 1,254,373 short tons, equivalent to about 410,000 short tons of sulfur.

During the last decade, the economics of the domestic sulfur industry has changed from a period of oversupply and low prices to one of shortage and rising prices. Export prices for bright and dark sulfur have increased from $25 to $24 per long ton f.o.b. gulf ports in 1963 to $29 and $28 in 1966. As the demand for sulfur is expected to grow, the domestic sulfur industry will have to depend increasingly on sources of supply other than the now dominant Frasch sulfur. In the future, new productive capacity may come from undeveloped and possibly new sour-gas fields, from the pyrites not presently being recovered from operating metal mines, from undeveloped or new sulfide deposits, from sulfur recovered from industrial air pollutants, and finally, if economic conditions are favorable, from the vast sulfur resources in anhydrite and gypsum.

Although at present there is no commercial production of sulfur in Missouri, deposits of pyrites have been utilized in the past and recent developments indicate that byproduct sulfur from smelter gases will constitute an important source in the future.

PYRITES

The term pyrites includes pyrite, marcasite, and fine-grained iron sulfides in which the minerals cannot be determined without microscopic or X-ray methods. Pyrites in Missouri occur in three geologic environments: in filled-sink deposits, in replacement-type deposits

associated with the sulfides of cobalt, nickel, copper, and lead, and in coal deposits. Only the former two have been productive.

Production and history.—Pyrites have been known to occur in the State since 1819 (Grawe, 1945, p. 25) and were frequently encountered in both the lead and iron mines. It was not until 1904, however, that pyrites were produced from filled-sink deposits in Phelps and Crawford Counties and were sold to manufacturers of sulfuric acid and phosphate fertilizer in the Kansas City area and in Tennessee. This first productive period of Missouri's pyrites mining lasted until 1906 when 4,500 long tons of ore was produced (fig. 48).

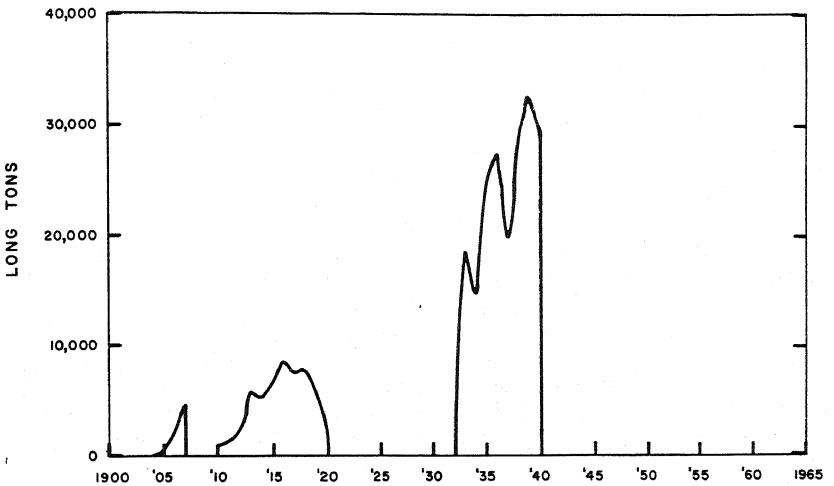


FIGURE 48.—Pyrites production in Missouri, 1900–65.

During the second productive period from 1910 to 1920, several of the filled-sink deposits supplied pyrites to a sulfuric acid plant in East St. Louis, Ill. When the United States entered World War I in 1917, the demand for pyrites increased sharply and prices rose from an average of about $3 to as much as $15 per ton for ore containing 50 percent sulfur. Between 1918 and 1920, the complex pyrites-bearing ores in Madison County were also mined. A lead concentrate was smelted at Fredericktown, but the complex sulfide concentrate was shipped to East St. Louis and to Indiana to be roasted. The sulfur content was converted into sulfuric acid and the metallic oxide residue returned to Fredericktown where the cobalt, nickel, and copper were recovered. There is no record of the actual amount of pyrites produced in this way, but approximately 19,000 tons of "sulfur concentrates" containing 37 percent sulfur were utilized in the manufacture of sulfuric acid. During this period, an attempt was also made to recover pyrites from Missouri coal, but none was shipped.

Nearly 80 percent of the total pyrites production of Missouri was mined between 1932 and 1940. During the depression, Missouri pyrites became a cheap source of sulfur for acid plants operated in conjunction with base-metal smelters in the East St. Louis area after several of the zinc mines had closed down. The steady market encouraged the

reopening of many of the old filled-sink deposits and the prospecting for new deposits. Mining was conducted both by underground and open pit methods. The most productive mines during this period were the Moselle No. 10 in Phelps County, which produced 134,513 tons of ore, the Cherry Valley No. 2 and the Hobo in Crawford County, and the Kelsey and Rueppele in Franklin County. Only a minor amount of ore was produced during this period from the pyrites deposits of Madison County. Most of the ore was sold to sulfuric acid plants in Monsanto, Ill., and St. Louis, Mo.

World War II brought about an increased demand for metals, and the smelters that used Missouri pyrites returned to roasting zinc sulfide ores. Production of pyrites ceased abruptly as illustrated in figure 48. Since 1940, there has been no commercial production of pyrites in the State. In 1944, the mining and milling of the complex cobalt, nickel, copper, and lead ores was resumed at Fredericktown by the St. Louis Smelting and Refining Co. (Division of National Lead Co. since 1948) and a pyrites concentrate was again made. This concentrate, however, was wasted, there being no demand for pyrites, and in 1961 the mine and mill were shut down.

At the Pea Ridge iron mine of the Meramec Mining Co. in Washington County (see chapter on iron, p. 83), a small amount of pyrite is mined with the magnetite-hematite ore. A pyritic concentrate is made at the mill which is subsequently added to the magnetic concentrate to make iron pellets. The byproduct pyrite recovered in this way, therefore, becomes a source of iron rather than sulfur.

Geologic occurrence.—The principal area of pyrites-bearing sink structures is in Dent, Phelps, Crawford, and Franklin Counties. This area coincides with that of the filled-sink hematite deposits (see fig. 18, p. 79). In most sink structures, the pyrites in the zone of oxidation have been altered to iron oxides that formed the basis of early "red iron ore" mining in the State. The geology of these deposits is discussed in detail by Grawe (1945) and is treated more fully in this report under the chapter on iron (p. 84). Most of the deposits were first mined for iron and in the course of prospecting for or mining it, the underlying pyrites were discovered. Some of the deposits were very large; the Cherry Valley deposit in Crawford County was 900 by 600 by 150 feet deep, and the Moselle No. 10 in Phelps County was 300 by 240 by 185 feet deep. At the Rueppele mine in Franklin County, pyrites ore extended to a depth of 335 feet. The grade of the ore was high in most of the mines, carload lots from the Moselle No. 10 contained 51 percent sulfur, and the average grade was 48 percent.

In the Fredericktown district of Madison County, pyrites occur intergrown with sulfides of cobalt, nickel, copper, and lead in the basal portion of the Bonneterre Formation and in the top of the Lamotte Sandstone. The geology and mineral paragenesis of these deposits are discussed by Grawe (1945) and in the lead-zinc section of this report. Pyrites also occur alone above the zone of complex ore. The deposits that contain pyrites with other sulfides have been economically more important because sulfur could be produced as a byproduct of the mining and concentration of the other ores.

Pyrites in Missouri also occur associated with sphalerite as fracture fillings in the Jefferson City Dolomite and with the residual limonite deposits in Howell County. In Jefferson and Washington Counties, pyrites are common gangue minerals in the copper, lead, zinc, and barite deposits. A pyritic zone was encountered by seven drill holes and one 45-foot shaft in the Jefferson City Dolomite in the vicinity of Norwood, Wright County, in 1918. Various attempts were made during the past to produce pyrites commercially from these deposits, but without success. Although the lead-zinc deposits of the Tri-State District also contain pyrites, these have never been recovered.

Future of pyrites mining.—It is believed that only small resources of filled-sink pyrites remain. Most of the deposits described by Grawe (1945) were worked out at the time of his study in the late 1930's and early 1940's. Exploration for iron by the U.S. Bureau of Mines in 1943 encountered some pyrites in a few structures, but no large reserve is known. Owing to the depth of the known ore in the area, underground mining would be required to extract it; oxidation of the sulfides, especially the marcasite, creates a very unpleasant atmosphere in subsurface workings and has even resulted in spontaneous combustion in some mines (Grawe, 1945, pp. 32–40). The cost of extraction might exceed its value. Only under very favorable economic conditions would the filled-sink pyrites deposits of Missouri become a source of sulfur again.

SULFUR IN COAL

Sulfur is present as an impurity in coal deposits in three forms: as pyrites, as sulfates, and as organic sulfur. In the Pennsylvanian coal and associated shale beds of Missouri (see fig. 2, p. 14), pyrites occur as bands or layers, as lenses and concretions, and as small disseminated grains. According to Netzeband and others (1964), the pyritic waste from cleaning operations of the high-sulfur coals in Missouri, Kansas, and Oklahoma contains from 3 to 12 percent sulfur. A study conducted in 1918 to determine the feasibility of byproduct pyrites recovery from coal mines in Missouri indicated that some of the coal beds might yield from 12 to 264 tons of pyrites daily containing at least 40 percent sulfur (Grawe, 1945). Because of the rapid development of the Texas and Louisiana sulfur industry following the introduction of the Frasch method of sulfur recovery in 1919, the idea of utilizing pyrites from Missouri coal deposits was abandoned.

Organic sulfur is distributed throughout the coal substance as part of the molecular structure. This type of sulfur in Missouri coals is generally less than that derived from pyrites and ranges from 0.90 to 2.01 percent. The amount of sulfate sulfur in fresh coals is generally less than 0.05 percent, but as pyrite and marcasite easily oxidize to the sulfate, this type of sulfur may be higher in weathered coals. Analyses of the various forms of sulfur in Missouri coals are given by Walker and Hartner (1966, pp. 20–21).

The removal of sulfur from coal depends on its form of occurrence. Bands, lenses, and concretions of pyrites can be removed relatively

easily by crushing and mechanical cleaning. Finely disseminated pyrites can be separated from the coal by very fine crushing and subsequent special treatment. No commercial methods for this separation have yet been developed, but research is in progress in this field (Walker and Hartner, 1966). The removal of organic sulfur is more complicated and requires chemical treatment. Only the coarser pyritic fraction is removed from Missouri coals, and they consequently remain fairly high in sulfur.

Sulfur in all forms is an undesirable constitutent in coals. It contributes to the formation of fireside boiler deposits during combustion that reduce boiler efficiency and lead to corrosion problems. As it has an affinity for metallic iron, sulfur from coal can be a particularly deleterious contaminant in blast furnaces. Gaseous sulfur products emitted into the atmosphere during coal utilization contribute greatly to air pollution. A report to the Greater St. Louis Committee for Nuclear Information in May 1966 indicated that 446,500 tons of sulfur dioxide are released to the air in the St. Louis area annually, of which more than half comes from five major steam electric generating plants using high-sulfur Illinois coals. (Robert A. Taft Sanitary Eng. Center, 1966). In June 1966, a model antipollution ordinance was drawn up by the Air Resource Management Program to be submitted to the St. Louis County legal department for drafting into a proposed ordinance for the county.

The growing national concern over air pollution may lead to local, State, and Federal regulations restricting the permissible amount of air pollutants in affected areas. This could necessitate the use of air-pollution control devices by many industries and lead to the recovery of much of the sulfur in coal as a byproduct.

SMELTER GASES

Byproduct sulfur in the form of sulfuric acid will be produced by Missouri's only operating primary metal smelter at Herculaneum, Jefferson County. The smelter has been operated by the St. Joseph Lead Company since 1891 treating lead and zinc sulfides from the company's mines in southeastern Missouri. An $11-million project is currently underway to double the plant's capacity to more than 200,000 tons of refined lead annually and to construct a sulfuric acid plant with an output capacity of 100,000 tons per year. This will be equivalent to about 32,600 tons of sulfur on a 100 percent acid basis. The acid plant is expected to be in operation by 1968.

Two new lead smelters are under construction in Iron County. Missouri Lead Operating Co.'s Bixby smelter will produce from 50,000 to 70,000 tons of byproduct sulfuric acid annually (about 20,000 tons equivalent sulfur on 100-percent basis). No plans for an acid plant have been announced for American Smelting & Refining Co.'s Glover smelter, but it will have an estimated potential capacity of 10,000 to 15,000 tons of equivalent sulfur. By 1968, two Missouri smelters will produce over 50,000 tons of byproduct sulfur and, should the Glover smelter also install an acid plant, the State's total sulfur production capacity would be well over 65,000 tons. This figure still constitutes less than 1 percent of the current national sulfur output.

At the present time, Missouri has two sulfuric acid plants in operation. National Lead Co. has a plant in St. Louis and the Davison Chemical Division of W. R. Grace Co. has one in Joplin. Both plants are captive, as practically all of their output is used at the plant locations or at other locations of the same firms; both plants use native sulfur as the raw material for acid manufacture. Missouri's markets for sulfuric acid are currently supplied by plants in Kansas, Oklahoma, and Illinois. (Reardon, 1965). The growing need for fertilizers will assure a market for commercial acid produced in the State.

In 1965, more than 23 million short tons of sulfuric acid were produced in the United States. Less than 10 percent of this was produced from smelter gases. The emphasis on reduction of atmospheric pollution will tend to increase the recovery of sulfur from gases at smelters and other industrial plants.

PHOSPHATE

(By P. W. Guild, U.S. Geological Survey, Washington, D.C.)

Phosphorus is essential to all life and a chief ingredient of fertilizers; it also has industrial uses in various chemical compounds. Although the primary source is in apatite, approximately $Ca_5(F,Cl,OH)(PO_4)_3$, a constituent of igneous rocks and in particular of certain iron ores, most phosphatic raw material is obtained from concentrations in sedimentary deposits. Consumption is rising rapidly; in 1965 U.S. output surpassed 26 million tons of phosphate rock containing more than 8 million tons of P_2O_5 and valued at more than $190 million. About 73 percent of this came from Florida, the remainder from mines in Tennessee, North Carolina, and various Western States. The United States produced 40 percent of the world output and is considered to have 30 percent of world reserves (Lewis, 1965b, p. 704).

Sulfuric acid is a necessary ingredient in the preparation of most phosphatic fertilizers, being used either directly to acidulate phosphate rock to the water-soluble superphosphate or to produce phosphoric acid for preparation of triple superphosphate or diammonium phosphate. Phosphoric acid can also be made in the electric furnace, but cheap electric power is required. In 1965 about 3 million tons of sulfur was used in the United States for making phosphatic fertilizers (see p. 213).

Missouri has not produced any phosphate rock and has only low-grade resources of uncertain quantity and tenor. Phosphates do, however, occur in two distinct geologic environments in the State, and as Missouri also produces sulfuric acid and will increase its capacity (see p. 218) it has the necessary raw materials to establish a small fertilizer industry.

Probably the most important source of phosphorus in Missouri is from apatite occurring as a gangue mineral associated with certain of the Precambrian iron ores. Parts of the Iron Mountain deposit contained so much phosphorus (in apatite crystals up to an inch or more across and several inches long) that the ore could not be used for making iron and steel. The Pea Ridge deposit also contains apatite, most of which is, however, removed during beneficiation. The

77-278 O—67——15

St. Joseph Lead Co. may decide to make a fertilizer product from this apatite, using sulfuric acid to be produced at its lead smelter at Herculaneum. No details have been announced, but the phosphorus content of the ore ranges from 0.4 to more than 1 percent (Hayes, 1959, p. 9; Frommer and Fine, 1960, p. 4), and averages 0.8 percent (E.J. Harmon, personal communication, Nov. 18, 1966), equivalent to 1.8 percent P_2O_5 or about 4 percent apatite. A small amount remains with the magnetite during beneficiation and some is no doubt lost in the tailings, but preliminary tests (Frommer and Fine, 1960, p. 14) suggested that 75 to 80 percent of the apatite can be recovered and that the quantity might amount to 100,000 tons a year. Missouri's output would be only a small fraction of 1 percent of the national total, unless other iron-ore deposits containing significant amounts of apatite should be developed. The Pilot Knob deposit does not contain appreciable apatite, so far as is known.

Phosphatic nodules are associated with many of the black slaty shales in the coal-bearing strata of Pennsylvanian age in Missouri. Accumulations in the refuse from stripping and coal washing operations could furnish modest amounts of phosphate if an economical means of recovering the nodules could be devised (see p. 171 and table 23). The average value of phosphate rock is only about $7 per ton, however, so no great expense could be incurred in separating the nodules from the rest of the waste material. Analyses of phosphatic shales of comparable age in eastern Kansas range from less than 1 to 4.24 percent P_2O_5 (Runnels, 1949, p. 44). The phosphate is concentrated in nodules which average 30.2 percent P_2O_5 (Runnels and others, 1953, p. 99), but laboratory attempts to upgrade the shales by grinding and flotation were unsuccessful (Runnels, 1949, p. 40).

TRIPOLI

(By L. D. Fellows, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Tripoli is a fine-grained, porous siliceous rock that is found in only a few places in the world. One of the best known and most productive areas is in southwestern Missouri and adjacent Oklahoma. The name was derived from Tripoli, North Africa, where deposits once thought to be identical with those in the Missouri-Oklahoma district have long been known.

Tripoli is composed almost entirely of silica in the form of chalcedony, with small admixtures of iron oxide, alumina, and other constituents (Table 33). The table gives representative analyses of tripoli from the Missouri-Oklahoma district and, for comparison, analyses of similar substances from other parts of the United States. The constituent particles of tripoli range from 0.1 to 0.00002 millimeters (0.004 to 0.0000008 inch) in diameter. (See table 29, p. 200, for a comparison with better-known materials.) These particles, which have no sharp edges or corners, have about the same hardness as quartz (seven on Moh's scale). The color of tripoli ranges from cream to rose, depending on the content of iron oxide. The rose variety has a higher percentage of the fine sizes than the cream. The specific surface area of tripoli may be as much as 11.9 square meters per gram.

TABLE 33.—*Representative analyses of tripoli and so-called "soft" silica from various areas in the United States*

[In percent]

Constitutent	Missouri-Oklahoma [1]		Arkansas	Illinois	West Tennessee Valley	East Tennessee-Georgia
	Rose	Cream				
SiO_2	92.08	97.810	99.72	99.44	98.92	93.98
Fe_2O_3	1.290	.290	.003	.14	.07	0.22–1.6
Al_2O_3	3.630	.640	.067	.22	.46	1.0–1.4
TiO_2	.106	.014	----	----	----	Tr. 20
CaO	.026	.090	.090	----	.37	Tr. 30
MgO	.018	.029	.001	----	----	Tr. 20
P_2O_5	.009	.007	----	----	----	----
MnO	.002	.004	----	----	----	----
Na_2O	.360	.320	----	----	----	----
K_2O	.020	.021	----	----	----	----
SO_3	.005	.006	----	----	----	----
Mositure at 100° C	.540	.230	----	----	----	----
Ignition loss, not including mositure	1.870	.509	.120	.25	----	0.3–0.7
Undetermined	.044	.030	----	----	----	----

[1] Statistics on Missouri-Oklahoma from the American Tripoli Division of the Carborundum Co. Other statistics from Chandler (1960, table 1).

Tripoli is useful both for its porosity and permeability and because of its hardness. It was originally shaped into filters for home water-filtering systems or was sawed into bricks for scouring and polishing. Now most of it is crushed and used largely as an abrasive. Its principal present uses are for buffing and lacquer-finishing compounds and automobile polishes. Additional uses are as foundry parting, filler, cleaner, floor sweep, wood finish, in polishing cloths, insecticides, putty, admixtures for concrete, and in polish for metals, buttons, and gems.

The original tripoli deposits of North Africa, which are now called tripolite, are composed almost entirely of the remains of diatoms, one-celled marine organisms that secrete siliceous shells. Tripoli from the Missouri-Oklahoma district, however, does not contain diatoms, but rather is the insoluble residue that remains after the intense chemical weathering of highly siliceous limestone. Deposits in other parts of the United States have compositions, properties, and uses similar to those of tripoli but were derived from the weathering of different rock formations. These deposits, known variously as "amorphous" silica, "soft" silica, and rottenstone, are commonly lumped together with tripoli when domestic production statistics are reported.

Tripoli was discovered in Newton County, Mo., near Seneca, in 1869 and first mined in 1871. In 1885, the first grinding mill was built in Seneca. Production was small until 1892 when the American Tripoli Co. was organized. Several companies were active near Racine in the early 1900's (Siebenthal and Mesler, 1908, pp. 436–437). The American Tripoli Co. expanded and in 1954 became the American Tripoli Division of the Carborundum Co. Missouri was the leading tripoli producer in the United States until 1914 when production began in Oklahoma. Now most of the tripoli is quarried in Oklahoma and processed at Seneca. A small quantity was mined in Missouri in 1965 for the first time in many years.

Detailed statistics on production are limited for several reasons. There has been only one producer in Missouri for many years and this company also processes the tripoli mined in Oklahoma. The U.S. Bureau of Mines lumps figures on production of tripoli from the

Missouri-Oklahoma district with those for "amorphous silica" from Illinois and "rottenstone" from Pennsylvania to avoid disclosing individual company data. Table 34 gives some figures for the industry. Bishop (1949, p. 81) estimated that the Missouri production of tripoli through 1947 had been 308,000 tons valued at $4,105,000. In 1958, the Missouri-Oklahoma district was the largest producer in the United States in both tonnage and value. The United States is the chief exporting country of tripoli and amorphous silica. Tripoli from the Missouri-Oklahoma district has been shipped abroad since 1894.

TABLE 34.—*Estimated production and value of tripoli mined and/or processed in Missouri for selected years*

Year	Production (short tons)	Total value (dollars)	Price per short ton	Year	Production (short tons)	Total value (dollars)	Price per short ton
1893	1,000	25,000		1916	±9,000	±90,000	
1894	1,375	35,500		1917			$6–$8
1905		50,000		1945	6,542	114,188	
1906		60,000	$6–$7	1946	12,180	211,244	
1913	7,529	83,995		1947	19,375	469,927	
1914	6,721	81,434		1958			50–55

Siebenthal and Mesler (1908, pp. 429–430) stated that tripoli in the Missouri-Oklahoma district is mostly in the "Boone formation" (Mississippian age) above the Short Creek Oolite Member. This places it in what is now known as the Warsaw Formation. That below the Short Creek is probably in the Keokuk Limestone of present-day classification. Both formations consist largely of gray, crinoidal limestone. Tripoli occurs in flat-lying deposits from 4 to 20 feet thick beneath residuum under broad, flat-topped hills. Three general areas of deposits are known (fig. 49) although tripoli is scattered throughout the Missouri-Oklahoma district.

Mining is by open cut. After the residuum (not more than 10 or 12 feet in thickness) has been removed, the tripoli is blasted into chunks that are hand sorted by color and grade. Chert nodules are removed by hand. Excessive quantities of chert may force abandonment of a deposit. The crude tripoli generally contains from 20 to 25 percent water, depending upon weather conditions and the season. Crude tripoli is stored in drying sheds for several months before milling. It is then coarsely crushed, artifically dried, ground one or more times, and screened or classified by a rising air column. Average screen analyses furnished by the American Tripoli Division of the Carborundum Co. are as follows:

(Tyler Standard) [1]	Once Ground	Double Ground	Air Float
35	Tr	0.000%	0.000%
48	.500%	.001	.001
65	3.000	.009	.009
100	5.000	.100	.010
150	4.000	.500	.500
200	4.500	3.000	1.000
Thru 200	83.000	94.390	98.480

[1] See table 29, p. 200.

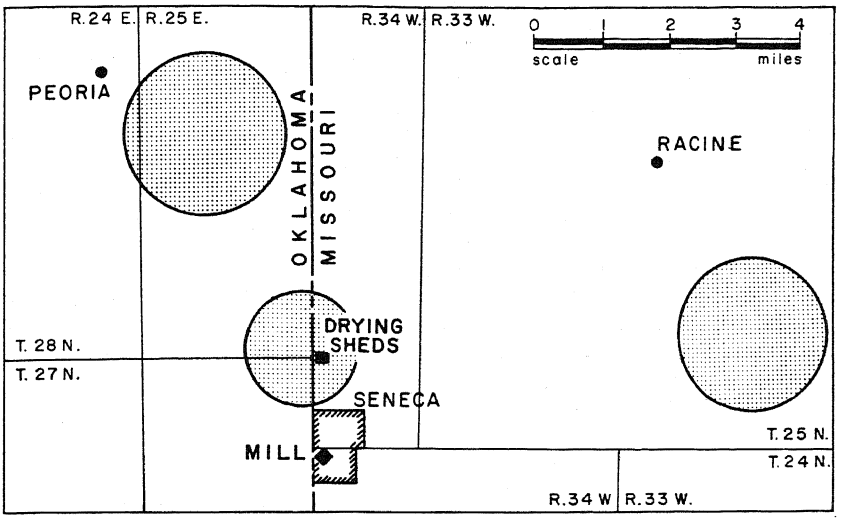


FIGURE 49.—General distribution of tripoli deposits in the southwestern Missouri area.

Tripoli is normally packaged in 100-pound lots in paper sacks for shipment.

The outlook for significant resumption of mining of the Missouri deposits cannot be predicted. The Oklahoma deposits being exploited are larger than those known in Missouri. Exhaustion of the former or a sharp increase in demand for tripoli would obviously hasten activity in Missouri.

GEM STONES

(By Eva B. Kisvarsanyi, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Gem stones are natural substances of unusual beauty that can be fashioned into jewelry and other decorative objects. Most gem stones are inorganic minerals (amethyst, turquoise, topaz, etc.) but some organic materials are also considered to be of gem quality (pearl, coral, amber, jet). Traditionally, only diamond, ruby, sapphire, and emerald were designated as precious stones and the large number of other gem quality materials were called semiprecious stones. This distinction was recognized to be arbitrary, and in recent years the term semiprecious has been falling into disuse.

Gem stones must be rare and durable as well as beautiful in order to be held in high esteem. The beauty of a stone depends on optical properties such as color, transparency, index of refraction and dispersion, and on various textural and structural features. Freedom from visible defects is an important requirement. Durability is primarily a factor of the hardness of the species that determines its resistance to abrasion, chipping, and splitting. Hardness of 7.5 or greater (Moh's scale) characterizes diamond, ruby, sapphire, and emerald, and most of the other gem stones have a hardness of 5 or more. Resistance to chemical alteration under normal atmospheric conditions is also an essential element of durability.

The major use of gem stones is in jewelry, small ornaments, and other decorative articles. The rough stone is processed by cutting, polishing, carving, or engraving to enhance its natural beauty. The process of tumbling has recently become very popular for irregularly shaped stones. A considerable proportion of gem stones are displayed in their natural form as mineral species in private and institutional collections. Some gem stones have important industrial uses. In the period between 1950 and 1955, about 83 percent of the world's diamond production was consumed in various industrial forms, such as bort in diamond drill bits, as tool stones, as wire-drawing dies, and as grit and powder for grinding (Jahns, 1960). The hardest and toughest gem materials are used for bearings in watches and in scientific instruments. The various forms of cryptocrystalline quartz are the chief raw material for laboratory mortars and pestles. Quartz crystal is used in electronic and optical instruments, and calcite (Iceland spar) in polarizing microscopes.

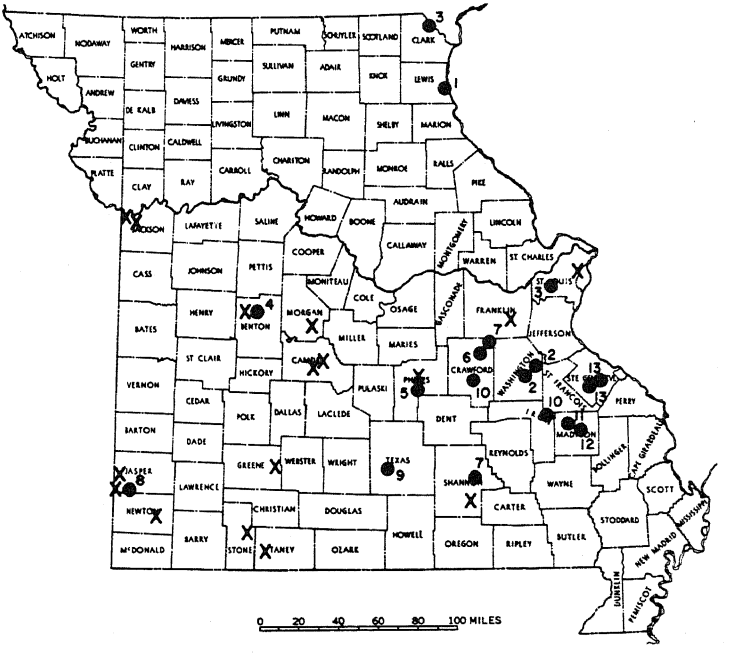
Gem stones occur principally in igneous and metamorphic rocks and in alluvial deposits derived from such rocks. Some of the more important varieties of gem stones that are commonly found in igneous rocks are diamond, of the famous kimberlite pipes of South Africa; beryl (emerald), tourmaline, quartz, topaz, and spodumene, of pegmatite dikes; and opal, quartz, and turquoise that occur in veins and cavities in volcanic rocks. Gem varieties of corundum (ruby and sapphire), garnet, andalusite, and jade are associated with metamorphic rocks. Because most of these gem stones are resistant to abrasion and chemical alteration, and have higher specific gravities than the common rock forming minerals, they become concentrated in alluvial deposits. Agate, jasper, and quartz crystal appear frequently in sedimentary rocks.

The estimated value of U.S. gem stone production was more than $1.4 million in 1963. In comparison, imports amounted to nearly $256 million. U.S. production came principally from Western States and consisted mainly of agate, jasper, jade, petrified wood, quartz crystal, and turquoise. Some minor production of tourmaline, fire opal, diamond, sapphire, rose quartz, amazonite, beryl, garnet, jasper, and a few other varieties is reported annually. The domestic gem stone production today is characterized by the activities of a few small companies, individual operators, and thousands of amateur collectors and lapidaries. Much of the output has remained in private hands or has been sold through local dealers. Because of this situation, no reliable production statistics of U.S. gem stone production are available.

Precious gems are usually marketed by their weight measured in carats. One carat is equivalent to 0.2 gram or 200 milligrams. Less precious gems are sold by the gram, kilogram, ounce, or pound. The average price per carat of rough gem diamond imported for consumption in 1963 was $74.23. Less precious transparent stones, when cut, are sold for $2 to $50 per carat, depending on size and quality. Cut and polished opaque minerals in the 10- to 15-carat size range command $5 to $30 per stone (Petkof, 1965, p. 376). In general, the value of a gem is greatly influenced by fashion, publicity, rarity, and world economic conditions.

Gem stone occurrences in Missouri.—The economic significance of gem stones in the mineral industry of Missouri is negligible. In 1963, the latest year for which gem stone production statistics are available, gem stones constituted only about 0.0003 percent by value of the total mineral production of the State. Nevertheless, various gem materials and mineral specimens have been collected here ever since man first settled the area.

Most of the gem stones found in Missouri belong to the quartz family. Agate, jasper, amethyst, and smoky quartz have been reported, as well as onyx, azurite, geodes, and petrified wood. Specimens of fluorite, barite, calcite, galena, sphalerite, hematite, limonite, pyrite, and marcasite may be collected at various localities (see fig. 50).



EXPLANATION

1. AGATE
2. DRUSY QUARTZ, BARITE
3. GEODES
4. MOZARKITE
5. AMETHYST, SMOKY QUARTZ
6. CITRINE
7. AZURITE, MALACHITE
8. CALCITE, FLUORITE, GALENA, SPHALERITE
9. BLUE BARITE
10. HEMATITE
11. WOLFRAMITE, ARSENOPYRITE, SPHALERITE, FLUORITE
12. "DEVONITE"
13. ONYX

X ROCK SHOP

FIGURE 50.—Gem and mineral occurences in Missouri.

Agates, or banded chert pebbles, are found in northern Missouri in glacial and stream gravels. A gravel pit near LaGrange, Lewis County, has been a particularly good source of agate. The LaGrange

gravel pit has also been a good source of petrified wood specimens. Banded chalcedony and quartz druse in the dolomite of the Potosi Dolomite in southeast Missouri is also prized. It is especially abundant in the open-pit barite mines in the vicinity of Cadet and Potosi in Washington County. Jasper (ferruginous chert) is present at various localities in Bollinger, Cape Girardeau, Madison, Iron, Wayne, and St. Louis Counties. Quartz crystal geodes are found in the Kahoka-Wayland area in Clark County and in St. Louis County. They occur in shales of the Keokuk Limestone and the Warsaw Formation of Mississippian age.

Compact chert suitable for cutting and polishing has been found in Benton and Dade Counties. A pink chert that occurs in the Cotter Dolomite of Ordovician age in the vicinity of Lincoln, Benton County, has been named mozarkite after its type locality in the Missouri Ozarks. At the time of its discovery in the late 1950's, there was considerable local excitement and a stock company was formed to promote sales of the stone. Rock hounds from various parts of the country were attracted to the area and probably several thousand pounds of the stone were collected. The rough stone was sold at prices ranging from 35 cents to $1 per pound; its current price is $1.50 per pound. Cut and polished mozarkite shows many colors of the rainbow and can be fashioned into very attractive pieces of jewelry. In this form, mozarkite is worth several dollars an ounce, depending on size and quality.

Amethyst, smoky quartz, citrine, azurite, and malachite occur in association with the hematite-pyrite deposits of the filled-sink type in Phelps, Crawford, and Franklin Counties (Grawe, 1945). Some of these minerals were reported to be of gem quality. The best specimens of amethyst came from the Moselle No. 10 mine in Phelps County. Smoky quartz was also obtained from this mine. Citrine was reported from the Scotia No. 1 mine in Crawford County, but it was not of gem quality. The blue copper carbonate, azurite, and the green copper carbonate, malachite, were found lining fractures in the iron ore and associated dolomite in the Copper Hill Mine in Crawford County. Botryoidal and rounded pellets were also present in the clay and in the soft iron ore. Both azurite and malachite were noted in various other mines in this area, but gem quality material was the exception rather than the rule. Today, as none of the mines are in operation, collecting is restricted to the material from the old dump sites. Azurite and malachite also occurred in the copper mines of the Eminence area in Shannon County, but none of gem quality was reported.

The onyx found in Missouri is of the variety known as Mexican onyx, which is calcium carbonate, colored pink, brown, or red by various impurities, mainly iron oxide, that takes a good polish. Onyx usually occurs in caves, and between the years 1898 and 1920 it was mined from various caves in Crawford, Camden, and Pulaski Counties and sold as ornamental stone. Two small surface deposits of onyx were described from Ste. Genevieve County (Weller and St. Clair, 1928), but these deposits are not known to have been worked.

Various beautiful mineral specimens from Missouri have found their way to private collections, museums, and universities throughout

the United States. From the now inactive mines of the Missouri section of the Tri-State zinc-lead district came calcite crystals of remarkable sizes and colors, as well as fluorite, pink dolomite, galena, and sphalerite. Filled-sink deposits in Morgan and Moniteau Counties yielded translucent crystals of barite, and an unusual occurrence of blue barite has been reported from Texas County (Kidwell, 1946). Specimens of hematite have been collected from abandoned open-pit workings in the Ironton-Iron Mountain area of Iron and St. Francois Counties and from various places in Phelps, Crawford, and Dent Counties. The old Pilot Knob Mine in Iron County and the Cherry Valley Mine in Crawford County have been especially favorable places for nice specimens. Limonite occurs quite commonly in residual deposits near the surface throughout the entire Ozarks and has been collected from many localities. Pyrite and marcasite are found associated with both the coal mines in western and northern Missouri and the iron mines in southeastern Missouri.

The old Einstein silver mine and two or three smaller mines in that vicinity in Madison County have yielded samples of argentiferous galena, wolframite, arsenopyrite, sphalerite, quartz, and fluorite. Topaz was found in the altered wall rock or greisen at these mines. It was reported to be white to clear and transparent (Tolman, 1933), and occurred in equidimensional particles ranging up to 0.1 mm. in diameter. It was found associated with quartz and sericite but was not observed to occur in crystals of gem quality. Collecting in this area today is restricted to the old dump sites.

A very unusual rock type that is unique to Missouri occurs about 3 miles southwest of Fredericktown in Madison County. It is hydrothermally altered diabase porphyry of Precambrian age that has been termed "devonite" from its type locality in a ravine on Mount Devon (Johannsen, 1937, p. 32.). It occurs in the form of a dike in granite porphyry. The "devonite" consists of pink, green, and gray feldspar phenocrysts that attain a length of 5 to 6 inches in a dark-gray fine-grained groundmass of augite and plagioclase. Polished slabs of this rock beautifully exhibit its spectacular texture and color combinations and make attractive paper weights or other small ornaments. The areal extent of this occurrence is limited and records do not indicate that it has been widely sought after for ornamental purposes. A detailed petrographic description of the Mount Devon diabase porphyry was published by Muilenburg and Goldich (1933).

The above is just a sampling of the wealth of minerals and rocks that makes Missouri a paradise for collectors. The State has nine active gem and mineral societies headquartered principally in the Kansas City and St. Louis areas. Their total membership amounts to several hundred persons. An ever-increasing number of private individuals take up gem collecting, cutting and polishing as a hobby each year. Almost any mineral or rock that takes a good polish, is attractive looking, or occurs in nice crystals represents value in the eyes of the collector. The gems are sold through local dealers, are traded on a barter basis, or are kept or donated to the various types of collections. In turn, they may be bought in any of the numerous roadside rock shops or through lapidaries.

There is no large-scale production of gem stones and minerals in Missouri. Reported production in recent years is shown below:

Year	Quantity in pounds	Value
1957	150	$150
1958	430	288
1959	6,609	2,846
1960	400	100
1961	8,410	1,571
1962	8,151	1,247
1963	1,080	549

These figures may represent only a fraction of the actual amount and value of material that has been recovered. Production during these years was reported from Benton, Bollinger, Cape Girardeau, Jasper, Jefferson, Phelps, Ozark, and St. Louis Counties and consisted of agate, jasper, mozarkite, petrified wood, and various mineral specimens.

SELECTED REFERENCES

Aid, Kenneth, 1942, Dolomite investigation for the production of magnesium, St. Francois County, Missouri: Missouri Geol. Survey and Water Resources, unpub. ms., 7 p.

Allen, V. T., 1935, Mineral composition and origin of Missouri flint and diaspore clays. Missouri Geol. Survey and Water Resources 58th Bienn. Rept., app. 4, 24 p.

———, 1937, The Cheltenham clay of Missouri: Missouri Geol. Survey and Water Resources 59th Bienn. Rept., app. 5, 29 p.

American Society for Testing Materials, 1958, Compilation of standards on cement (C–1) including manual of cement testing: Philadelphia, Pa.

———, 1965a, Book of ASTM standards, pt. 9, Cement, lime, gypsum: Philadelphia, Pa., 544 p.

———, 1965b, Book of ASTM standards, pt. 10, Concrete and mineral aggregates: Philadelphia, Pa., 578 p.

Anderson, R. E., 1962, Igneous petrology of the Taum Sauk area, Missouri: Ph.D. thesis, Washington Univ., St. Louis, Mo. (unpub.).

Anonymous, 1919, History and properties of lightweight aggregate: Eng. News-Rec., v. 82, no. 17, p. 802–805.

Austin, C. R., Nunes, J. L., and Sullivan, J. D., 1942, Basic factors involved in bloating of clays: Am. Inst. Mining Metall. Engineers, Mining Tech. v. 6, no. 4, (Tech. Pub. 1486), 11 p.

Barton, W. R., 1965a, Cement, *in* U.S. Bur. Mines Minerals Yearbook 1964—V. 1, Minerals and metals (except fuels): Washington, D.C., p. 319–348.

Barton, W. R., 1965b, Cement, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 630, p. 189–204.

Barton, W. R., and Cotter, P. G., 1965a, Lime, *in* U.S. Bur. Mines Minerals Yearbook 1964—V. 1, Minerals and metals (except fuels): Washington, D.C., p. 699–708.

———, 1965b, Crushed stone, *in* U.S. Bur. Mines Minerals Yearbook 1964—V. 1, Minerals and metals (except fuels): Washington, D.C., p. 989–1014.

———, 1965c, Sand and gravel, *in* U.S. Bur. Mines Minerals Yearbook 1964—V. 1, Minerals and metals (except fuels): Washington, D.C., p. 919–942.

Beveridge, T. R., 1959, Undeveloped industrial rocks and minerals of Missouri [abs.]: Mining Eng., v. 11, no. 1, p. 13.

Bishop, O. M., 1949, The mineral industry of Missouri in 1946 and 1947, with total production summarized: Missouri Geol. Survey and Water Resources Inf. Circ. no. 4, 93 p.

Bowles, Oliver, 1929, Metallurgical limestone: U.S. Bur. Mines Bull. 299, 40 p.

———, 1952, The lime industry: U.S. Bur. Mines Inf. Circ. no. 7651, 43 p.

———, 1956, Limestone and dolomite: U.S. Bur. Mines Inf. Circ. no. 7738, 29 p.

———, 1960, Dimension stone, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial minerals and rocks: New York, 3d ed., p. 321–337.

Bowles, Oliver, and Jensen, N.C., 1947, Industrial uses of limestone and dolomite: U.S. Bur. Mines Inf. Circ. no. 7204, 19 p.

Boynton, R. S., 1966, Chemistry and technology of lime and limestone: New York, John Wiley and Sons, 520 p.

Boynton, R. S., and Gutschick, K. A., 1960, Lime, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial minerals and rocks: New York, 3d ed., p. 497–519.

Brobst, D. A., 1958, Barite resources of the United States: U.S. Geol. Survey Bull. 1072–B, p. 67–130.

———, 1960, Barium minerals, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial minerals and rocks: New York, 3d ed., p. 55–64.

Brown, J. A., 1960, Granules, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial minerals and rocks: New York, 3d ed., p. 443–454.

Buckley, E. R., and Buehler, H. A., 1904, The quarrying industry of Missouri: Missouri Bur. Geology and Mines, 2d ser., v. 2, 371 p.

Buehler, H. A., 1907, The lime and cement resources of Missouri: Missouri Bur. Geology and Mines, 2d ser., v. 6, 255 p.
Burwell, A. L., 1954, Lightweight aggregate from certain Oklahoma shales: Oklahoma Geol. Survey Mineral Rept. 24, 20 p.
Clausen, C. F., 1960, Cement materials, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial minerals and rocks: New York, 3d ed., p. 203–231.
Coghill, W. H., and O'Meara, R. G., 1932, Milling methods and costs at a Flat River (Mo.) mill: U.S. Bur. Mines Inf. Circ. no. 6658, 36 p.
Colby, S. F., 1941, The occurence and uses of dolomite in the United States: U.S. Bur. Mines Inf. Circ. no. 7192, 21 p.
Conley, J. E., and others, 1948, Production of lightweight concrete aggregates from clays, shales, slates, and other materials: U.S. Bur. Mines Rept. Inv. no. 4401, 121 p.
Cotter, P. G., 1965a, Lime and calcium, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 630, p. 521–529.
———, 1965b, Stone, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 630, p. 875–893.
———, 1965c, Sand and gravel, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 630, p. 779–788.
Currier, L. W., 1960, Geologic appraisal of dimension-stone deposits: U.S. Geol. Survey Bull. 1109, 78 p.
Dake, C. L., 1918, The sand and gravel resources of Missouri: Missouri Bur. Geology and Mines, 2d ser., v. 15, 274 p.
———, 1930, The geology of the Potosi and Edgehill quadrangles: Missouri Bur. Geology and Mines, 2d ser., v. 23, 233 p.
Davis, W. E., 1950, Clays and shales of western Missouri: Missouri Geol. Survey and Water Resources, unpub. ms., 9 p.
Davis, W. E., Herold, P. G., and McManamy, J. L., 1941, Further investigations of southeastern Missouri clays: Missouri Geol. Survey and Water Resources 61st Bienn. Rept., app. 1, 48 p.
Diamond, W. G., Early, T. R., and Robertson, H. F., 1964, Expanded clay and shale lightweight aggregate industry in the south-central United States: U.S. Bur. Mines Inf. Circ. no. 8233, 50 p.
Ehlers, E. G., and Richardson, J. H., 1958, Mineralogical factors involved in the formation of lightweight aggregates—Pt. 2, *in* Everhart, J. O., and others, A study of lightweight aggregates: Ohio State Univ., Eng. Expt. Sta. Bull. 169, p. 24–44.
Farrar, Willard, Grenfell, D. S., and Allen, V. T., 1935, The geology and bleaching clays of southeast Missouri: Missouri Geol. Survey and Water Resources 58th Bienn. Rept., app. 1, 78p.
Farrar, Willard, and McManamy, J. L., 1937, The geology of Stoddard County, Missouri; Missouri Geol. Survey and Water Resources 59th Bienn. Rept., app. 6, p. 34–37.
Frommer, D. W., and Fine, M. M., 1960, Recovering iron concentrates from the Pea Ridge deposit, central Missouri: U.S. Bur. Mines Rept. Inv. no. 5550, 14 p.
Gault, H. R., and Ames, John, 1960, Fluxing stone, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial minerals and rocks: New York, 3d ed., p. 189–192.
Gay, T. E., Jr., 1957, Specialty sands, *in* Mineral Commodities of California: California Dept. Nat. Res., Div. Mines Bull. 176, p. 547–564.
Gillson, J. L., and others, 1960, The carbonate rocks, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial minerals and rocks: New York, 3d ed., p. 123–201.
Grawe, O. R., 1945, Pyrites deposits of Missouri: Missouri Geol. Survey and Resources, 2d ser., v. 30, 482 p.
Greene, F. C., and Pond, W. F., 1926, The geology of Vernon County: Missouri Bur. Geology and Mines, 2d ser., v. 19, 152 p.
Grim, R. E., 1953, Clay mineralogy: New York, McGraw-Hill Pub. Co., 384 p.
———, 1962, Applied clay mineralogy: New York, McGraw-Hill Pub. Co., 422 p.
Hamlin, H. P., and Templin, George, 1962, Evaluating raw materials for rotary-kiln production of lightweight aggregate: U.S. Bur. Mines Inf. Circ. no. 8122, 23 p.
Hayes, W. C., Jr., 1959, Geology and exploration of Missouri iron deposits: Missouri Geol. Survey and Water Resources Misc. Pub., 16 p.

Hayes, W. C., Jr., 1961, Guidebook to the Geology of the St. Francois Mountain area, Association of Missouri Geologists, 8th annual field trip, 1961: Missouri Geol. Survey and Water Resources Rept. Inv. no. 26, 137 p.
Herold, P. G., Kurtz, Peter, Jr., Planje, T. J., and Plunkett, J. D., 1958, Study of Missouri shales for lightweight aggregate: Missouri Div. Geol. Survey and Water Resources Rept. Inv. no. 23, 39 p.
Hinchey, N. S., 1946, Missouri marble: Missouri Geol. Survey and Water Resources Rept. Inv. no. 3, 47 p.
Hinchey, N. S., Fisher, R. B., and Calhoun, W. A., 1947, Limestone and dolomites in the St. Louis area: Missouri Geol. Survey and Water Resources Rept. Inv. no. 5, 80 p.
Howe, W. B., and Koenig, J. W., 1961, The stratigraphic succession in Missouri: Missouri Geol. Survey and Water Resources, 2d ser., v. 40, 185 p.
Jackman, H. W., Mirza, M. B., White, W. A., and Hefinstine, R. J., 1965, Illinois clays as binders for iron ore pellets: Illinois State Geol. Survey, Indus. Minerals Note no. 22, p. 1–8.
Jahns, R. H., 1960, Gem stones and allied materials, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial minerals and rocks: New York, 3d., p. 383–441.
Johannsen, Albert, 1937, A descriptive petrography of the igneous rocks—V. 3, The intermediate rocks: Chicago, Ill., Chicago Univ. Press, 360 p.
Keller, W. D., 1952, Observations on the origin of Missouri high-alumina clays, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Problems of clay and laterite genesis: Symposium, Feb. 1951, p. 115–134.
Keller, W. D., Westcott, J. F., and Bledsoe, A. O., 1954, The origin of Missouri fire clays, *in* Swineford and Plummer, eds., Clays and clay minerals: Natl. Research Council Pub. 327, p. 7–46.
Kessler, D. W., Insley, H., and Sligh, W. H., 1940, Physical, mineralogical, and durability studies on the building and monumental granites of the United States: Natl. Bur. Standards, Jour. Research, v. 25, p. 161–206.
Key, W. W., 1966, Use of mineral fillers, granules, and roofing rock in California asphalt-consuming industries: U.S. Bur. Mines Inf. Circ. no. 8300, p. 34.
Kidwell, A. L., 1946, Blue barite from Texas County, Missouri: Rocks and Minerals, v. 21, no. 12, p. 849–850.
Kisvarsanyi, E. B., 1965, Mineral resources and industry map of Missouri: Missouri Geol. Survey and Water Resources.
Klinefelter, T. A., and Hamlin, H. P., 1957, Syllabus of clay testing: U.S. Bur. Mines Bull. 565, 67 p.
Kluge, R. W., Sparks, M. M., and Tuma, E. C., 1949, Lightweight-aggregate concrete: Am. Concrete Inst. Jour., v. 20, no. 9, p. 625–642.
Kuklis, Andrew, and Hayes, W. C., 1965, The mineral industry of Missouri, *in* U.S. Bur. Mines Minerals Yearbook 1964—V. 3, Area reports, domestic: Washington, D.C., p. 573–602.
Lamar, J. E., 1928, Preliminary report on the fuller's earth deposits of Pulaski County: Illinois State Geol. Survey Rept. Inv. no. 15.
———, 1943, Agricultural limestone resources of Illinois: Illinois State Geol. Survey Circ. no. 94, 33 p.
———, 1961, Uses of limestone and dolomite: Illinois State Geol. Survey Circ. no. 321, 42 p.
Lamar, J. E., and Willman, H. B., 1938, A summary of the uses of limestone and dolomite: Illinois State Geol. Survey Rept. Inv. no. 94, 50 p.
Landes, K. K., 1963, Metallurgical limestone reserves in the United States: Washington D. C., Natl. Lime Assoc., 31 p.
Larson, L. N., 1947, Ceramic properties of some Missouri clays and shales: Masters thesis, Missouri Univ. School Mines and Metall., Rolla, Mo., 108 p. (unpub.).
Lenhart, W. B., 1960, Sand and gravel, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial minerals and rocks: New York, 3d ed., p. 733–758.
Lewis, R. W., 1965a, Barium, *in* Mineral facts and problems: U. S. Bur. Mines Bull, 630, p. 91–99.
———, 1965b, Phosphate rock, *in* Mineral facts and problems: U.S. Bur. Mines Bull, 630, p. 699–710.
McCracken, M. H., Compiler, 1961, Geologic map of Missouri: Missouri Div. Geol. Survey and Water Resources (scale 1:500,000).
McQueen, H. S., 1943a, Fire clay districts of east-central Missouri: Missouri Geol. Survey and Water Resources, 2d ser., v. 28, 250 p.

McQueen, H. S., 1943b, Occurrence of dolomite in the Fredericktown area, Madison County, Missouri: Missouri Geol. Survey and Water Resources 62d Bienn. Rept., app. 2, 16 p.
McQueen, H. S., and Aid, Kenneth, 1937, Rock wool resources in central Missouri: Missouri Geol. Survey and Water Resources 59th Bienn. Rept., app. 2, 24 p.
Mather, W. B., 1946, The mineral deposits of Morgan County, Missouri: Missouri Geol. Survey and Water Resources Rept. Inv. no. 2, 207 p.
———, 1947, Barite deposits of central Missouri: Am. Inst. Mining Metall. Engineers Tech. Pub. 2246, 15 p.; Trans., v. 173, p. 94–108.
Miller, B. K. and Moore, G. E., Jr., 1947, Prospecting for fire clay in Missouri; Am. Inst. Mining Metall. Engineers, Mining Tech., v. 11, no. 1, (Tech. Pub. 2057), 8 p.
Missouri State Highway Commission, 1961, Standard specifications for state roads, materials, bridges, culverts, and incidental structures: Jefferson City, Mo., 782 p.
Muilenburg, G. A., 1954, Barite mining in Missouri, *in* Kansas Geol. Soc., Guidebook, 17th Field Conf.: Missouri Geol. Survey and Water Resources Rept. Inv. no. 17, p. 45–50.
———, 1957, Barite mining and production in Missouri: Missouri Geol. Survey and Water Resources Misc. Pub., 13 p.
Muilenburg, G. A., and Goldich, S. S., 1933, Petrography and petrology of the Mount Devon diabase porphyry: Am. Jour. Sci., v. 26, p. 355–367.
Murphy, T. D., 1960, Silica sand and pebble, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial Minerals and Rocks: New York, 3d ed., p. 763–772.
Murray, H. H., 1960, Clays, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial minerals and rocks: New York, 3d ed., p. 259–284.
National Lime Association, 1951, Chemical lime facts; Natl. Lime Assoc. Bull. 214, 42 p.
———, 1965, Lime stabilization construction manual: Natl. Lime Assoc. Bull. 326, 46 p.
Netzeband, F. F., Early, T. R., Ryan, J. P., and Miller, W. C., 1964, Sulfur resources and production in Texas, Louisiana, Missouri, Oklahoma, Arkansas, Kansas, and Mississippi, and markets for the sulfur: U.S. Bur. Mines Inf. Circ. no. 8222, 77 p.
Petkof, Benjamin, 1965, Gem stones, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 630, p. 361-377.
Pit and Quarry Publications, Inc., 1960, Directory of the nonmetallic minerals industries, 1960 ed.: Chicago, Pit and Quarry Pubs., Inc., 324 p.
Plummer, N. V., and Hladik, W. B., 1951, The manufacture of lightweight concrete aggregate from Kansas clays and shales; Kansas State Geol. Survey Bull. 91, 100 p.
Portland Cement Association, 1963, Portland cements: Portland Cement Assoc., 7 p.
———, 1964, Cement and concrete reference book: Portland Cement Assoc., 136 p.
———, 1966, 50th anniversary of P.C.A.—symposium, *in* American Society of Civil Engineers, Civil Engineering: v. 36, no. 3, p. 32–42.
Pryor, W. A., and Glass, H. D., 1961, Cretaceous-Tertiary clay mineralogy of the Upper Mississippi Embayment: Jour. Sed. Petrology, v. 31, no. 1, p. 38–51.
Reardon, P. A., 1965, The Missouri market for sulfuric acid, opportunities for growth: Missouri Div. Commerce and Ind. Devel., Missouri Univ. Business and Public Adm. Research Center, Columbia, Mo.
Reynolds, B. D., 1940, Technical problems of the tripoli, chat, and ground limestone industries, *in* Mineral industries conference, proceedings, Rolla, Missouri, October 21–22, 1938: Missouri Univ. School of Mines and Metall. Bull., Tech. Serv., v. 14, no. 1, p. 68–70.
Riley, C. M., 1951, Relation of chemical properties to the bloating of clays; Am. Ceramic Soc. Jour., v. 34, no. 4, p. 121–128.
Ritchie, K. M., 1960, Mineral wool—rock, slag, and glass wool, *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial minerals and rocks: New York, 3d ed., p. 595–604.
Robert A. Taft Sanitary Engineering Center, 1966, Interstate air pollution study, St. Louis-East St. Louis metropolitan area; Public Health Service, Air Pollution Div., Cincinnati, Ohio.
Runnels, R. T., 1949, Preliminary report on phosphate-bearing shales in eastern Kansas: Kansas Geol. Survey Bull. 82, pt. 2, p. 37–48.

Runnels, R. T., Schleicher, J. A. and Van Nortwick, H. S., 1953, Composition of some uranium-bearing phosphate nodules from Kansas shales: Kansas Geol. Survey Bull. 102, pt. 3, p. 93–104.
Sackett, E. L. H., 1962, Barite: Mining Eng., v. 14, no. 5, p. 46–49.
Searight, W. V., 1957, Asphaltic rocks in western Missouri: Missouri Geol. Survey and Water Resources Inf. Circ. no. 13, 26 p.
Severinghaus, Nelson, 1960, Crushed stone *in* Am. Inst. Mining, Metall., and Petroleum Engineers, Industrial minerals and rocks: New York, 3d ed., p. 285–302.
Siebenthal, C. E., and Mesler, R. D., 1908, Tripoli deposits near Seneca, Missouri, *in* Contributions to economic Geology, pt. 1: U.S. Geol. Survey Bull. 340, p. 429–437.
Smith, R. W., 1938, Limestone mining at Ste. Genevieve, Missouri: Am. Inst. Mining Metall. Engineers Tech. Pub. 902, 23 p.
Stewart, D. R., 1945, Geology of the Missouri dinosaur occurrence, *in* Gilmore, C. W., and Stewart, D. R., A new sauropod dinosaur from the Upper Cretaceous of Missouri: Jour. Paleontology, v. 19, no. 1, p. 23–29.
Stewart, D. R., McManamy, J. L., and McQueen, H. S., 1943, Occurrence of bauxitic clay in Stoddard County, Missouri: Missouri Geol. Survey and Water Resources 62d Bienn. Rept., app. 3, 21 p.
Sweeney, J. W., and Hamlin, H. P., 1964, Lightweight aggregates—expansion properties of selected Iowa shales, clays, and loess: U.S. Bur. Mines Rept. Inv. no. 6393, 33 p.
———, 1965, Lightweight aggregate-expansion properties of selected Illinois shales and clays: U.S. Bur. Mines Rept. Inv. no. 6614, 34 p.
Tarr, W. A., 1918, The barite deposits of Missouri and the geology of the barite district: Missouri Univ. Studies, v. 3, no. 1, 111 p.
———, 1919, The barite deposits of Missouri: Econ. Geology, v. 14, no. 1, p. 46–47.
Tennissen, A. C., 1960, Kaolin deposits near Glen Allen, Bollinger County, Missouri: Missouri Geol. Survey and Water Resources Misc. Pub., 18 p.
———, 1963, Mineralogy, petrography, and ceramic properties of Lower Cabaniss underclays in western Missouri: Ph.D. dissert., Missouri Univ. School of Mines and Metall., Rolla, Mo., 186 p. (unpub.).
Thornberry, M. H., 1925, A treatise on Missouri clays: Missouri Univ. School of Mines and Metall. Bull., Tech. Ser., v. 8, no. 2, 69 p.
Tolman, Carl, 1933, The geology of the Silver Mine area, Madison County, Missouri: Missouri Geol. Survey and Water Resources 57th Bienn. Rept., app. 1, 39 p.
Uhley, R. P., and Scharon, H. L., 1954, Gravity surveys for residual barite deposits in Missouri: Mining Eng., v. 6, no. 1, p. 52–56.
U.S. Department of Agriculture, 1966, Missouri handbook for 1966 Agricultural Conservation Program: U.S. Dept. Agriculture, Agr. Stabilization Conserv. Service, Columbia, Mo.
Utley, R. W., Lovell, H. L., and Spicer, T. S., 1965, The preparation of coal refuse for the manufacture of lightweight aggregate: Am. Inst. Mining, Metall., and Petroleum Engineers Trans., v. 232, p. 346–352.
Walker, F. E., and Hartner, F. E., 1966, Forms of sulfur in U.S. coals: U.S. Bur. Mines Inf. Circ. no. 8301, 51 p.
Washa, G. W., 1956, Properties of lightweight aggregates and concretes: Am. Concrete Inst. Jour., v. 28, no. 4, p. 375–382.
Weigel, W. M., 1929, The barite industry of Missouri: Am. Inst. Mining Metall. Engineers Tech. Pub. 201, 26 p.; Trans. 1929, Yearbook, p. 256–279.
Weller, Stuart, and St. Clair, Stuart, 1928, Geology of Ste. Genevieve County, Missouri: Missouri Bur. Geology and Mines, 2nd ser., v. 22, 352 p.
Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Jour. Geology, v. 30, no. 5, p. 377–392.
Wheeler, H. A., 1896, Clay deposits: Missouri Geol. Survey and Water Resources, 1st ser., v. 11, 622 p.
White, W. A., 1960, Lightweight aggregate from Illinois shales: Illinois State Geol. Survey Circ. 290, 29 p.
Wilson, M. E., 1922, The occurrence of oil and gas in Missouri: Missouri Bur. Geology and Mines, 2nd ser., v. 16, 293 p.
Williams, L. R., 1965, Magnesium and magnesium compounds, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 630, p. 537–551.

MINERAL FUEL RESOURCES

COAL

(By Walter V. Searight, Missouri Geological Survey and Water Resources, Rolla, Mo.)

About one-third of Missouri is underlain by bituminous coal-bearing strata, and coal has been mined in 55 of the 63 counties in which it occurs. As shown on figure 51, the coal deposits occur in an area of some 24,000 square miles extending northeastward across the State from Jasper County to Clark County. The coal is in more than 40 different coal beds, all associated with rocks of Pennsylvanian age. Some of these are very persistent and crop out over large areas, whereas others are restricted or patchy in area.

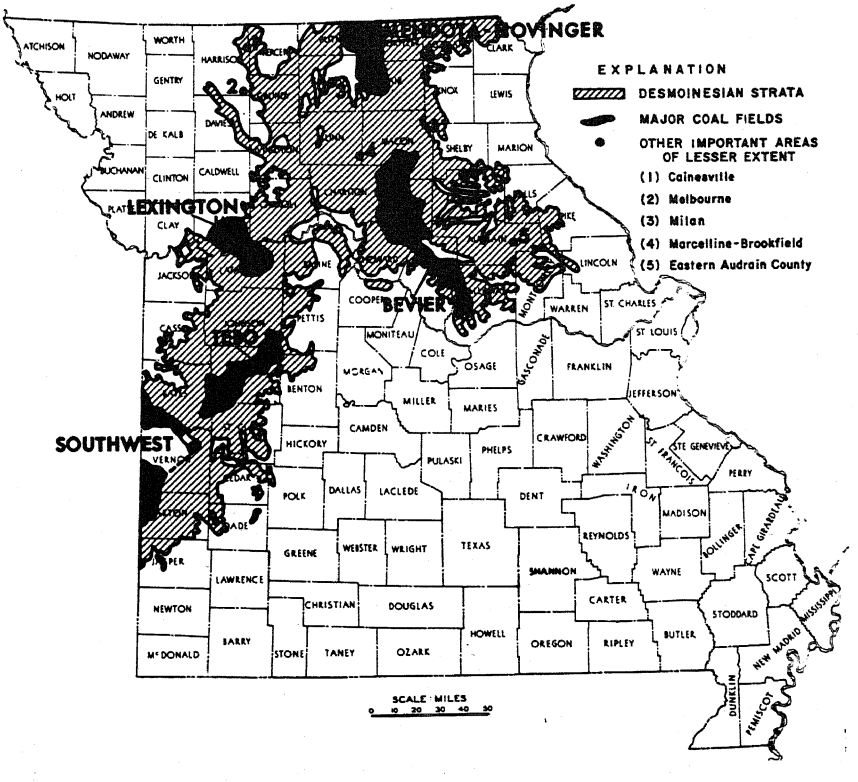


FIGURE 51.—Distribution of the principal coal-bearing strata and coal fields of Missouri.

77-278 O—67——16

Numerous publications of the Missouri Geological Survey and of the U.S. Geological Survey deal extensively with the geology of Missouri coal. Two reports, both the result of cooperative work of the Missouri Geological Survey (then the Missouri Bureau of Geology and Mines) and the U.S. Geological Survey are very important to anyone interested in Missouri coal. The first of these is "The Coal Deposits of Missouri" by Henry Hinds (Hinds, 1912) and the second, "The Stratigraphy of the Pennsylvanian of Missouri" by Henry Hinds and F. C. Greene (Hinds and Greene, 1915). These two works discuss and describe the coal beds, character, stratigraphy, depth, and mining methods of that time. The coal resources of each county are treated with remarkable completeness. Estimates were made of the original tonnage in each county.

In preparation of this chapter, annual reports of the State Division of Mine Inspection have been used as the chief source for information on production. Reports of the U.S. Bureau of Mines have also given production statistics. In general, the overall production figures derived from different sources do not differ significantly.

Production.—Historically, coal production in Missouri has fluctuated with national and international economic conditions. In recent years production has risen from a low of 2,592,000 tons in 1958 to a high of 3,564,000 in 1965, the last year for which data are available. Production for 1965 (as reported by the U.S. Bureau of Mines) for Missouri and other ranking western interior region States, the two leading Rocky Mountain region States, and that of the United States is given below:

	Tons
Missouri	3, 564, 000
Iowa	1, 043, 000
Oklahoma	974, 000
Colorado	4, 790, 000
Utah	4, 992, 000
U.S. total	512, 088, 000

Total Missouri coal production since 1840 is shown graphically in figure 52.

The total cumulative tonnage mined in this period has been approximately 310 million tons. Annual production first exceeded a million tons in 1876, and since 1882 has been more than 2 million tons except during the "Great Strike" of 1886. More than 5 million tons was produced annually in 1917, 1918, and 1920, during and following World War I. Most of the production over the years was for domestic, railroad, and industrial fuel. During the economic readjustment following World War II, the coal industry lost the railroad fuel market as steam locomotives were replaced by diesel-electric units. The coal market was further curtailed by the progressive installation of oil- and gas-burning equipment for domestic use. Much electricity was made in steam-coal powerplants, but even here oil- and gas-burning equipment made serious inroads into the coal market. As a result of these factors, coal production in Missouri was lowest in 1953 and 1954. Expansion in the use of coal for the production of electric power in steam generating plants and the rapid expansion in the use of electricity for heat, light, and power has caused output to increase.

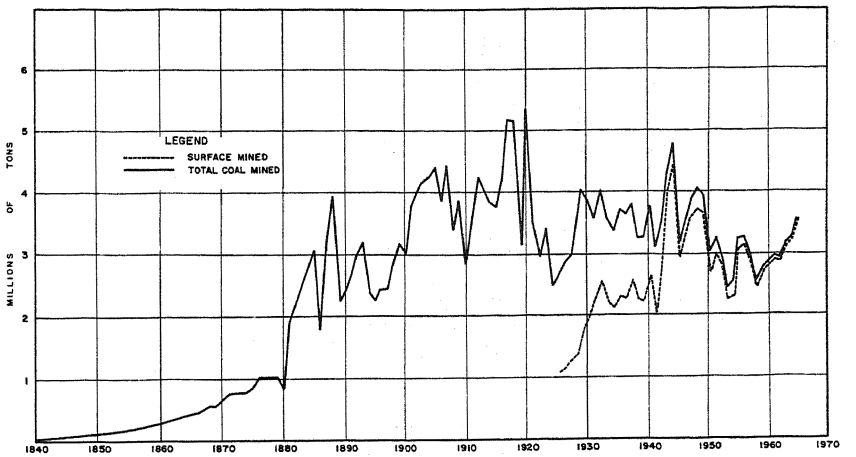


FIGURE 52.—Coal production in Missouri, 1840–1965. Data from the Missouri Geological Survey and Water Resources, and from the annual reports of the State mine inspector. (Production from strip mines is recorded as early as 1843, but has equaled or exceeded that from underground mines only since 1925.)

Missouri coal is of high-volatile bituminous rank. Some of it is high-volatile C, some high-volatile B, and a lesser amount is a high-volatile A. The rank of a coal depends upon its position in the metamorphic series from peat to graphite. It is determined from the percentage of dry, mineral-matter-free, fixed carbon and the B.t.u. value of moist, mineral-matter-free coal (ASTM, 1962). All high-volatile coals contain less than 69 percent dry mineral-matter-free fixed carbon and are commonly agglomerating.

The coalbeds are distributed unequally throughout the Pennsylvanian succession. Some parts contain only a few thin coals and others, such as the Shawnee Group (Table 1, p. 16), none at all. The most important deposits are in the Desmoinesian Series (figs. 51 and 53). Both the Cherokee and the Marmaton Groups include coalbeds, but the most valuable coals are in the former. Inasmuch as the Desmoinesian lies near the base of the Pennsylvanian, the thickest and most useful coals are shallowest near the eastern outcrop area of the Pennsylvanian System (figure 51) and become progressively deeper toward the northwest corner of the State.

Except for some erratic coals of unusual thickness found in isolated pockets outside the main coal areas, Missouri coals range in thickness from less than an inch to a maximum of 6½ feet. Of the more than 40 beds known, however, about half (21 coalbeds) are of sufficient thickness to have been mined somewhere in the State. Many of the coals mined are thin; that is, they are between 14 and 28 inches thick; and a few are intermediate in thickness, from 28 to 42 inches thick. Except for the coalesced Bevier and Wheeler beds—the "Bevier" bed of commerce—coals in Missouri more than 42 inches thick are lenticular and attain such thicknesses only locally.

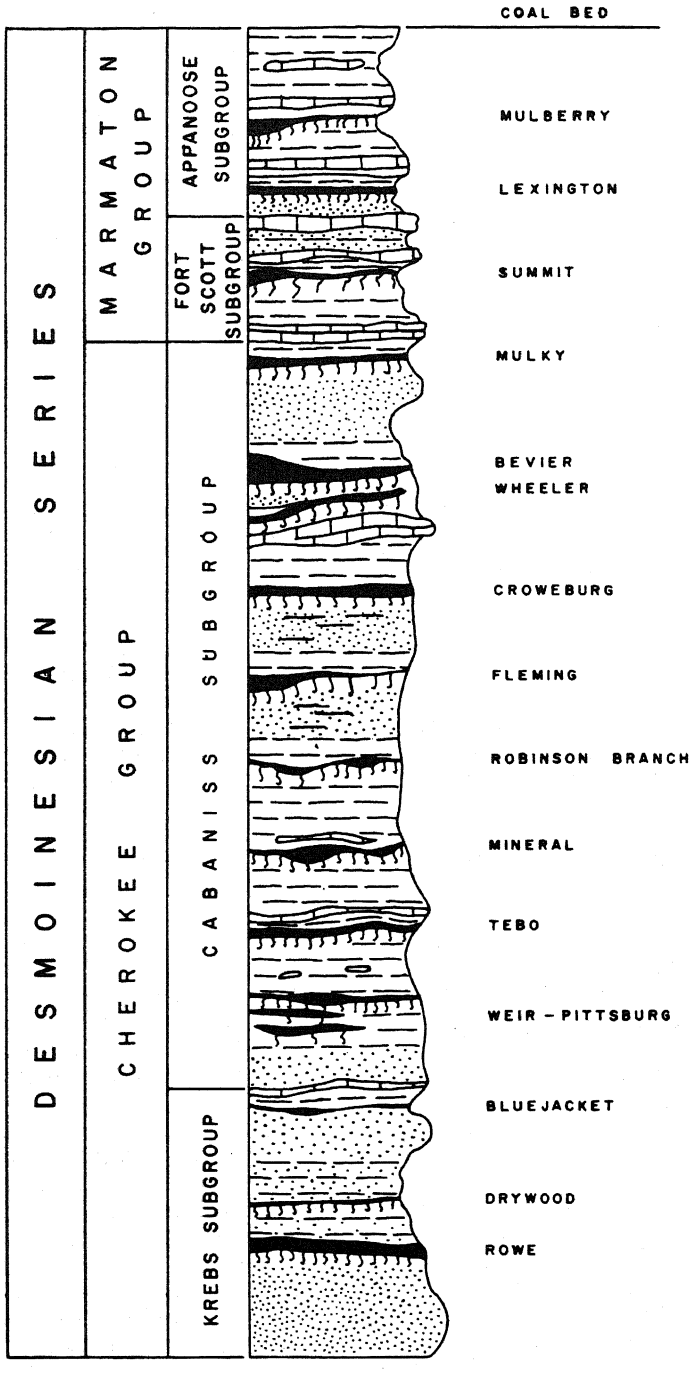


FIGURE 53.—Stratigraphy of the principal coal-bearing rocks of Missouri.

Of the beds shown in figure 53, the Weir-Pittsburg, Tebo, Mineral, Wheeler and Bevier together, Lexington, and the Mulberry have been of most importance in past production. Several other coalbeds are too thin for mining in commercial quantities. Of these, the Burgner (of Atokan age), Riverton, Laredo, Nodaway, Elmo, and Nyman beds may be noted. Of interest also are the coals, in many cases canneloid, that occur with clay and sandstone in filled sinks. These deposits are of very restricted area, but because of the considerable thickness of coal in some, they have attracted much attention.

The Missouri coalfields lie in the Western Interior Basin, and many coalbeds known in Missouri extend into Iowa, Kansas, and Oklahoma. Although names are different, numerous coalbeds are common to both the Western Interior and the Eastern Interior Basins.

Mining and utilization.—Coal has been mined in Missouri through shafts, drifts, slopes, and by surface or strip mining. The common systems of underground mining have been followed and, except in the case of the Lexington, most of the coal has been mined by some modification of the room and pillar method. The Lexington, however, has been mined underground almost wholly by the longwall system.

Until 1925, most coal in the State was mined underground, but since that year, more coal has been mined by surface methods (fig. 52). From the early 1940's on most of the Missouri output has been from surface operations, and less than 1 percent is currently mined underground.

Approximately two-thirds of the coal mined in Missouri is used to produce electricity. The remainder is used in other industry and for domestic use. In 1963, 5.2 million tons of coal was used by electric utilities in Missouri. Of this tonnage, 2.2 million tons was mined in the State. As most of eastern Missouri is closer to the Illinois coalfields than to the Missouri fields, the powerplants in this area use more Illinois than Missouri coal. On the other hand, those plants near or in the coalfields of the State utilize Missouri coal because of lesser freight rates. The Montrose plant in Henry County, which is essentially a mine-mouth operation, used 1.2 million tons of coal in 1963. This represents most of the coal production of that county, the largest producer in the State during that year, and was more than one-third of the total tonnage of coal produced from Missouri mines in 1963. The new plant at Thomas Hill, in Randolph County, will utilize much of the available coal in that area. The new Empire District Electric Co.'s steam generating plant (announced in October 1966) will be a mine-mouth operation utilizing coal from Barton County, Mo.

Coal fields.—Most of the Missouri coal has been mined from five coalfields (fig. 51); the Southwest Field, the Tebo Field, the Lexington Field, the Bevier Field, and the Mendota-Novinger Field.

1. Southwest Field: This field includes coal districts in western and southern Bates County and in Vernon and Barton Counties. The Mulberry district is located along the west border of Bates County in the area surounding Amoret, Foster, Sprague, and Hume. The important mid-Marmaton Mulberry bed is mined there. The bed ranges in thickness between 6 and 42 inches, but in the Foster area it averages aproximately 34 inches. In the Amoret area, it probably averages about 32 inches.

In southern Bates County and in north-central Vernon County, the locally important Mineral coal ranges from less than 14 inches to as much as 72 inches thick. Most of the known readily available Mineral coal has been mined out.

In the Walker district of northeastern Vernon County, the Mineral, Robinson Branch, and Fleming coals have been mined. Each of these coals is irregular in thickness and ranges from less than 14 inches to as much as 36 inches for the Mineral bed, and to 30 inches for each of the others. Strippable coal of the Walker district is considered to be mined out and the area has been abandoned.

The main coal of southwest Vernon County and northwest Barton County is the Weir-Pittsburg. The coal ranges in thickness between 24 and 37 inches in Missouri, but probably averages 30 inches. This bed has been extensively mined since pioneer days and is considered to be exhausted in this district. Southwest of this area in Barton and Vernon Counties is a considerable area underlaid by coals of the Krebs Subgroup, especially the Rowe and Drywood coals. The Rowe is as much as 18 to 24 inches thick. The Drywood is commonly a foot or less thick, but in some localities it is so near the Rowe that the two coalbeds are separated only by a thin parting.

2. The Tebo Field: The Tebo Field extends diagonally across Henry County from northeast to southwest, parallel with the general strike of the Tebo coal. The north end of the field lies in southeast Johnson County and the southwest end extends into Bates County and into the formerly important Appleton City area of northwest St. Clair County.

The main coal of this field is the Tebo. It is persistent in the field and ranges in thickness from 20 to 36 inches, but most of it averages 30 inches or less. More Tebo coal than any other coal is being mined currently in Missouri. Locally, the Mineral coal is 15 to 16 inches thick but commonly it is much thinner. In part of the field, the Croweburg coalbed is 12 to 22 inches thick. Locally, a coal below the Tebo, known in Henry County as the Weir-Pittsburg, is 16 to18 inches thick and has been mined alone and in tandem with the Tebo. To the southeast of the cropline of the Tebo coal, the coals of the Krebs Subgroup crop out or lie near the surface. The Rowe, which thickens and thins within short distances, was an important source of coal in Henry County at the turn of the century, when it was known as the Jordan coal. In a single locality, the Bluejacket coal, which lies near the top of the Krebs Subgroup immediately below the Seville limestone, is thick enough to mine on a small scale.

3. Lexington Field: The Lexington Field lies mostly in central and north-central Lafayette County but extends into Ray County to include adjacent areas north of the Missouri River. The coal of this field is the Lexington, which, although thin, is remarkably persistent within the area. The coal ranges in thickness from 14 to 30 inches and average 21 inches. The hard underclay, the tough fissile black roof shales ("drawslate") and the limestone "caprock" permitted extensive longwall mining. The district was close to the Kansas City market and was for many decades an important coal-producing area. The field is now essentially exhausted and abandoned.

4. Bevier Field: The Bevier Field is the largest coal field in the State, extending from near the middle of Macon County southward

about 75 miles through Chariton, Randolph, Howard, and Boone Counties into Callaway County. The main coal is the "Bevier" of commerce which actually consists of a thicker upper "bench" of coal, the Bevier, and a thinner lower "bench", the Wheeler. In the Bevier Field, a thin clay parting, rarely more than an inch thick, separates the two "benches". Together, these two coalbeds constitute the thickest persistent coal in Missouri. In Macon County, the coal ranges in thickness from 38 to 54 inches and averages 47 inches; in Randolph County, the range is from 38 to 53 inches and the average 44 inches; in Howard County, the range is from 30 to 42 inches and the average is 38 inches; in Boone County, the range is from 34 to 48 inches and the average is 40 inches; and in Callaway County, the range is from 26 to 36 inches and the average is 30 inches.

The Mulky coal overlies the Bevier in the Bevier Field. It is commonly 18 inches thick in Randolph and Macon Counties. The Summit coal is locally present above the Mulky; it is commonly less than 14 inches thick except in a few restricted localities in Randolph and Boone Counties where it is a few inches thicker. It attains a thickness of 28 inches in a small area in Boone County. Little is known of the Croweburg coal, which lies below the Bevier. Where it is known in Boone County, it is only 14 to 16 inches thick.

5. Mendota-Novinger Field: The Mendota-Novinger Field includes a district to the north, mostly in Putnam County, which is underlain by the Lexington coal, and a district to the south, mostly around Novinger in Adair County, underlain by the Bevier and Wheeler coals which are mined together as the "Bevier."

In the Mendota district the Lexington coal consists of three beds or benches separated by two clay partings, each of which ranges in thickness from a featheredge up to as much as 3 inches. The coal ranges in thickness from 30 to 44 inches and averages approximately 36 inches. The coal was mined for many years through shafts, drifts, and slopes. In recent years, however, most of the output has been from surface mines.

In the Novinger district, the "Bevier" coal ranges in thickness from 35 to 48 inches and averages 42 inches. In thins toward the north in Adair County. The "Bevier" has been mined through shafts, slopes, and drifts for many years and the district has until recent years been an important coal producer.

Other areas: Several areas which are not associated directly with the coalfields discussed previously have been sources of significant quantities of coal in the past. Although they are not of immediate utility, they have potential future value. The more important of these areas (identified by numerals on fig. 51) are: (1) the Cainesville area, (2) the Melbourne area, (3) the Milan area, (4) the Marcelline-Brookfield area, and (5) the eastern Audrain County area.

The Cainesville area in eastern Harrison County is underlain by a coal known in the past as the "Cainesville." It is probably the Weir-Pittsburg combined with one of the unnamed beds that commonly underlie it. These combined coals, separated by a parting, range in thickness from 44 to 60 inches and average 48 inches. In addition, 14 or more coals are present at depth under this area. Most of them are thin, but one is reported to be 42 inches thick. The Weir-Pittsburg ("Cainesville") bed lies 475 feet below the surface at Cainesville.

At Melbourne, in the southeast corner of Harrison County, the Lexington bed is 30 to 41 inches thick and averages 36 inches. It lies at a depth of 140 feet.

In the Milan area in central Sullivan County, the Bevier and Wheeler coalbeds together are 36 to 46 inches thick. Here the two beds are separated by a clay parting 1 to 26 inches thick. The coal lies at a depth of approximately 200 feet.

The Marcelline-Brookfield area in Linn and Macon Counties is an area underlaid by the Croweburg coal (formerly referred in this area to the Tebo), which ranges in thickness from 24 to as much as 42 inches. The average thickness is probably 28 to 30 inches. The coal lies at a depth of 125 to 130 feet.

In eastern Audrain County in the Vandalia, Farber, and Martinsburg area, coal 65 to 110 feet below the surface is 28 inches thick. The coal, which is separated into two benches by a thin clay and pyrite parting, is presumed to be the combined Mulky and Bevier.

Coal resources.—Since the settlement of the State, the coal resources of Missouri have been known to be very large. In 1873, Broadhead estimated that coal more than 18 inches thick within 200 feet of the surface is present under an area of about 7,000 square miles. Based on these figures, the minimum tonnage is 12,090 million tons of coal. In 1912, Hinds estimated the original resources of coal more than 14 inches thick to be 79,393 million tons.

In the years since the Hinds estimate was made, stratigraphic studies have indicated that many of his correlations of coalbeds were in error and that the persistence in thickness which he assumed cannot be demonstrated in many localities. These factors are of particular significance for coalbeds from which important tonnages of coal are being or have been mined. For example, the "Rich Hill" (Mineral) is not the Bevier coal and is not continuous with it, nor is it the "Bevier" (Croweburg) of Johnson County. The "Fort Scot Red" (Mulky) is not the same coal as the Lexington, nor is the Tebo the "Tebo" of north Missouri. Coal beds thin and thicken from one area to another and in many instances in very short distances. An additional factor of considerable importance in the area north of the Missouri River is that glacial drift occupies the position of coalbeds in many places. Details of this relationship can be established only by drilling or mining but, in general, considerable areas are affected.

A reevaluation of Missouri's original (before mining) coal resources is presented on a county-by-county basis in table 35. These estimates take into consideration the changes necessitated by corrections in coal bed identification, increased data on thicknesses of the principal coal beds, and other factors. The estimates of 1912 are presented also for comparison with current estimates. In reviewing the coal resources of certain counties, it was found that little additional data were available beyond those used by Hinds in 1912. In many counties, however, current information does not support the large resources indicated by Hinds, and these have consequently been adjusted downward. In some cases, only 10 percent of the previous estimate has been retained, and others have been cut to as little as 1 percent of the earlier estimate. The total tonnage represented in the current estimate is 23,977 million tons, less than one-third that of 1912 but approximately double that based on Broadhead's figures.

In order to arrive at an estimate of existing coal resources in the State, the estimated original tonnage present must be reduced by the

amount that has been removed by mining (310 million tons) plus the amount lost and wasted in mining (estimated to be about equal to the amount mined). The coal remaining is, therefore, estimated to be approximately 23,400 million tons. Of this, it is considered that approximately 45 percent is thin (14 to 28 inches thick), 40 percent of medium thickness (28 to 42 inches), and 15 percent is thick (more than 42 inches).

TABLE 35.—*Estimated original coal resources of Missouri*

[Millions of short tons]

County	Hinds (1912)	Searight (1966)	County	Hinds (1912)	Searight (1966)
Adair	2,263.6	900.1	Jasper	100.0	93.6
Andrew	1,209.6	12.1	Johnson	5,460.0	1,240.0
Atchison	411.8	41.2	Lafayette	877.4	559.9
Audrain	1,320.0	207.3	Lewis		0.1
Barton	464.3	150.0	Linn	2,190.1	269.6
Bates	3,989.8	2,311.7	Livingston	1,532.2	153.2
Boone	846.7	500.0	Macon	2,985.9	1,985.9
Buchanan	4,203.4	4.2	Mercer	4,329.6	2,956.8
Caldwell	1,260.4	12.6	Monroe	288.5	207.4
Callaway	450.9	188.2	Montgomery	315.6	311.0
Carroll	1,000.0	56.2	Nodaway	914.7	10.0
Cass	2,460.7	24.6	Pettis	300.0	30.0
Cedar	170.3	40.0	Platte	3,385.0	3.4
Chariton	2,168.0	21.7	Putnam	4,296.2	*2,142.0
Clark	200.0	2.0	Ralls	44.0	82.9
Clay	1,953.6	19.5	Randolph	2,020.7	1,522.6
Clinton	1,521.2	15.2	Ray	1,098.2	616.1
Cooper	31.5	2.2	St. Clair	602.1	602.9
Dade	33.9	14.0	St. Louis	70.8	
Daviess	2,752.7	27.5	Saline	337.1	112.1
De Kalb	1,209.6	12.0	Schuyler	337.9	136.3
Gentry	1,280.5	12.8	Scotland	20.0	2.0
Grundy	1,417.0	354.2	Sullivan	2,971.1	1,125.0
Harrison	3,363.8	1,681.9	Vernon	1,257.4	1,257.4
Henry	1,832.7	832.7	Worth	1,140.5	11.4
Holt	823.2	8.2	Other counties	500.0	
Howard	1,280.7	394.4			
Jackson	2,097.8	699.3	Total	79,392.7	23,977.4

*Estimate by R. J. Gentile (1965).

It is probable that only that part of those coal resources which can be mined by large-scale surface methods will be recovered within the next 25 to 30 years. The greater part of such resources have already been explored and evaluated by major coal operators. They probably include most if not all of the resources which can be currently classified as measured resources. Because most of the currently pertinent exploration in Missouri has been done by only two companies, reserve information cannot be revealed. On the basis of projected needs of powerplants now in operation or committed to construction, however, it is estimated that reserves of strippable coal amounting to not less than 85 to 100 million tons are present in Missouri.

OIL AND GAS

(By K. H. Anderson and Jack S. Wells, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Oil and gas have been produced in Missouri since the earliest drilling in the Kansas City area shortly after the Civil War. Production has never been important in comparison to that of major petroluem-producing States, but both oil and gas have made consistent contributions to Missouri's economy. Low-gravity, high-viscosity oil is present at shallow depths over large areas in western Missouri. This is a re-

source that cannot be extracted at a profit with existing technology but which may be of importance in the future.

Geologic conditions that are unfavorable for the occurrence of oil and gas prevail over much of the area of the State. This applies especially to the Ozark region. The remainder of the State has as a whole not been adequately prospected, although extensive drilling has been carried out in some counties, particularly in western Missouri.

HISTORY AND PRODUCTION

The first drilling for oil and gas in Missouri took place in the Kansas City area shortly after the Civil War. During the late 1800's and early 1900's, large numbers of shallow holes were drilled in the western Missouri area, mostly in Jackson, Cass, Bates, Vernon, Clay, Ray, and Lafayette Counties. This resulted in shallow oil production at a number of localities and in a large number of small gas wells, most of which supplied individual homes, farmsteads, and small municipalities for varying lengths of time. In addition to the counties already mentioned, scattered drilling was carried on in central and eastern Missouri counties such as Carroll, Chariton, Macon, Marion, Randolph, and St. Charles. In the early 1900's, minor amounts of gas were discovered in McDonald County in the southwestern part of the State. By the end of 1932, it was estimated (Greene, 1933, p. 5) that 2,495 wells had been completed in Missouri. Of these, 320 were reported to have produced oil, 1,139 had produced gas, and 1,036 were recorded as dry holes. It is probable that many more dry holes went unreported. The location of currently producing oil and gas fields and the areas of former production are shown in figure 54.

In the 1930's and early 1940's, considerable amounts of natural gas were discovered and produced from fields in Cass, Jackson, Clay, and Platte Counties. Much of this gas was sold to pipelines for commercial distribution. In 1940, the Polo gas field in Caldwell County was discovered by the Skelly Oil Company (Greene and McQueen, 1943). The area was not served by a pipeline and the gas was not utilized except by individual farmsteads until the early 1960's when a part of it began to be used as a municipal supply for the city of Polo.

The search for oil and gas continued in western Missouri during World War II, and in 1942 the Tarkio pool in Atchison County was discovered by the Cities Service Oil Company (Greene, 1945, p. 14–16). This proved to be one of the most productive oil pools in western Missouri. No new pools were found in the State until 1953, when oil was discovered during exploration drilling for natural gas storage in northern St. Louis County in what became known as the Florissant pool (McCracken, 1955). In 1952, gas was discovered near Turney in Clinton County, and in 1955, the gas was piped to Plattsburg as a municipal supply.

Exploratory drilling has continued at numerous localities in Missouri subsequent to discoveries of the Turney gasfield and the Florissant oil pool in the early 1950's. Important shows of oil have been encountered in several areas, particularly in northeastern Missouri, but no production has resulted from this drilling activity except that associated with a deep test in 1960 near Corning in Holt County. This well had an initial production of approximately 125 barrels of oil per day, but the yield declined rapidly and the well was plugged and abandoned in 1961.

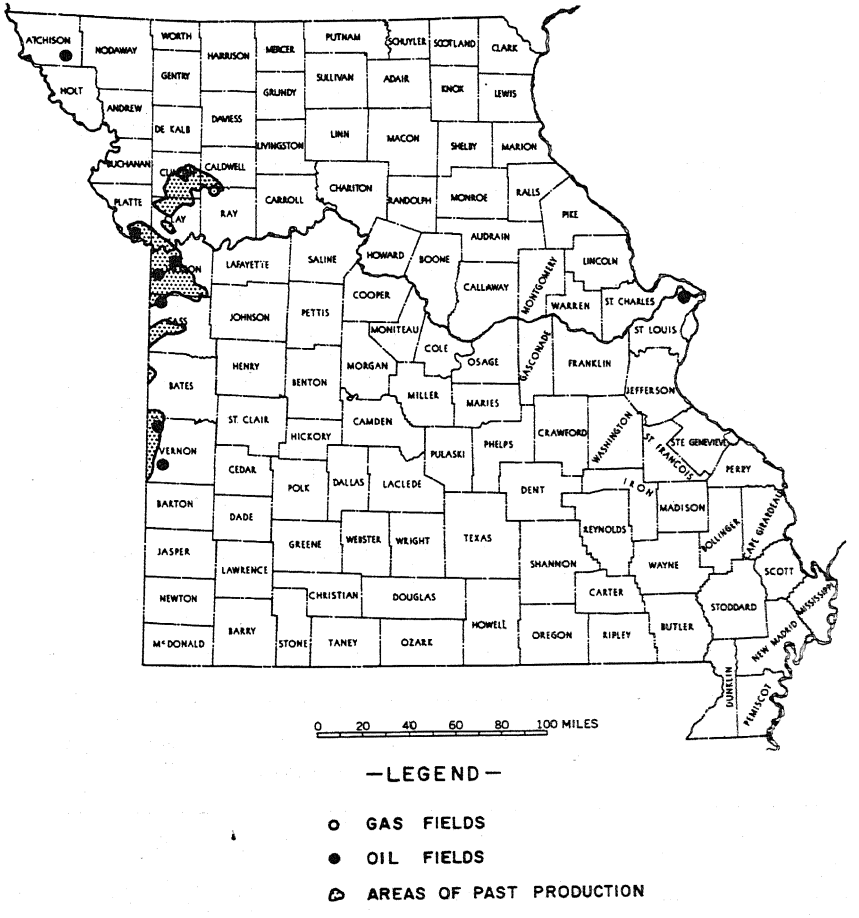


FIGURE 54.—Oil and gas fields of Missouri.

Essentially all of the shallow oil wells in the western Missouri area are classed as stripper wells and have averaged less than 10 barrels per day. Most of the shallow gas wells in western Missouri have had rather limited production potential. The discovery well in the Polo gas field was gauged at 2,190,000 cubic feet, at a pressure of 86 pounds per square inch (Greene and McQueen, 1943, p. 5). This was an exceptional well, with much higher volume than average. As another example of the productivity of western Missouri gas wells, the combined flow of six of the early wells in the Turney gas field was estimated at 2,500,000 cubic feet per day. In the Florissant pool in St. Louis County, the initial production of the oil wells averaged about 20 barrels per day.

Much information relating to the history and production of oil and gas in Missouri is shown in table 36. Most of the recorded gas production took place in the 1930's and early 1940's, with more than 1 billion cubic feet of gas produced annually in 1930, 1931, and 1938. Production fell off very sharply following this period, owing mostly to the ex-

hausting and abandonment of fields in Jackson, Cass, Clay, and Platte Counties. Stabilization of gas production in Missouri following 1956 is due mostly to the development and utilization of the gas from the Turney field. This, along with that sold at Polo, was the only commercial production of natural gas in the State in 1966. The sharp increase in oil production in 1953 and 1954 was due almost entirely to the production from the Florissant pool. Currently, the steadiest production in western Missouri is that from the Tarkio pool in Atchison County and the Longview pool, near Lees Summit, Jackson County.

OCCURENCE OF OIL AND GAS IN MISSOURI

All of the oil and gas currently produced in western and northwestern Missouri is from strata of Pennsylvanian age, mostly those assigned to the Cherokee and Marmaton Groups. The principal productive horizons are shown in Fig. 55. Of these the "Bartlesville" and "squirrel" sands have been the most productive. Most, if not all, of the production is associated with small domal or anticlinal structures, and essentially all of the production is from sandstones, with some minor gas production from black fissile shales. Most of the known western Missouri structures are small, many not more than one-quarter section in extent.

TABLE 36.—*Production of oil and gas from Missouri*

Year	Oil			Gas		
	Oil in barrels	Value of oil	Number of wells	Gas in thousands of cubic feet	Value of gas	Number of wells (commercial)
1865–1932	136,729	$27,749	NA	5,621,195	$604,874	NA
1933	10,000	6,000	NA	673,000	59,224	NA
1934	35,000	29,000	NA	549,000	78,500	NA
1935	45,000	40,000	NA	609,000	87,000	NA
1936	40,000	35,000	NA	399,000	57,000	NA
1937	40,000	42,000	NA	444,000	38,000	NA
1938	40,000	42,000	NA	1,369,000	109,520	NA
1939	40,000	40,000	NA	538,000	48,420	NA
1940	44,000	40,000	NA	310,000	29,846	NA
1941	47,000	41,000	NA	196,000	27,440	NA
1942	36,000	41,000	NA	100,000	14,000	NA
1943	36,000	41,000	NA	124,000	17,360	NA
1944	45,000	52,650	NA	152,477	22,429	NA
1945	37,714	40,731	NA	77,575	8,913	NA
1946	42,728	44,375	NA	37,863	4,467	NA
1947	31,462	54,326	NA	30,035	3,907	NA
1948	30,700	68,994	89	31,110	4,159	11
1949	32,028	54,356	99	23,340	3,257	11
1950	33,000	62,000	89	81,589	7,144	14
1951	22,525	46,013	70	17,295	1,961	6
1952	19,830	38,050	70	13,272	1,593	2
1953	38,733	83,917	92	15,160	1,655	3
1954	96,021	270,078	114	15,479	1,688	3
1955	72,280	192,160	120	14,915	1,626	2
1956	65,212	176,723	103	7,000	1,750	3
1957	65,151	171,512	107	30,668	7,667	3
1958	83,953	242,383	105	42,399	10,600	4
1959	75,471	214,174	121	64,928	16,232	7
1960	74,694	210,306	120	75,702	18,925	9
1961	65,252	180,000	117	96,000	25,000	12
1962	55,856	159,635	118	103,425	24,542	6
1963	55,295	148,644	115	103,139	24,239	10
1964	65,281	163,203	100	103,464	25,875	11
1965	72,392	184,610	136	112,669	25,748	10
Totals	1,730,307	3,283,589		12,181,699	1,414,561	

Source: Data compiled by Missouri Geological Survey and Water Resources.

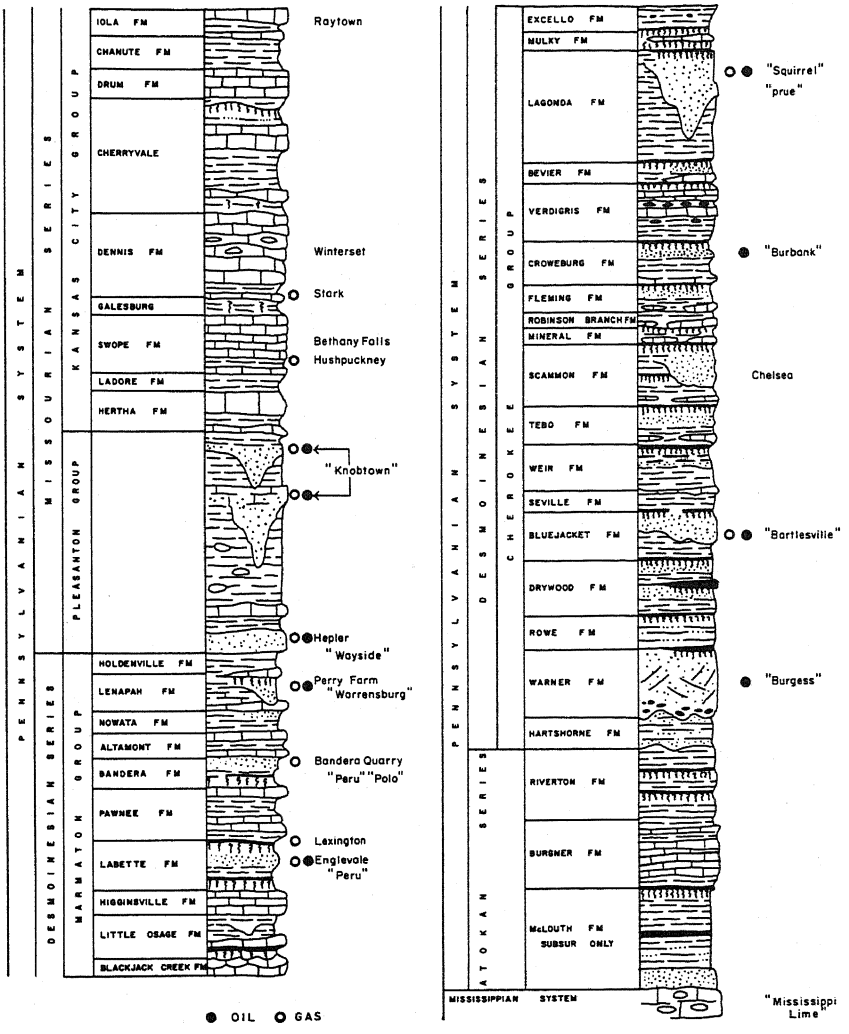


FIGURE 55.—Stratigraphy of the Pennsylvanian oil- and gas-bearing rocks of Missouri

The Florissant Dome, which was described by McCracken (1955), has been the source of most of Missouri's oil production since 1954 when it produced its maximum of 76,545 barrels. The oil in the Florissant pool is from the Kimmswick Formation (Ordovician) and this formation has therefore been the target of much of the exploration in the northeastern areas of Missouri. Oil shows have been encountered in it in northeastern Missouri, and the oil from the one deep well in Holt County mentioned earlier was also in the Kimmswick.

Low-gravity, high-viscosity oil in western Missouri

Low-gravity, high-viscosity oil has been known in western Missouri for at least a hundred years. It has been reported as "tar springs," as "pitch," as "asphalt," and commonly described simply as "heavy oil". Technically, the material ranges from a true oil of low gravity and high viscosity present at shallow depths to a bituminous or asphaltic residue developed where the oil-bearing formations occur near the surface or in exposures. Searight (1957) describes the physical characteristics and provides data on the areal and stratigraphic distribution of asphaltic material in Pennsylvanian rocks in the Western Missouri area. The low-gravity, high-viscosity material is differentiated from producible western Missouri crudes whose gravity may average 27 or 28 and which can be produced by pumping, with additional recovery through water flooding.

The fact that this material is of such wide distribution and that it does occur as oil at shallow depths has caused it to receive much attention as a possible source of petroleum in Missouri. Considerable time and money have been expended by several major oil companies in attempts to develop methods to recover this oil, most of which is too viscous to flow satisfactorily and be produced from ordinary drill holes. Major companies that have attacked the problem include the Carter Oil Co., which carried on an extensive experimental program in western Vernon County in the early 1950's; the Phillips Petroleum Co., in the southeastern Vernon County area in the 1950's; the Shell Oil Co., which carried on an intensive program in western Vernon County and other areas in western Missouri; and the Marathon Oil Co., which operated an experimental plant in northwestern Cass County for some years. Several smaller companies and individuals have also attempted to recover the oil. All of the projects carried out by the major oil companies have been thermal recovery projects, including *in situ* combustion or fire flooding and steam injection procedures. Articles by Enright (1964), Trantham and Marx (1965), and Goebel (1966) are typical of the many technical reports emphasizing the potential and problems in methodology involved in the recovery of this oil.

The formations in which the viscous, low-gravity oils of western Missouri occur are sandstones of the middle and lower parts of the Cherokee Group. The oil-bearing sands are of widespread extent and occur at depths of only a few hundred feet over large areas. No well authenticated estimate of the oil in place has been made public by any of the major oil companies, who because of their extensive activity presumably have the best information available. Estimates of oil in place by other technical and professional people have been as high as 30 billion barrels. The ultimate recovery of this material would be of great importance to the State's economy.

Areas for future or additional exploration.—Three relatively large regions in Missouri merit further exploration for oil and gas, although some drilling has been carried out in each (fig. 56). These are (1) the Forest City Basin, (2) the Lincoln Fold area, and (3) the Mississippi Embayment area of southeastern Missouri.

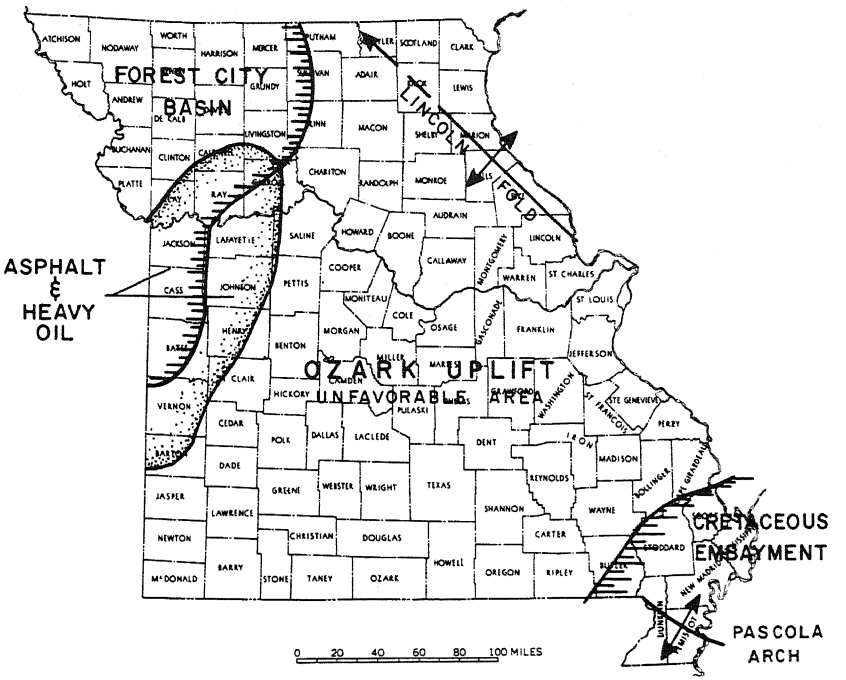


FIGURE 56.—Areas of interest for potential production of oil and gas.

Oil and gas possibilities of the Forest City Basin have been discussed by McQueen and Greene (1938), Greene (1945), and Anderson and Wells (1965). Oil from the Silurian and Devonian Hunton Formation in southeastern Nebraska, that from the Pennsylvanian "Bartlesville" sandstone near Tarkio, Mo., and the impressive initial production from the Ordovician Kimmswick Formation in Holt County, Mo., are each evidence of the potential of the Forest City Basin. Although scattered deep tests have been made, no significant production has resulted. Because of the large area underlain by potentially productive strata, much additional drilling is required to establish or disprove the potential of this region of the State.

The Lincoln Fold area in northeastern Missouri has been the focal point of interest both on the part of major oil companies and of independents. The principal interest has been in the possibility of Kimmswick production such as that in St. Louis County to the south. Some drill holes have encountered oil shows, but no production has been established in the region. The importance of exploration in this region was brought out by McCracken in 1956, following the discovery of the Florissant pool in St. Louis County.

In the Mississippi Embayment area, greatly thickened formations of early Paleozoic age dip to the southeast under thick Tertiary and Quaternary deposits. This general relationship is interrupted by the

northwest-trending Pascola Arch (Grohskopf, 1955; McCracken and McCracken, 1965), so that there has been interest in the possibility of production both over and on the flanks of that structure as well as within the southeastward-dipping succession to the north and south. Thus far, relatively few deep holes have been drilled in the Embayment area, and the possibilities of oil and gas occurrence cannot be said to have been sufficiently tested.

SELECTED REFERENCES

American Society for Testing Materials, 1962, Standard specifications for classification of coal by rank, *in* Standards on coal and coke: Am. Soc. Testing Materials, 14th ed., p. 1–6.

Anderson, K. H., and Wells, J. S., 1965, The Forest City Basin of Missouri, Kansas, Nebraska, and Iowa: Am. Assoc. Petroleum Geologists Midcontinent Regional Mtg., Tulsa, Okla., Oct. 15, 1965.

Bartle, G. G., 1933, The geology of the Blue Springs gas field, Jackson County, Missouri: Missouri Bur. Geol. and Mines 57th Bienn. Rept., app. 3, 64 p.

Bishop, O. M., 1949, The mineral industry of Missouri in 1946 and 1947, with total production summarized: Missouri Geol. Survey and Water Resources Inf. Circ. no. 4, 93 p.

Broadhead, G. C., 1873, Geology of northwestern Missouri, *in* Preliminary report on iron ores and coal fields, 1872: Missouri Geol. Survey, pt. 2, p. 1–213.

Clair, J. R., 1943, Oil and gas resources of Cass and Jackson Counties, Missouri: Missouri Geol. Survey and Water Resources, 2d ser., v. 27, 208 p.

Enright, R. J., 1964, Heavy oil—a billion-barrel prize: Oil and Gas Jour., v. 62, no. 24, p. 41–44.

Gentile, R. J., 1965, Mineral commodities of Putnam County, Missouri: Missouri Geol. Survey and Water Resources Rept. Inv. no. 29, 48 p.

Goebel, E. D., 1966, Thermal recovery projects are increasing in Kansas and Missouri: World Oil, v. 162, no. 4, p. 78–80.

Greene, F. C., 1914, The coal resources of northeastern Missouri: U.S. Geol. Survey Bull. 541, p. 223–242.

———, 1933, Oil and gas pools of western Missouri: Missouri Bur. Geol. and Mines 57th Bienn. Rept., app. 2, 68 p.

———, 1945, Recent drilling in northwestern Missouri: Missouri Geol. Survey and Water Resources Rept. Inv. no. 1, 153 p.

Greene, F. C., and McQueen, H. S., 1943 The Polo gas field, Caldwell County, Missouri: Missouri Geol. Survey and Water Resources 62d Bienn. Rept., app. 1, 24 p.

Greene, F. C., and Pond, W. F., 1926, The geology of Vernon County: Missouri Bur. Geol. and Mines, 2d ser., v. 19, 152 p.

Grohskopf, J. G., 1955, Subsurface geology of the Mississippi embayment of southeast Missouri: Missouri Geol. Survey and Water Resources, 2d ser., v. 37, 133 p.

Hinds, Henry, 1912, The coal deposits of Missouri: Missouri Bur. Geol. and Mines, 2d ser., v. 11, 503 p.

Hinds, Henry, and Greene, F. C., 1915, The stratigraphy of the Pennsylvanian series in Missouri: Missouri Bur. Geol. and Mines, 2d ser., v. 13, 407 p.

Howe, W. B., Koenig, J. W., and others, 1961, The stratigraphic succession in Missouri: Missouri Geol. Survey and Water Resources 2d ser., v. 40, 185 p.

McCracken, Earl, 1955, Northeast Missouri's oil possibilities improve: Oil and Gas Jour., v. 53, no. 35, p. 154–155.

McCracken, Earl, and McCracken, Mary, 1965, Subsurface maps of the Lower Ordovician (Canadian series) of Missouri: Missouri Geol. Survey and Water Resources, ser. 6 maps (scale 1:1,000,000).

McQueen, H. S., and Greene, F. C., 1938, The geology of northwestern Missouri: Missouri Geol. Survey and Water Resources, 2d ser., v. 25, 217 p.

Missouri Division of Mine Inspection: State Mine Inspector Ann. Repts.

Searight, W. V. 1949, Coal production, distribution, and consumption in Missouri: Missouri Geol. Survey and Water Resources Inf. Circ. no. 3, 52 p.

———, 1957, Asphaltic rocks in western Missouri: Missouri Div. Geol. Survey and Water Resources Inf. Circ. no. 13, 26 p.

77–278 O—67——17

Trantham, J. C., and Marx, J. W., 1965, Bellamy (Missouri) field test—oil for tar by counterflow underground burning: Soc. Petroleum Engineers Paper no. 1269, preprint, 7 p. (presented at 40th Ann. Mtg. Soc. Petroleum Engineers of AIME, Denver, Colo., October 1965).

Unklesbay, A. G., 1952, Geology of Boone County, Missouri: Missouri Div. Geol. Survey and Water Resources, 2d ser., v. 33, 159 p.

U. S. Bureau of Mines Minerals Yearbooks.

Wilson, M. E., 1922, The occurrence of oil and gas in Missouri: Missouri Bur. Geol. and Mines, 2d ser., v. 16, 284 p.

WATER RESOURCES

INTRODUCTION

(By A. Homyk, E. J. Harvey, and H. G. Jeffery, U.S. Geological Survey, Rolla, Mo.)

In Missouri the supply of available water constitutes one of the State's most important natural assets. Interest is growing in the State's water resources and in problems related to their development as the population increases and as the use of water becomes greater. This section of the report is a compilation of information about water in Missouri, its use and management.

The kind of water supply developed for purposes other than hydroelectric power in Missouri is determined by the sources of water available. If surface and ground water sources are both available the comparative cost of obtaining and treating the water is taken into account. Along the major rivers where big cities and their attendant industries require large quantities of water the source is principally the river. North of the Missouri River where development of ground water supplies is difficult and minimum flows of streams are inadequate without storage, reservoirs store the drainage from small areas. During extended dry spells some of these supplies are inadequate. Most of the towns south of the Missouri River and many immediately north of the river depend on wells from which adequate supplies usually can be obtained.

Important surface water supplies of good to fair chemical quality are found in the Mississippi and Missouri Rivers and some of their principal tributaries.

The Ozark region of Missouri has one of the largest concentrations of springs in the Nation. Of the Nation's 69 first-magnitude springs (those having an average flow of 100 cubic feet per second or more) reported by Beckman and Hinchey (1944, p. 17), 10 are found in the Ozark region of Missouri. These springs discharge large quantities of water; consequently, streams in this region have well-sustained base flows and carry bountiful supplies of good water into adjoining States, much of it unused within the borders of Missouri except for recreation.

The average annual runoff from streams in the State varies from 4 inches in the northwest to 22 inches in the southeast (fig. 57).

Moderate to large quantities of ground water (150,000 to 1,500,000 gallons a day per well) are available at various depths in the Ozarks. In the St. Francois Mountains in the eastern part of the Ozarks, supplies of several hundred thousand gallons a day can be obtained from sandstone and dolomite overlying the igneous rocks. Where only igneous rocks are present at the surface, ground-water supplies are small. North and west of the Ozarks the supply of potable water from wells is generally smaller because of the shallow depth to saline water.

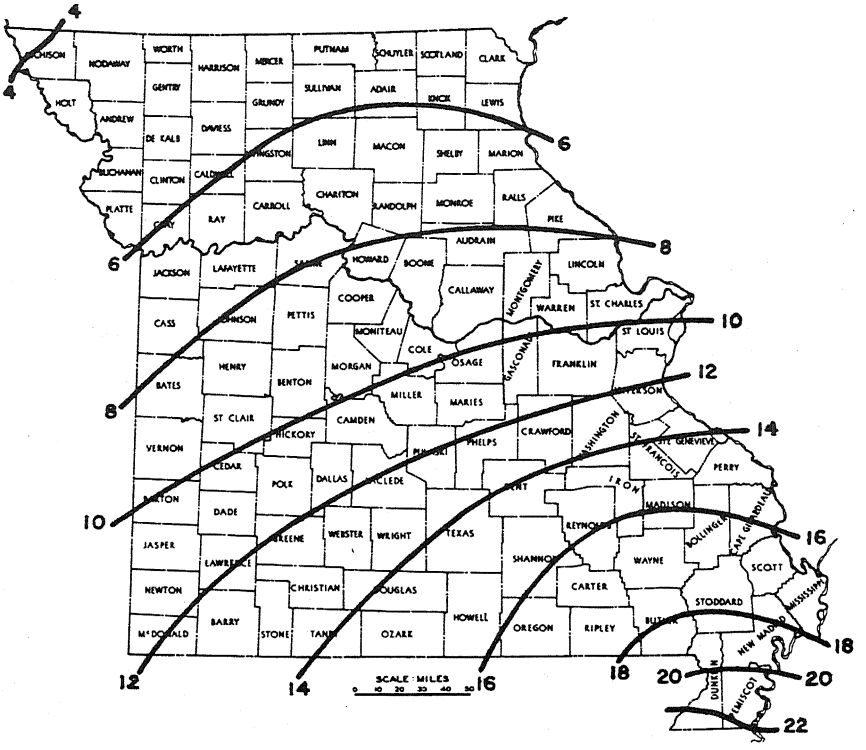


FIGURE 57.—Average annual runoff, in inches.

Large quantities of fresh water are available from sand and gravel of Cretaceous, Tertiary, and Quaternary ages in the southeast corner of the State. Small to large yields are obtained from a few wells in the glacial deposits north of the Missouri River. Generally large quantities of water can be obtained from alluvium in the Missouri and Mississippi River Valleys.

Water with a chemical quality that generally is adequate for most uses or that can be made so with suitable treatment is available in most parts of the State. The kind and amount of mineral constituents dissolved in the waters of the State are controlled principally by the geology and the chemical character of the rocks which the water moves over or through (see table 37, after Boswell and others, 1965). In the Ozarks area of the State the dissolved-solids content of the surface and ground water generally is less than 300 ppm and the waters are a calcium bicarbonate or a calcium-magnesium bicarbonate type. In the Plains area of the State the dissolved-solids content of surface waters is slightly higher than in the Ozarks. The waters are a calcium bicarbonate type, but they also contain significant amounts of magnesium and sulfate. Much of the water in consolidated aquifers in the western and northern parts of the State is saline. The quality of water in glacial drift material is variable. The dissolved-solids content of water from glacial drift generally is greater than 400 ppm

and in many places the waters are saline. Calcium, magnesium, sodium, bicarbonate, and sulfate are the principal constituents dissolved in the water.

TABLE 37.—*Source and significance of dissolved mineral constituents and properties of water*

Constituent or property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 p.p.m. High concentrations, as much as 100 p.p.m. generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high-pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 p.p.m. of soluble iron in surface waters generally indicates acid wastes from mine drainage or other sources.	More than about 0.3 p.p.m. stains laundry and utensils reddish brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. USPHS (1962)[1] drinking-water standards state that iron should not exceed 0.3 p.p.m. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Manganese (Mn)	Dissolved from some rocks and soils. Not so common as iron. Large quantities often associated with high iron content and acid waters.	Same objectionable features as iron. Causes dark brown or black stain. USPHS (1962) drinking-water standards state that manganese should not exceed 0.05 ppm.
Calcium (Ca) and magnesium (Mg).	Dissolved from practically all rocks and soils, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see Hardness). Waters low in calcium and magnesium desired in electroplating, tanning, and dyeing and in textile manufacturing.
Sodium (Na) and potassium (K).	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers, and a high sodium content may limit the use of water for irrigation.
Bicarbonate (HCO_2) and carbonate (CO_3).	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot-water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium they cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives a bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. USPHS (1962) drinking-water standards recommend that the sulfate content should not exceed 250 ppm.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial wastes.	In large amounts in combination with sodium gives salty taste to water. In large quantities increases the corrosiveness of water. USPHS (1962) drinking-water standards recommend that the chloride content not exceed 250 ppm.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth depending on the concentration of fluoride, the age of the child, the amount of water consumed, and the susceptibility of the individual. The maximum concentration of fluoride recommended by the USPHS (1962) varies with the annual average of maximum daily air temperatures and ranges downward from 1.7 p.p.m. for an average maximum daily temperature of 50.0° F. to 0.8 p.p.m. for an average maximum daily temperature of 90.5° F. Optimum concentrations for these ranges are from 1.2 to 0.7 p.p.m.

[1] "Public Health Service Drinking Water Standards," revised 1962, apply to drinking water and water-supply systems used by carriers and others subject to Federal quarantine regulations.

TABLE 37.—*Source and significance of dissolved mineral constituents and properties of water*—Continued

Constituent or property	Source or cause	Significance
Nitrate (NO_2)	Decaying organic matter, legume plants, sewage, nitrate fertilizers, and nitrates in soils.	Concentration much greater than the local average may suggest pollution. USPHS (1962) drinking-water standards suggest a limit of 45 ppm. Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding. Nitrate has been shown to be helpful in reducing the intercrystalline cracking of boiler steel. It encourages the growth of algae and other organisms which may cause odor problems in water supplies.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils.	USPHS (1962) drinking-water standards recommend that the dissolved solids should not exceed 500 p.p.m. However, 1,000 p.p.m. is permitted under certain circumstances. Waters containing more than 1,000 p.p.m. of dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters, nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters of hardness up to 60 ppm are considered soft; 61–120 ppm, moderately hard; 121–180 ppm, hard; more than 180 ppm, very hard.
Specific conductance (micromhos at 25°C).	Mineral content of the water	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. It varies with the concentration and degree of ionization of the constituents, and with temperature.
Hydrogen-ion concentration (pH).	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 denote increasing acidity. pH is a measure of the activity of hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline water may also attack metals.
Color	Yellow-to-brown color of some water usually is caused by organic matter extracted from leaves, roots, and other organic substances. Color in water also results from industrial wastes and sewage.	Water for domestic and some industrial uses should be free from perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes.
Temperature	Climatic conditions, use of water as a cooling agent, industrial pollution.	Affects usefulness of water for many purposes. Most users desire water of uniformly low temperature. Seasonal fluctuations in temperatures of surface waters are comparatively large depending on the volume of water.
Suspended sediment	Erosion of land and stream channels. Quantity and particle-size gradation affected by many factors such as form and intensity of precipitation, rate of runoff, stream channel and flow characteristics, vegetal cover, topography, type and characteristics of soils in drainage basin, agricultural practices, and some industrial and mining activities. Largest concentrations and loads occur during periods of storm runoff.	Sediment must generally be removed by flocculation and filtration before water is used by industry or municipalities. Sediment deposits reduce the storage capacity of reservoirs and lakes and clog navigable stream channels and harbors. Particle-size distribution is a factor controlling the density of deposited sediment and is considered in the design of filtration plants. Sediment data are of value in designing river-development projects, in the study of biological conditions and fish propagation, and in programs of soil conservation and watershed management.

The climate of Missouri is continental. The average annual temperature ranges from 60° F. in the southeast corner of the State to about 53° F. in the northwest corner. Average annual precipitation is about 48 inches in the southeast and 32 inches in the northwest.

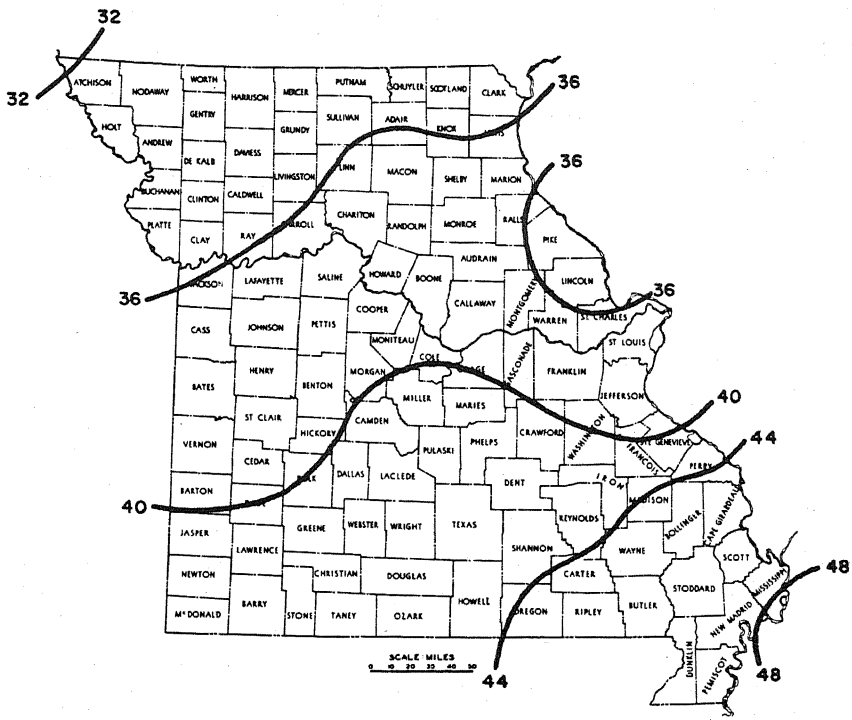


FIGURE 58.—Average annual precipitation, in inches.

Figure 58 shows the distribution of precipitation in Missouri. On the average about 42 percent of the precipitation occurs during the period May to August, inclusive. During this period rainfall frequently occurs as thunderstorms which are occasionally severe; at times more than 10 inches of rainfall has been recorded in 24 consecutive hours.

The most unusual thunderstorm occurred on June 22, 1947, at Holt, in northwestern Missouri, when 12 inches of rainfall was recorded in 42 minutes; the storm ranks as the most intense 42-minute rainfall recorded anywhere in the world. Evaporation over the State averages about 36 inches annually.

The water-use inventory for 1965 showed that 2,300 million gallons a day were used in the State for all purposes except hydroelectric power. This is an increase of 300 million gallons over 1960 (MacKichan and Kammerer, 1961). Uses include industrial cooling, municipal and rural supplies, livestock raising, irrigation, steam electric power generation, and fish propagation. It was estimated that about 6,200 million gallons a day were used for the generation of hydroelectric power in 1960 (MacKichan and Kammerer, 1961).

WATER RESOURCES INVESTIGATIONS

A program to appraise the water supply of Missouri and to investigate the problems arising from the use of water is being carried on by the Water Resources Division of the U.S. Geological Survey, in cooperation with the Missouri Geological Survey and Water Resources and other city, State, and Federal agencies. The use of water may be for navigation on the Missouri and Mississippi Rivers, dilution of industrial waste, water supply for a farm, or any one of many other needs. Much of the information on water is published in reports by the State agencies or by the State and Federal Geological Surveys. Streamflow, ground water levels, water quality, sediment data, and logs from well-drilling operations are among the types of information collected in the program.

SURFACE WATER

(By A. Homyk and H. G. Jeffery, U.S. Geological Survey, Rolla, Mo.)

INTRODUCTION

All of Missouri is drained either directly or indirectly by the Mississippi or Missouri Rivers, two of the largest river systems in the Nation. The Mississippi is the entire eastern boundary of the State from Keokuk, Iowa, to a point a few miles below Cottonwood Point, Mo., a distance of about 500 miles. The Mississippi River above Cottonwood Point drains about 30 percent of the total area of the continental United States. The Missouri River is the western boundary of the State from the Iowa line to Kansas City, a distance of about 200 miles. From Kansas City it flows eastward, bisecting the State, to its confluence with the Mississippi River 15 miles above St. Louis, a distance of about 375 miles. The Mississippi and Missouri Rivers, above their confluence, are partially controlled by lakes and reservoirs.

Distinctive low-flow regimens exist in each of Missouri's physiographic regions. In the Plains section, the low-flow potential of the streams is small because of the low storage capacity of the shales and clays of the area. The streams of the Ozark Plateaus, where the base flow is almost entirely from springs, have the highest base flows in Missouri, primarily because of the widespread distribution of soluble carbonate rocks which store large quantities of water. In the Southeast Lowland, large amounts of surface water are available without storage, and the region ranks second to the Ozarks in terms of available surface water.

The yield of streams during long periods of low precipitation is larger south of the Missouri River in the Ozark region than in the glaciated areas of northern Missouri. The rock formations underlying the Ozarks contribute more water to sustain the low flow of streams than do those underlying the glaciated area. Figures 59 and 60, graphs showing annual flows of the Gasconade River in the Ozarks and the Grand River in the glaciated area, illustrate this difference in the low flow characteristics of the two areas.

The severe droughts of the mid-1930's and mid-1950's caused the lowest flows recorded at long-time stream-gaging stations. In general, streamflow was lowest in north Missouri in 1934 and 1936 and lowest in central and south Missouri in 1954 and 1956.

Minimum streamflows in Missouri usually occur during the late summer or fall. At longtime continuous-record stations, more record minimum flows have occurred in August than in any other month, with September and October in second and third place, respectively.

This discharge of the principal streams in the State is shown schematically on figure 61. The width of the streams represents the average discharge in cubic feet per second (c.f.s.).

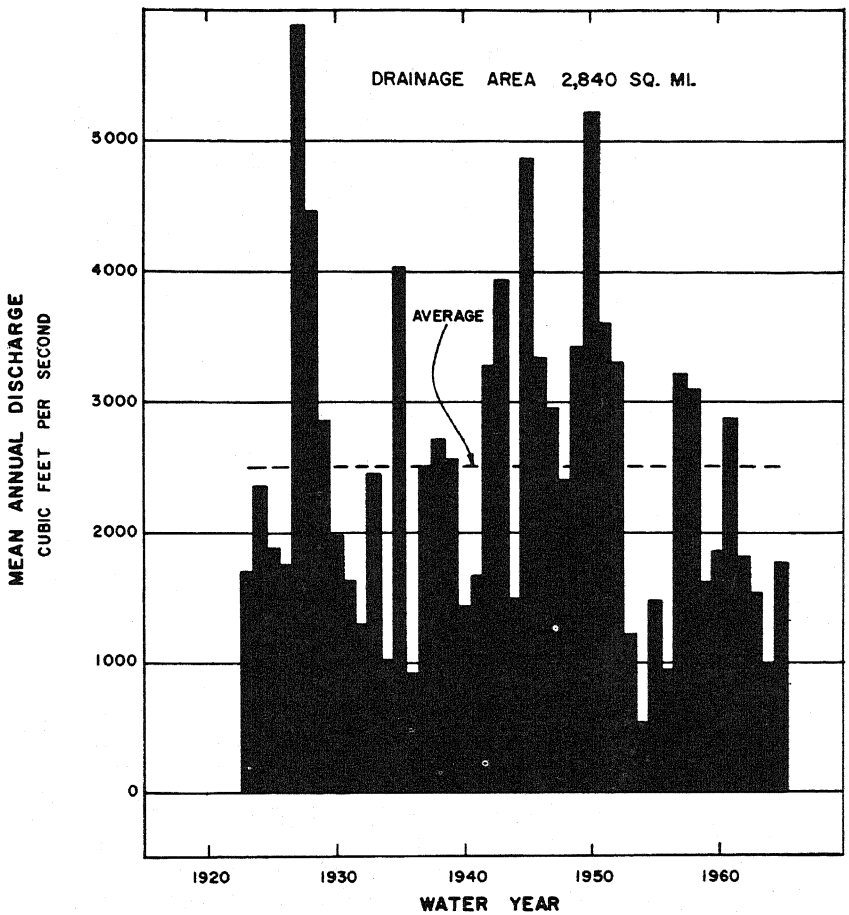


FIGURE. 59.—Annual discharge of the Gasconade River at Jerome (Ozark region).

The dissolved-solids content and hardness of water are two of the more important characteristics that determine the suitability of water for many uses. The maximum and minimum hardness and dissolved-solids content of surface waters in different areas are shown in figure 62.

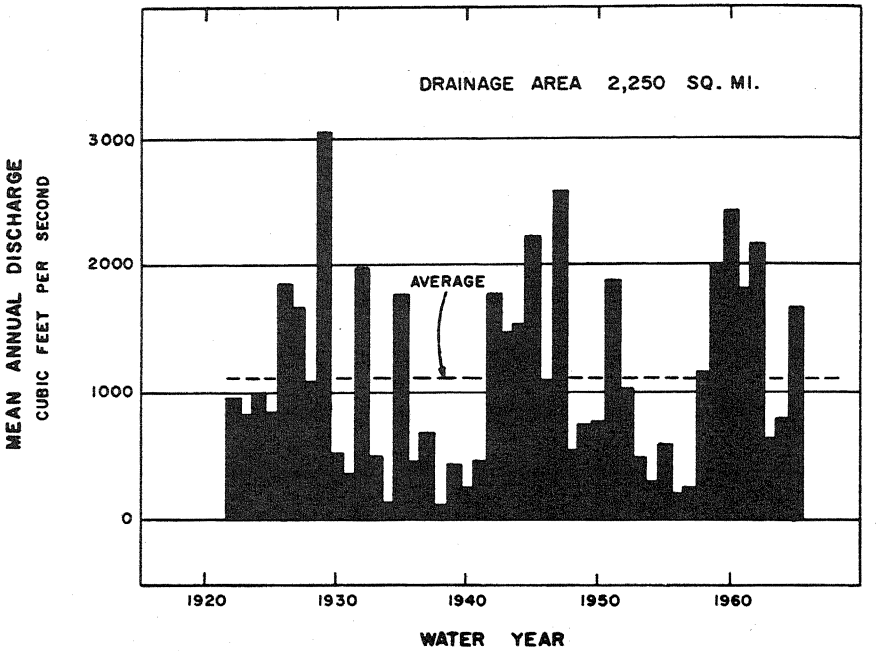


FIGURE 60.—Annual discharge of the Grand River near Gallatin (glaciated area).

The preceding discussion presents general statements of the surface water resources of Missouri. Descriptions of the main rivers and their tributaries with specific information on the rates of streamflow and general water-quality conditions are given below.

MISSISSIPPI RIVER MAIN STEM

The Mississippi River rises in Lake Itasca, Minn. and flows southward 2,440 miles to the Gulf of Mexico. The reach of the river contiguous to the State of Missouri forms the entire eastern boundary of the State from Keokuk, Iowa, to a point a few miles below Cottonwood Point, Mo., a distance of about 500 miles. At Cottonwood Point the area drained by the Mississippi is 923,500 square miles, or about 30 percent of the total area of the continental United States.

The importance of the Mississippi to the State's history and development is well known. Presently it is one of the State's most valuable assets, its waters being used extensively for navigation, recreation, and for public and industrial water supplies for the larger Missouri cities along its banks. At six sites along the Mississippi between Keokuk and St. Louis, locks and dams have been constructed to maintain a 9-foot deep navigation channel. The natural flow of the river is affected by regulation of these and tributary dams, and by diversions for irrigation.

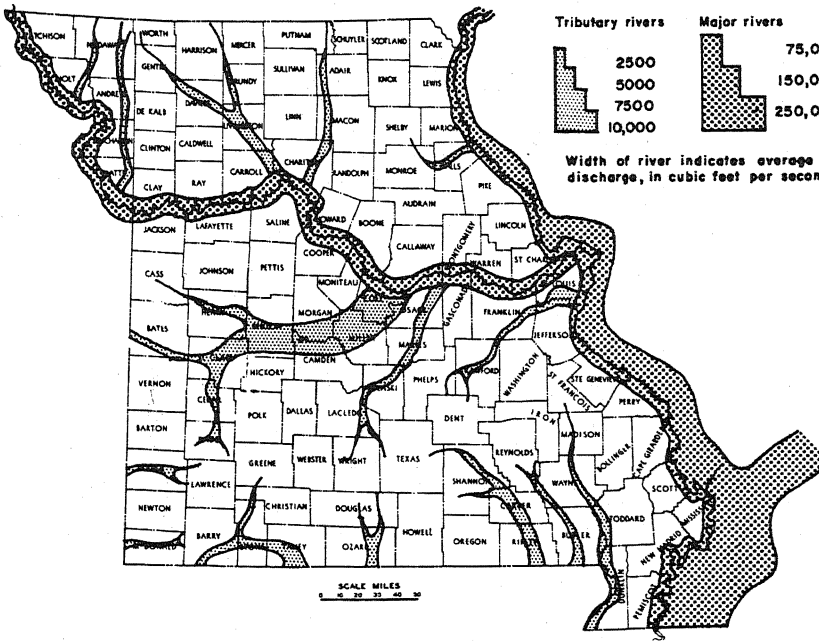


FIGURE 61.—Average discharge of the principal rivers.

The principal contributor to the Mississippi from the west is the Missouri River, which enters the Mississippi about 15 miles above St. Louis. The area drained by the Mississippi above this confluence is about 171,500 square miles, the Missouri at this point adds about 528,200 square miles. The two rivers together form the longest waterway in the world, stretching from the Montana Rockies to the Gulf of Mexico. The Mississippi has a lower gradient than the Missouri, which probably causes the large channel depositions below the mouth of the Missouri.

Streamflow of data for the main stem of the Mississippi River

Mississippi River at—	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
Keokuk, Iowa	119,000	86	60,670	[1] 314,000	[1] 5,000
Alton, Ill	171,500	37	91,960	[2] 437,000	7,960
St. Louis, Mo	701,000	103	173,800	[1] 1,019,000	[1] 18,000
Chester, Ill	712,600	37	173,900	886,000	[1] 30,000
Thebes, Ill	717,200	32	176,400	893,000	23,400

[1] Daily figure.
[2] Includes 90,000 cubic feet per second floodwater overflow from the Missouri River.

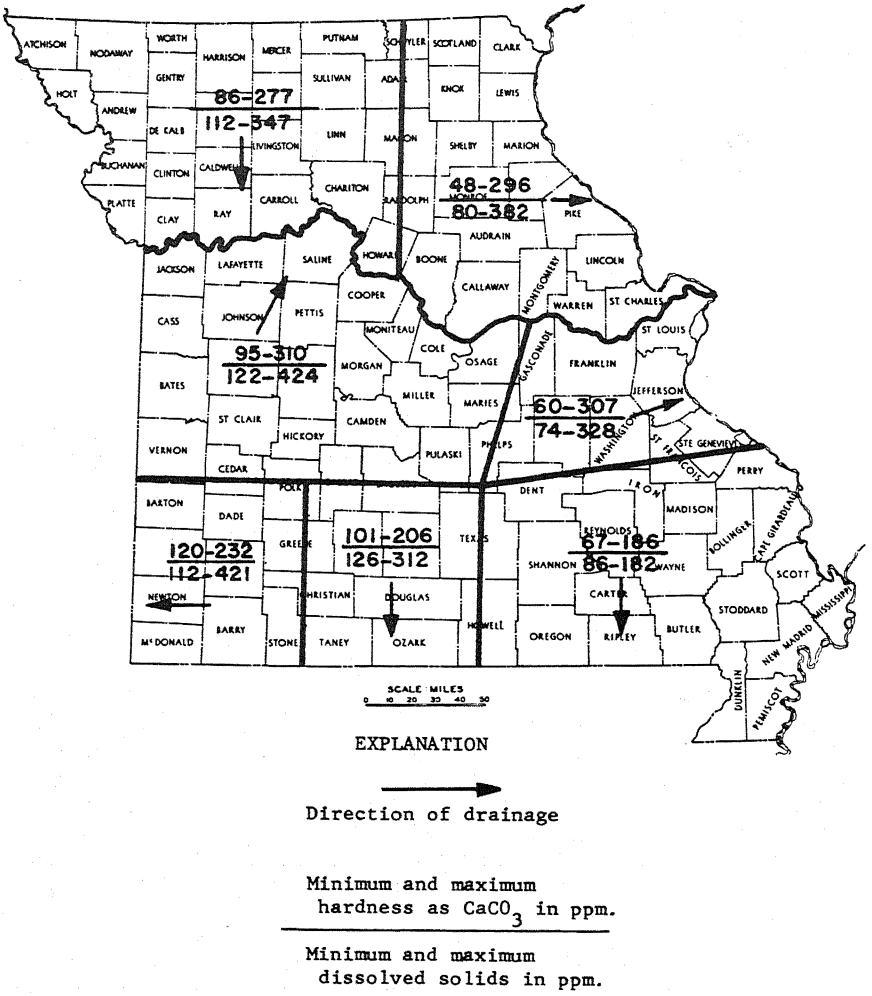


FIGURE 62.—Representative ranges in hardness and dissolved solids in surface water.

Water in the Mississippi River is moderately mineralized, the dissolved solids being composed essentially of carbonate and sulfate salts of calcium and sodium. The water is slightly less mineralized above the confluence of the Missouri River, but the principal effect of inflow of the Missouri is the increased turbidity of the Mississippi. Inflow from the Missouri does not mix completely during periods of low flow for some distance downstream and records at the East St. Louis Water Co. intake, about 2 miles below the mouth of the Missouri, are indicative of the quality of water in the Mississippi above the con-

fluence with the Missouri, whereas records at the Chain of Rocks water plant, about 5 miles downstream, are indicative of the quality of inflow from the Missouri. During the 10-year period 1940–49 the average monthly turbidity (expressed as parts per million of silica) at the East St. Louis water plant ranged from 88 to 609 parts per million, alkalinity as $CaCO_3$ ranged from 125 to 159 parts per million, and hardness as $CaCO_3$ ranged from 159 to 208 parts per million. At the Chain of Rocks plant for the same period the average monthly turbidity ranged from 346 to 2,579 parts per million, alkalinity as $CaCO_3$ ranged from 110 to 177 parts per million, and hardness as $CaCO_3$ ranged from 158 to 232 parts per million. The average monthly dissolved-solids content at the Chain of Rocks plant ranged from 284 to 401 parts per million. The average monthly water temperature at East St. Louis ranged from 38° F. to 83° F., and at the Chain of Rocks plant the range was from 37° F. to 80° F.

Because of the large volume of flow in the Mississippi River in relation to the small amount of inflow below St. Louis, the chemical quality of the water in the Mississippi below St. Louis is essentially the same as that at St. Louis.

The sediment load of the Mississippi River is measured at the McArthur Bridge in St. Louis. This is 15 miles downstream from the mouth of the Missouri River, which carries a heavier load of sediment than does the upper Mississippi River. At the McArthur Bridge the waters of the two rivers have not mixed completely; consequently the sediment concentration is usually relatively low near the east bank and increases progressively toward the west bank. Differences between concentration near the east and west banks have been as much as 2,400 parts per million. The concentration gradient has no apparent relation to the proportion of flow that is from the Missouri River or from the Mississippi River. Only very infrequently have concentrations near the east bank been greater than those near the west bank.

Suspended-sediment discharges at St. Louis from April 1948 to September 1962 ranged from 4,250 to 7,010,000 tons per day and averaged 471,000 tons per day. Daily sediment concentrations for the same period ranged from 35 to 6,420 parts per million. The mean annual concentrations decreased steadily from 1,690 parts per million in 1949 to 403 parts per million in 1956, increased to 911 parts per million in 1960, and decreased to 710 in 1962. The larger sediment discharges occur during periods of high flows, and as much as 41 percent of the annual sediment load has been discharged in a 30-day period.

UPPER MISSISSIPPI RIVER BASIN

The section of the upper Mississippi River basin in Missouri covers the northeast part of the State from the mouth of the Des Moines River at the Iowa-Missouri State line on the north to the confluence of the Mississippi and Missouri Rivers, 15 miles above St. Louis. The area was covered by two major glaciers which left a drainage pattern of narrow drainage basins nearly paralleling the Mississippi River to a point near their confluence. The streams in the area flow in comparatively wide alluvial valleys. The terrain upstream then becomes hilly with broken areas which in turn becomes rolling prairies, form-

ing divides between drainage areas. The low-flow potential of streams in this area is poor because of low permeability of the shales and clays in the area. During periods of flood, streams in this area usually reach their crests well before the Mississippi River and make a relatively small contribution to the crest discharge of the main stream.

Surface waters in the upper Mississippi River basin are a calcium bicarbonate type, but magnesium and sulfate also constitute a large part of the dissolved minerals. The waters are moderately mineralized with the dissolved-solids content ranging from 80 to 382 parts per million. The larger amounts of dissolved solids generally occur during periods of low flow. The hardness of the waters ranges from 48 to 296 parts per million, and most of the time the waters are very hard. The waters generally are of good chemical quality and are suitable for most uses. However, for municipal and some industrial uses some treatment such as softening would be desirable.

General descriptions of tributary basins that make up the upper Mississippi River basin and streamflow data are given on the following pages and streamflow data are tabulated below:

Streamflow data for the upper Mississippi River drainage basin in Missouri

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
Fox River at Wayland	400	42	221	25,000	0
Wyaconda River:					
Above Canton	393	32	211	17,700	0
Near Canton	447	10	315	16,000	0
North Fabius River:					
At Monticello	452	42	250	17,400	0
At Taylor	930	11	467	30,300	0
Middle Fabius River:					
Near Baring	185	30	108	9,540	0
Near Monticello	393	19	212	16,800	0
South Fabius River near Taylor	620	30	349	19,700	0
North River:					
At Bethel	58	28	35.6	6,930	0
At Palmyra	373	29	208	27,400	0
Bear Creek at Hannibal	31.0	21	15.3	6,500	0
Salt River:					
Near Shelbina	481	31	257	23,000	0
Near Hunnewell	626	10	346	15,400	0
Near Monroe City	2,230	25	1,276	71,100	0
Near New London	2,480	42	1,498	64,700	0
South Fork Salt River at Santa Fe	298	25	172	13,100	0
Middle Fork Salt River at Paris	356	25	205	23,100	0
Elk Fork Salt River near Paris	262	20	181	20,600	0
Douglas Creek near Emden	2.69	4		1,200	0
Davis Creek near Mexico	59	11		2,820	0
Youngs Creek near Mexico	67.4	28	41.3	6,530	0
Peno Creek at Frankford	54.2	8		6,050	0
Lost Creek near Elsberry	12.2	7	5.46	3,880	0
West Fork Cuivre River near Ladonia	32	9		2,780	0
Cuivre River near Troy	903	42	616	120,000	0

Fox River Basin

The Fox River rises in southeastern Iowa and flows southeasterly to the Mississippi River at a point about 6 miles below the mouth of the Des Moines River. Its principal tributary, the Little Fox, flows into the Fox about 20 miles above its mouth. The basin is about 75 miles in length and 10 miles at its greatest width. The drainage area at its confluence with the Mississippi is 502 square miles, of which 278 square miles are in Missouri.

Wyaconda River Basin

The Wyaconda River basin lies just south of the Fox River. It is formed by the North and South Wyaconda Rivers, which have their source in southern Iowa. Both flow southeasterly to their junction in Missouri to form the Wyaconda River, 44 miles above the Wyaconda's confluence with the Mississippi River, 10 miles above Quincy, Ill. The basin drains 458 square miles, of which 336 square miles are in Missouri, is about 70 miles long, and varies in width from 5 miles at its headwaters to 8 miles at its center and lower reaches. At the junction of its two main forks the elevation is about 630 feet above mean sea level; and at its junction with the Mississippi River it is about 480 feet.

Fabius River Basin

The Fabius River Basin's two principal streams, the North and South Fabius Rivers, rise in southern Iowa just north of the Missouri-Iowa State line and flow southeasterly in nearly parallel valleys to their junction, forming the Fabius River 3.4 miles upstream from the mouth of the Fabius. At one time this juncture was within 1 mile of the Mississippi; construction of a cutoff moved it 2.4 miles farther upstream. The basin drains 1,570 square miles, of which 100 are in Iowa, is about 80 miles long, and has a maximum width of 25 miles.

North River Basin

The North River, lying between the Fabius and Salt River Basins, flows in an easterly direction to its confluence with the Mississippi River about 3 miles downstream from the mouth of the Fabius River. It lies entirely in the State of Missouri and drains 382 square miles. The basin is about 55 miles in length and has a maximum width of about 14 miles. Its principal tributaries are the South Fork and Tiger Fork.

Salt River Basin

The Salt River Basin's 2,920 square miles make it the second largest basin north of the Missouri River in Missouri. Only the Grand River Basin is larger. Salt River flows generally in a southeasterly direction to its junction with the Mississippi about 2 miles upstream from Louisiana, Missouri. Its principal tributary, the South Fork, drains 1,220 square miles. The basin is about 125 miles long and has a maximum width of 40 miles and a minimum of 6 miles near its mouth. A few communities in the basin use the Salt or its tributaries for their municipal supply. Presently authorized for construction is Cannon Dam on the Salt River. Its primary purpose will be flood control, water supply, power, recreation, and fish and wildlife propagation.

Cuivre River Basin

The Cuivre River, formed by the junction of the North and West Forks, flows in a southeasterly direction for 37 miles to its junction with the Mississippi River about 17 miles upstream from the mouth of the Illinois River. The basin is elliptical in shape, 60 miles in length, with a maximum width of 40 miles. It drains 1,230 square miles of the State.

MISSOURI RIVER MAIN STEM

The Missouri River extends some 2,450 miles from its headwaters along the Continental Divide in Montana and Wyoming to its con-

fluence with the Mississippi River a few miles upstream from St. Louis. Its drainage area of 529,000 square miles, about one-sixth of the conterminous United States, includes about one-half of Missouri and all or parts of Montana, Wyoming, North Dakota, Nebraska, Colorado, Kansas, Minnesota, and Iowa.

The Missouri River forms part of the western boundary of Missouri for 200 miles as it flows from the northwest corner of the State in a generally southeast direction to Kansas City, where it turns and flows east 375 miles across the State to the Mississippi River. The alluvial valley ranges in width from 2 to 8 miles and is bordered by steep bluffs. The valley is seldom more than 2 miles wide, in the reach from Boonville, near the center of the State, to its mouth, where the river flows through the rough, hilly, dissected area of the northern part of the Ozark foothills. The average slope of the 575 miles of the river adjacent to or in Missouri is 0.85 feet per mile. At its confluence with the Mississippi River the elevation is about 400 feet above sea level.

The important role played by this river in the history of the development of the State and Nation is well known. Presently it is one of the State's most important resources; about 50 percent of the State's population, including metropolitan Kansas City and St. Louis, depend on the river or its alluvium for their daily supply of water and to carry away their wastes. In addition, its waters in the State are used for the generation of steam-electric power, navigation, and irrigation. Flow of the Missouri River is affected by many reservoirs in the upper reaches of the basin.

Data on the flows of the Missouri River are listed below:

Missouri River at—	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
Rulo, Nebr.	418,905	15	36,180	358,000	4,420
St. Joseph	424,300	36	36,720	397,000	2,300
Leavenworth, Kans.	425,000	7	52,540	241,000	3,450
Kansas City	489,200	67	54,710	573,000	1,500
Waverly	491,200	35	45,530	549,000	1,700
Glasgow	502,875	4		550,000	9,540
Boonville	505,700	39	55,460	550,000	1,800
Bonnots Mill	523,400	8	56,690	417,000	10,000
Hermann	528,200	67	78,570	676,000	4,200

The chemical quality of water in the Missouri River is the result of mixing of many types of water from hundreds of tributaries. In Missouri, the water generally is hard and moderately mineralized. The dissolved-solids content of the water varies with streamflow and is higher during periods of low flow. Turbidity of the water also varies with streamflow and it is higher during periods of high flow. The lower turbidity values generally occur during the winter months.

The average annual content of dissolved solids is less than 500 parts per million but values up to 839 parts per million have been observed. Inflow to the Missouri River between Kansas City and St. Louis acts as a diluent and decreases the dissolved-solids content, on the average, by about 100 parts per million between the two cities. At Kansas City the 10-year (1942–51) average dissolved-solids content was 452 parts per million, and at St. Louis the average for the 10-year period (1940–

49) was 365 parts per million. Calcium, magnesium, sodium, bicarbonate, and sulfate are the predominant chemical constituents dissolved in the water, and variations in the dissolved solids content are caused primarily by variations in the amounts of these constituents. The percentage composition (ratio of each dissolved constituent to total dissolved solids) of the dissolved-solids content remains fairly constant.

Missouri River water is treated before use because of its consistently high turbidity. Turbidities, expressed as parts per million silica, have ranged from 18 to 9,300 parts per million. The hardness of the water, also an undesirable characteristic in many uses, has ranged from a minimum of 88 parts per million near the mouth to a maximum of 396 parts per million at Kansas City. The temperature of the water ranges from the freezing point up to 90° F.

The turbidity values reported are a measure of the optical properties of the water-sediment mixture, and although they are reported in terms of parts per million silica, they are not synonymous with the weight of sediment per unit volume of water. The suspended sediment discharge of the Missouri River is extremely variable. The larger sediment discharges occur during periods of high flows and the sediment load generally increases downstream. Daily sediment loads for the 1949–63 water years ranged from a minimum of 216 tons per day at St. Joseph to a maximum of 13,163,000 tons per day at Kansas City. The annual suspended sediment loads for this period ranged from 37,400,000 tons at St. Joseph to 494,000,000 tons at Kansas City. More detailed information on sediment loads in the Missouri River is available in publications of the Corps of Engineers, U.S. Army.

MISSOURI RIVER BASIN

Tarkio River Basin

The Tarkio River is formed by the union of the East Tarkio and West Tarkio Creeks in the northwest section of the State. The drainage basin is narrow at its upper end in Iowa, gradually widens to about 15 miles in the lower half, and narrows again near its mouth. For flood protection of the adjoining farmland, the channel has been straightened and bank improvements have been made. The most significant change made by these channel improvements was the moving of the mouth of the river from its natural entry to the Missouri River to a point about 20 miles upstream, thus cutting off from its drainage basin one of its principal tributaries, the Little Tarkio River, resulting in the decrease of the drainage area of the main stem from 730 square miles to 534 square miles. No chemical quality-of-water information is available on the waters of the Tarkio River. Data on streamflow of the Tarkio River are given below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
West Tarkio Creek near Westboro	105	6	23.4	8,720	0
Tarkio River at Fairfax	508	42	187	16,300	0

Nodaway River Basin

The Nodaway River begins at the junction of the West and Middle Forks of the Nodaway River in southern Iowa and flows in a southerly direction to its junction with the Missouri River upstream from St. Joseph. The total area drained is about 1,780 square miles, of which 586 square miles are in Missouri. The basin is about 115 miles long but only the last 50 miles are in Missouri; its width ranges from 10 miles at its lower reaches to 35 miles near its upper reaches. Much of the main channel of the Nodaway River has been straightened and banks have been improved to protect adjacent farmlands from flooding. At the gaging station on the Nodaway River near Burlington Junction, Mo., drainage area 1,240 square miles, the average discharge was 503 cubic feet per second, for the 42-year period of record (1922–64); the maximum of 32,000 cubic feet per second occurred on June 14, 1947, and the minimum of 1.1 cubic feet per second occurred on August 7, 1934.

No records of the chemical quality of water of the Nodaway River basin are available.

Platte River Basin

The Platte River rises in southwestern Iowa and flows in a southerly direction, entering the Missouri River between Kansas City and St. Joseph. The basin in Missouri is about 135 miles long and has a maximum width of 28 miles. The area drained by the Platte is 2,440 square miles, of which 1,640 square miles are in Missouri. The channel of the Platte has been straightened and banks have been improved to protect adjacent farmlands from flooding. The waters of its principal tributary, the One Hundred and Two River, are used by the city of Maryville for municipal supply. Data on the flow of the Platte River basin are given below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
Platte River:					
At Ravenwood	486	6	394	11,000	3.0
At Conception Junction	492	6	219	12,000	.1
Near Agency	1,760	37	820	50,000	0
One Hundred and Two River near Maryville	500	32	199	14,200	0
White Cloud River near Maryville	6.06	11	2.99	4,100	0
Jenkins Branch at Gower	2.72	14	1.42	2,420	0

Chemical quality information for the Platte River near Agency, Mo., indicates that surface water in the basin is a hard, moderately mineralized, calcium-magnesium bicarbonate type. The analyses of samples collected at monthly intervals from August 1962 to June 1963 show the dissolved-solids content of water in the Platte ranging from 139 to 298 parts per million. Hardness of the water ranged from 91 to 242 parts per million. Calcium, magnesium, and bicarbonate are the principal constituents but sulfate is also a significant part of the dissolved solids. The sulfate content of the water ranges from 22 to 48 parts per million. Except for the high hardness, and large turbidity

during periods of high streamflow, the chemical quality of water in the Platte River near Agency is adequate for most uses.

Blue River Basin

The Blue River rises in east-central Kansas near the Missouri-Kansas State line and flows for 47 miles in a northeasterly direction, much of it through urban areas, to the Missouri River near the eastern city limits of Kansas City. The basin, draining 272 square miles, lies entirely within the Osage Plains and is about 31 miles long and its maximum width is 17 miles. The average slope of the river is about 8.3 feet per mile. At the gaging station on the Blue River, drainage area 188 square miles, for the 25-year period of record (1939–64) the average discharge was 135 cubic feet per second; the maximum discharge was 41,000 cubic feet per second; at times there was no flow. The natural waters of the Blue River are a calcium bicarbonate type.

Little Blue River Basin

The Little Blue River's 225 square miles of drainage area lie wholly within the State, part of it draining Metropolitan Kansas City. The basin is about 38 miles long with a maximum width of about 13 miles. It lies within the Osage Plains province. At the gaging station, drainage area 184 square miles, the average discharge for the 16-year period of record (1948–64) was 99.2 cubic feet per second; the maximum discharge was 9,460 cubic feet per second; at times there has been no flow. The waters of the Little Blue River are a calcium bicarbonate type.

Grand River Basin

The Grand River rises in southwestern Iowa and flows southeasterly through northwestern Missouri to its confluence with the Missouri River about 250 miles upstream from the mouth of the Missouri. The basin is the largest river basin in the State north of the Missouri River; it has a drainage area of about 7,900 square miles and about 80 percent of this area is in Missouri. It is elliptical in shape, its major axis lying in a north-south direction, 150 miles in length and 90 miles at its greatest width. Basin elevations range from 625 feet above mean sea level at the mouth to 1,300 feet at its head waters in Iowa. The area is a part of the prairie section of the State and was covered by two major glaciers. The low-flow potential of the streams in the basin is poor because of the low permeability of the shales and clays of the area. The Grand River is 217 miles long, and has an average slope of 3.6 feet per mile, the extreme lower reaches having a slope of only 0.5 foot per mile. There has been considerable straightening of the channel and bank improvement along the Grand and its tributaries to protect the low adjacent lands from flooding.

About 70 percent of the precipitation in the area occurs from April to September; flooding in the lower reaches occurs quite frequently during this period. The water of the Grand River is used extensively for public water supply, dilution of municipal and industrial wastes, livestock watering, fish and wildlife propagation, and limited recreation. Three miles of the Grand River are considered navigable; however only a few commercial craft have been using it in recent years.

Principal tributaries, important now and to the future development of the Grand River Basin, and their drainage areas in square miles

are: the East Fork Grand, 434; Grindstone Creek, 324; Big Creek, 400; Thompson River, 2,200, of which 580 belong to its principal tributary, the Weldon River; Shoal Creek, 628; Medicine Creek, 512; Locust Creek, 631; and Yellow Creek, 593. Data on flows of streams in the Grand River Basin are:

Streamflow for the Grand River basin in Missouri

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
Grand River:					
Near Gallatin	2,250	43	1,108	69,100	2.2
Near Sumner	6,880	41	3,700	180,000	10
Thompson Branch near Albany	5.58	4	----------	1,700	10
East Fork Big Creek near Bethany	95	30	48.6	8,120	0
Thompson River:					
Near Mt. Moriah	891	4	----------	30,200	[1] 8
At Trenton	1,670	38	901	95,000	[1] 1
Weldon River:					
Near Mercer	246	20	138	50,000	0
At Mill Grove	494	35	250	46,000	0
Shoal Creek near Braymer	391	7	267	26,000	0
Medicine Creek:					
Near Galt	225	43	137	24,200	0
Near Sturgis	368	4	----------	10,400	2.5
Locust Creek:					
Near Milan	225	12	152	3,880	0.1
Near Linneus	550	36	324	38,000	0
West Fork Yellow Creek near Brookfield	135	5	85.7	3,900	0
Hamilton Branch near New Boston	2.51	4	----------	693	0
Yellow Creek near Rothville	405	6	220	9,000	0.2

[1] Minimum daily discharge.

Surface waters in the Grand River Basin generally are slightly alkaline, moderately mineralized, and very hard. Calcium and bicarbonate are the predominant ions in solution, but magnesium and sulfate also are significant parts of the dissolved solids. The dissolved-solids content of the waters range from 112 to 328 p.p.m., and the hardness of the waters ranges from 86 to 274 p.p.m. Generally, the higher dissolved-solids content and the harder waters occur during periods of low streamflow. The surface waters in the basin generally are of good chemical quality and are suitable for most uses.

Chariton River Basin

The Chariton River rises in south-central Iowa, flows in a southeasterly direction to the Missouri-Iowa State line, then flows southward to its confluence with the Missouri River about 25 miles downstream from the mouth of the Grand River. The river is about 280 miles long, has an average slope of about 1.3 feet per mile, and drains 2,960 square miles, 70 percent of which lies in Missouri. Over 50 percent of the river's channel has been straightened, including one project in which the mouth of the river was moved 6 miles upstream from its natural location. This construction caused the Little Chariton River, once a principal tributary, to discharge directly into the Missouri River. The basin is 150 miles long and 22 miles in maximum width.

Data on the flow of streams in the Chariton River Basin are given below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
Chariton River:					
At Novinger	1,370	32	721	22,900	0.1
At Elmer	1,660	9	1,080	22,500	14
At Prairie Hill	1,870	36	1,068	25,600	4.6
Mussel Fork at Musselfork	267	5	125	4,380	0
East Fork Chariton River near Huntsville	220	2		1,210	0

No information on the chemical quality of water in the upper part of the Chariton River Basin is available, but in streams that are unaffected by coal mining the dissolved-solids content and chemical characteristics of the waters probably are similar to those found in the Grand River Basin and the Upper Mississippi River Basin. Chemical analyses of water from the East Fork Chariton River near Huntsville indicate that water in this stream and other streams which drain coal mining areas is acidic and contains fairly large amounts of dissolved solids. In the East Fork Chariton River, pH as low as 2.60 (extremely acid) and amounts of dissolved-solids, manganese, and iron as high as 1,790, 23, and 8.6 p.p.m., respectively, have been observed.

Lamine River Basin

The Lamine River is located in west-central Missouri, south of the Missouri River. The Blackwater River, which makes up about 59 percent of the Lamine River Basin's 2,640 square miles, is the principal tributary. The basin is about 60 miles wide in a north-south direction and about 70 miles in length in an east-west direction. The elevation of the headwaters of the basin is 900 feet above sea level and at its mouth it is 580 feet. The Lamine River is about 102 miles long and has an average river slope of 3.1 feet per mile. The Blackwater joins the Lamine about 10 miles upstream from the Missouri River. Some of the waters of the Lamine River or its tributaries are used for municipal supply and stock watering.

Data on the flow of streams in the Lamine River Basin are given below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
Flat Creek near Sedalia	148	6	79.6	14,100	0
Lamine River at Clifton City	598	42	450	65,500	0
South Fork Blackwater River near Elm	16.4	10	9.32	5,600	0
Blackwater River at Valley City	547	6	362	66,500	0
Blackwater River at Blue Lick	1,120	37	667	54,000	.1
Shiloh Branch near Marshall	2.87	12	1.34	934	0

The chemical quality of surface water in the Lamine River Basin varies with the source. In the Lamine River above the confluence of Blackwater River, the water is moderately mineralized and fairly uniform in composition. Calcium, magnesium, and bicarbonate are the principal constituents. The dissolved-solids content ranges from 122 to 278 parts per million, and the hardness of the water ranges from 95 to 236 parts per million.

Water in the Blackwater River is variable in both dissolved-solids content and type. The dissolved solids range from 189 to 1,510 parts per million with the higher values occurring during periods of low flow. The stream receives inflow from saline springs, and during periods of low flow the water is a sodium chloride type. At other times calcium and bicarbonate are the predominant ions. The sulfate content of the water is higher than that in the Lamine River and at times it exceeds 100 parts per million. Hardness of the water ranges from 116 to 502 parts per million. Water in the Lamine River is of good chemical quality and is suitable for most uses. At times the dissolved solids and chloride content of water in the Blackwater River is excessive for many uses.

Osage River Basin

The Osage River rises in east central Kansas and flows in an easterly direction through Kansas and Missouri for a distance of about 520 miles to its confluence with the Missouri River, 12 miles downstream from Jefferson City. The official name of the river in Kansas is the Marais des Cygnes. That part of the basin in Kansas and the part in Missouri draining the Osage Plains is gently rolling prairie land. The lower part in Missouri is rugged, broken terrain of the Ozark Mountain foothills which border the Osage River on the south. The drainage area of the Osage River basin is about 15,300 square miles, of which about 70 percent is in Missouri. The elliptical basin is about 250 miles long in an east-west direction and 100 miles wide.

The Osage River is about 500 feet above mean sea level near its mouth and about 1,250 feet at the headwaters. The average slope from the headwaters to Osceola, Mo., is about 5.2 feet per mile and from Osceola to the mouth about 0.74 feet per mile.

In the Osage Plains section of the basin the low-flow yield of the streams is poor, but in the Ozark Plateau section streams have well-sustained low flows.

Waters of the Osage River are used for hydroelectric power production, recreation, municipal water supply, wildlife propagation, and for the carrying away of municipal and industrial wastes. Lake of the Ozarks, formed by Bagnell Dam, has developed into the most extensively water-based recreational area in the State. Bagnell Dam is an important source of hydroelectric power in the Union Electric Co. of Missouri system. Tunnel Dam on the lower Niangua River is a source of hydroelectric power for the Sho-Me Power Co. The Missouri Public Service Co. operates a hydroelectric plant on the main stem at Osceola.

Other developments of the Osage River in Missouri are the Pomme de Terre Reservoir, on the Pomme de Terre River, whose primary purpose is flood control with additional benefits to navigation; the Stockton Reservoir, on the Sac River, under construction, whose primary purposes are flood control and power; and the Kaysinger Bluff Reservoir on the main stem, under construction, whose primary purposes are flood control, power, and recreation. These projects are discussed under the section on "Water Resources Development."

The principal tributaries of the Osage River and the areas drained by them, in square miles, are: the Little Osage River, 1,720; Marmaton River, 1,150; Sac River, 1,970; Pomme de Terre River, 828; South Grand River, 2,040; Niangua River, 1,040; and the Maries River, 305.

Data on the flow of streams in the Osage Basin are shown below:

Streamflow for the Osage River basin in Missouri

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
Osage River:					
At Osceola	8,220	45	5,067	146,000	3.6
At Warsaw	11,500	6	9,160	89,700	42
Near Bagnell	14,000	84	9,516	220,000	[1] 220
Near St. Thomas	14,500	33	9,766	216,000	346
Little Osage River at Stotesbury	427	3	----------	13,600	0
Sac River:					
At Stockton	1,160	43	990	120,000	0
Near Collins	1,900	2	----------	35,700	9
Little Sac near Springfield	40	4	----------	7,000	.1
Oak Grove Branch near Brighton	1.30	3	----------	845	0
Cedar Creek near Pleasant View	420	19	273	33,900	0
Pomme de Terre River:					
Near Bolivar	225	14	154	18,300	.1
Near Hermitage	615	4	----------	9,000	0
At Hermitage	655	43	589	70,000	0
Lindley Creek near Polk	112	7	82.4	28,000	0
South Grand River:					
At Urich	670	4	----------	29,200	0
Near Brownington	1,660	43	1,027	63,900	0
Big Creek at Blairstown	414	4	----------	24,400	0
Niangua Branch at Marshfield	.82	7	.57	483	0
Niangua River:					
Near Decaturville	627	35	627	33,400	6
Near Roach	698	8	1,010	27,200	160
Starks Creek near Preston	4.19	3	----------	1,400	0
Van Cleve Branch near Meta	.75	3	----------	1,200	0
Maries River near Westphalia	257	16	195	20,000	.1

[1] Minimum daily discharge.

Water in streams in the Osage River Basin generally contains less than 400 p.p.m. of dissolved solids and is a calcium bicarbonate or a calcium-magnesium bicarbonate type, depending on the surface materials. Waters in the Osage River main stem and its tributaries from the north are more mineralized and contain appreciable quantities of sulfate. The dissolved-solids content of water in the Osage and its northern tributaries ranges from 132 to 424 p.p.m. The sulfate content ranges from 20 to 173 p.p.m., and the hardness ranges from 97

to 310 p.p.m. Waters in two of the tributaries from the south, the Sac and Pomme de Terre Rivers, are less mineralized and contain less sulfate than the main stem Osage and northern tributaries. The dissolved-solids content and sulfate in the Sac and Pomme de Terre Rivers range from 160 to 239 p.p.m. and 8.1 to 16 p.p.m., respectively. Water in the Sac River is a calcium bicarbonate type and in the Pomme de Terre River it is a calcium-magnesium bicarbonate type. Hardness of the water in the two streams ranges from 148 to 230 p.p.m. The quality of water in the Osage Basin generally is suitable for most uses.

Gasconade River Basin

The Gasconade River rises in the south-central part of the State on the northern slope of the Ozark Mountains and flows northeast to its junction with the Missouri River about 40 miles downstream from Jefferson City. The basin's 3,600-square-mile area is roughly bottle-shaped, 130 miles long, 50 miles wide near its headwaters and narrowing to 8 miles near its mouth. The Gasconade River is 270 miles long and has a fall of about 700 feet. The Gasconade and its tributaries have a high, well-sustained base flow, because of the many springs in the basin. The principal tributaries of the Gasconade and their drainage areas in square miles are: the Osage Fork, 520; Roubidoux Creek, 300; Big Piney River, 760; and the Little Piney Creek, 272. The Gasconade and its tributaries are used extensively for recreation, primarily float fishing, and for fish propagation. Fort Leonard Wood depends on waters of the Big Piney for municipal supply and to carry away the treated sewage.

Data on the flow of streams in the Gasconade River Basin are given below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
Gasconade River:					
Near Hazelgreen	1,250	36	977	76,400	18
Near Waynesville	1,680	50	1,409	89,000	44
At Jerome	2,840	44	2,522	101,000	254
Near Rich Fountain	3,180	43	2,939	96,400	271
Osage Fork at Drynob	404	2	----------	8,970	16
Big Piney River near Big Piney	560	43	536	32,700	69
Beaver Creek near Rolla	14.0	7	13.4	3,800	.1
Little Beaver Creek near Rolla	6.41	16	5.28	7,420	0
Little Piney Creek at Newburg	200	36	153	32,500	24

Water in the Gasconade River Basin is moderately mineralized and fairly uniform in chemical characteristics. The water is a calcium-magnesium bicarbonate type. Dissolved-solids content ranges from 143 to 209 parts per million and hardness of the water ranges from 140 to 210 parts per million. Concentrations of constituents other than calcium and magnesium bicarbonate are usually small, and variations in the dissolved-solids content result mostly from changes in the

concentration of calcium, magnesium, and bicarbonate. In general, water in the Gasconade River Basin is of good quality and is suitable for most uses. Because of the high hardness of the water, softening is desirable for some uses.

Other Missouri River tributaries

Information about other streams draining into the Missouri River in the State is given in the following table:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
Mill Creek at Oregon	4.90	9	1.71	2,640	0
East Fork Fishing River at Excelsior Springs	20.0	14	11.0	23,100	0
Crooked River near Richmond	159	16	88.2	27,000	0
Wakenda Creek at Carrollton	248	16	126	7,000	.2
Burge Branch near Arrow Rock	0.33	5	0.11	134	0
Shiloh Branch near Marshall	2.87	12	1.34	934	0
Moniteau Creek near Fayette	81	15	32.1	4,330	0
Petite Saline Creek near Boonville	182	16	103	6,120	0
Moreau River near Jefferson City	531	15	319	23,000	.1
Big Hollow near Fulton	4.05	2		936	0
Rumbo Branch at Danville	1.40	5	.61	434	0
Loutre River at Mineola	202	16	102	12,900	0
Coldwater Creek near St. Louis	43.6	4		6,170	4.2

LOWER MISSISSIPPI RIVER BASIN

Meramec River Basin

The Meramec River and its two principal tributaries, the Bourbeuse and Big Rivers, lie wholly within the State and drain 3,980 square miles of east-central Missouri. The river rises in the Ozark Plateau and flows in a general northeasterly direction, entering the Mississippi River about 12 miles south of St. Louis. The basin is 110 miles long. Its greatest width, near the center of the basin, is 60 miles, gradually decreasing to about 10 miles near its mouth.

The basin is a highly dissected plateau with land surface sloping gently to the north and becoming increasingly more rugged to the south. The elevation ranges from 1,500 feet above mean sea level at its headwaters to about 450 feet at its mouth. There are many sinkholes in the basin. Many large springs cause the high sustained base flow of the Meramec and its tributaries.

The Meramec and its tributaries are used for municipal supply, recreation, fish propagation, and for the dilution and carrying away of municipal and industrial wastes.

The water resources of the Meramec Basin at present are relatively undeveloped. Because of its proximity to large centers of population and its recreation potential, the basin has been studied intensively to insure future orderly development.

Data on the flow of streams in the Meramec Basin are given below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
Meramec River:					
Near Steelville	781	42	569	47,800	74
Near Sullivan	1,475	33	1,170	77,300	131
At Robertsville	2,673	12	2,569	102,000	256
Near Eureka	3,788	45	3,025	120,000	196
Green Acre Branch near Rolla	.62	16	.416	1,900	0
Bemke Branch near Rolla	1.05	11	.904	1,190	0
Bourbeuse River:					
Near St. James	21.3	16	16.3	8,250	0
Near Spring Bluff	608	----------	----------	50,700	----------
At Union	808	43	632	33,100	11
Lanes Fork near Rolla	.225	12	.164	136	0
Dry Branch near Bonne Terre	3.65	4	----------	1,520	0
Big River:					
Near DeSoto	718	16	661	55,800	20
At Byrnesville	917	43	839	42,100	25

Surface water in the Meramec River Basin is moderately mineralized and a calcium-magesium bicarbonate type. The dissolved-solids content of water in the main stem of the Meramec River is lowest near the headwaters and increases slightly as the water moves downstream. Near Sullivan the dissolved-solids content of the water ranges from 87 to 199 parts per million, and at Paulina Hills, about 10 miles above the mouth, the dissolved solids range from 127 to 265 parts per million. The dissolved-solids content of water in Big River near DeSoto ranges from 68 to 341 parts per million, and in the Bourbeuse River above Union the range in dissolved solids is from 81 to 221 parts per million. Hardness of water in the basin ranges from 60 to 307 parts per million. Local pollution exists in the basin but it has not seriously affected the overall quality of water in the principal streams except possibly in the lower reaches of the Meramec River. Water in the basin generally is of a quality suitable for most uses.

St. Francis River Basin

The St. Francis River rises in the St. Francois Mountains and flows south for a distance of about 475 miles to its confluence with the Mississippi River about 8 miles upstream from Helena, Ark. Its principal tributary in Missouri, the Little River, originates just east of the headwaters of the St. Francis and flows southward to its confluence with the St. Francis at Marked Tree, Ark. In Missouri the drainage area in the upper reaches of the main stem and its principal tributary is rough and hilly to the edge of the Mississippi embayment and the reach in the embayment is flat and, in a few sections, swampy. The drainage area of the main stem in Missouri is about 100 miles long, with a maximum width of 30 miles, and drains 1,500 square miles. The Little River's original drainage area was about 3,000 square miles. To assist in the reclaiming of the lowlands a diversion canal was con-

structed which carries off the flood waters from about 1,190 square miles of the uplands directly into the Mississippi River at Cape Girardeau, Mo. South of the diversion channel a network of lateral ditches was constructed, the waters of these ditches discharging into Big Lake on the Missouri-Arkansas State line. Wappapello Dam and Reservoir, constructed in 1941, affords flood protection for the lower reaches of the St. Francis River. The reservoir is a major recreation area in the State. Large quantities of ground water are stored in the lowlands of the St. Francis River Basin; it is released to the rivers and ditches more uniformly than in the uplands because the movement of water through the clay, sand, and gravels of the lowlands is much slower than in the hill country. However, large quantities of surface water are available without storage. The region ranks second to the Ozarks in the available supply of surface water.

Data on the flow of streams and ditches in the St. Francis River Basin are shown below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
St. Francis River:					
Near Patterson	956	44	1,100	79,200	8
At Wappapello	1,311			22,300	0
At Fisk	1,370	14	1,308	50,000	5
Wappapello Reservoir at Wappapello	1,310				
Barnes Creek near Fredericktown	4.03	4		5,550	0
Clark Creek near Piedmont	4.39	3		1,400	.2
Castor River:					
At Zalma	[1] 423	44	506	40,400	16
At Aquilla	175	19	152	5,900	0
Little River:					
Ditch 81 near Kennett	111	38	200	2,760	8
Ditch 1 near Kennett	235	38	415	7,660	8
Ditch 251 near Lilbourn	235	19	312	3,530	29
Ditch 1 near Morehouse	450	19	482	8,250	21
Ditch 251 near Kennett	883	37	744	8,380	52
Ditch 66 near Kennett		38	274	4,350	0
Ditch 66A near Kennett		37	42.8	2,340	0
Ditch 259 near Kennett	89.0	37	107	4,140	0

[1] Headwaters of diversion channel.

The few data that are available for the quality of surface water in the lower St. Francis Basin indicate that the water is a moderately mineralized calcium bicarbonate or calcium-magnesium bicarbonate type, depending on the surface materials drained. The dissolved-solids content of streams in the highlands is less than that in streams which drain the alluvial plain in southeast Missouri. The dissolved-solids content of water in the St. Francis River at Fredericktown ranges from 90 to 155 parts per million, and the average dissolved solids content of streams in the alluvial plain is about 240 parts per million.

White River Basin

The White River rises in northwestern Arkansas, flows northeastward into Missouri, then east and south into Arkansas. Its drainage

area as it leaves Missouri is 4,420 square miles. In its reach in Missouri are two significant developments, Lake Taneycomo, created by Powersite Dam, a hydroelectric installation of the Empire District Electric Co., and Table Rock Dam and Reservoir, a Corps of Engineers power and other beneficial water use project. Both developments form one of the most widely used recreational areas in the State. Streams in the White River Basin that are discussed in more detail are the James, North Fork, Black, Current, and Eleven Point Rivers.

James River.—The James River is the principal tributary entering the White River in Missouri. The James River drains about 1,460 square miles. Its basin is 60 miles long, 20 miles wide in the upper two-thirds of its length, and 30 miles wide in its lower third.

In its upper reaches the City of Springfield Utilities operates a steam electric plant and uses the waters of Lake Springfield for cooling. Lake Springfield is also used extensively for recreation. The lower reach of the James River is one of the most popular float fishing streams in the State. One of the James River's principal tributaries, Wilson Creek, is used to carry away the treated municipal and industrial wastes of the city of Springfield. These wastes adversely affect the quality of the water in the James River below the mouth of Wilson Creek. The James River has a fairly well sustained low flow due to many springs.

North Fork River.—The North Fork River and its principal tributary, Bryant Creek, rise in the Ozark region of south-central Missouri and flow southward, joining a short distance north of the Missouri-Arkansas State line in the upper reaches of Norfolk Reservoir. They drain 1,310 square miles of Missouri. Both the North Fork and Bryant Creek basins are practically identical with respect to drainage area, surficial geology, basin shape, climate, and topography; however, in the lower reaches the base flow for North Fork is twice that of Bryant Creek. The North Fork basin has many more sinkholes than the Bryant Creek basin. A large spring system above the confluence of the two streams increases the flow of North Fork by about 150 percent, accounting for the difference in the base flow of the two streams. Many springs in the North Fork basin give the streams in the basin a relatively high sustained base flow. Both North Fork and Bryant Creek are popular float fishing streams; there is some commercial trout raising in the basin. That section of the river in Missouri which is a part of Norfolk Reservoir is a popular recreational area.

Black River.—The Black River rises in the St. Francois Mountains in the southeastern section of the State and flows southeasterly, then southward to its confluence with the White River in Arkansas. The basin in Missouri is 90 miles long, its greatest width of 25 miles is at the upper end of the basin, its minor width of 14 miles is near its center. It drains about 1,400 square miles of the State. The upper basin is rough and hilly to the vicinity of Popular Bluff, below which the river flows in the broad, flat plains of the Mississippi embayment area. The base flows of the streams in the basin are among the

highest in the State, because of the many large springs. The Black River is the source of municipal and industrial water supply for the city of Popular Bluff and is used to carry away the treated wastes of the city. Other uses of the basin's waters are fish propagation and recreation. Clearwater Dam and Reservoir, a flood control and other purpose project, is a popular recreational area in the basin. To protect the valuable lands of the lower basin, levees have been constructed and channels have been improved.

The most significant recent development in the basin is the Taum Sauk hydroelectric plant, operated by the Union Electric Co. of Missouri, on the East Fork of the Black River. A dam has been constructed across the stream, and water is pumped from the dam's impoundment to an upper reservoir during periods of low power demand and released during peak-power demand.

Current River.—The Current River originates at Montauk Springs in the south-central Missouri Ozarks and flows for 140 miles to the Missouri-Arkansas State line. It drains 2,120 square miles of the State; the basin is 90 miles in length and about 50 miles at its maximum width. Its principal tributary, Jacks Fork, drains 422 square miles. There are four springs of first magnitude in the Current River Basin, among them Big Springs, the largest single-outlet spring in the Nation. These four springs and other smaller springs give the streams in the basin the highest sustained base flow in the State. The Current River and Jacks Fork are the most popular float fishing streams in the State. Some of the spring waters in the basin are used for raising trout.

The basin is on the Salem Plateau; the topography is rough and hilly. Elevations in the basin range from 1,300 feet above sea level on the north and west, to 500 feet at the southeast corner. Because of the basin's natural attractiveness, some of the lands adjacent to the upper reaches of Current River and Jacks Fork has been set aside as the Ozark National Scenic Riverways administered by the National Park Service.

Eleven Point River.—The Eleven Point River rises in south-central Missouri, flows east, then south to join the Black River in Arkansas. The length of the basin in Missouri is about 60 miles and its greatest width is 22 miles. It drains about 1,000 square miles in Missouri. The Eleven Point's high base flow is sustained by many large springs, most significant of which are Greer Spring, the second largest in the State, and Blue Spring, the 10th largest in the State. Both are springs of first magnitude. The basin is part of the Salem Plateau, where the topography is rough and hilly, and elevations range from 1,300 to 500 feet above mean sea level. The principal use of the stream is for recreation.

Data on the flow of streams in the White River Basin in Missouri are shown below.

Streamflow for the White River Basin in Missouri

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
White River:					
At Reeds Spring	3,617	14	4,368	196,000	148
Near Branson	4,022	13	3,173	89,100	0
At Forsyth	4,544	23	4,959	209,000	[1] 34
James River:					
Near Springfield	246	9	176	24,800	.1
Near Battlefield	303	3	----------	16,200	25
At Galena	987	43	920	52,700	10
Wilson Creek near Springfield	19.0	7	19.8	2,440	1.5
North Fork River:					
Near Tecumseh	561	20	702	27,400	187
At Tecumseh	1,157	24	1,194	53,000	280
Bryant Creek near Tecumseh	570	20	519	26,800	96
Black River:					
Near Annapolis	484	25	551	45,400	66
At Leeper	957	43	955	78,400	70
At Poplar Bluff	1,245	26	1,258	52,600	236
East Fork Black River at Lesterville	94.5	4	----------	7,200	0
Little Black River near Fairdealing	187	3	----------	6,270	15
Cane Creek at Harviell	188	3	----------	7,840	8
Big Creek near Yukon	8.36	15	6.83	4,860	0
Jacks Fork at Eminence	398	43	439	40,000	64
Current River:					
Near Eminence	1,272	43	1,443	75,100	324
At Van Buren	1,667	52	1,853	125,000	473
At Doniphan	2,038	46	2,712	94,000	852
Eleven Point River:					
Near Thomasville	361	14	87.0	16,900	2.7
Near Bardley	793	43	744	40,000	152
Kings Creek near Willow Springs	4.71	4	----------	568	0

[1] Minimum daily discharge.

Surface waters of the White River Basin in Missouri are, in general, moderately mineralized and fairly uniform in chemical characteristics. The quality of water in the James River has been adversely affected by industrial and municipal effluents, and the stream generally contains more dissolved solids and is more variable in chemical characteristics than other waters in the basin. In the western part of the basin the streams drain limestone terranes and the water is a calcium bicarbonate type. Streams in the eastern part of the basin drain dolomite terranes and the water is a calcium-magnesium bicarbonate type. The dissolved solids content ranges from 101 to 210 parts per million, with the streams draining dolomite generally having a dissolved solids content slightly higher than streams that drain limestone. Hardness of the water ranges from 98 to 188 parts per million, and it also is slightly higher in streams that drain dolomite.

The waters of the White River Basin are of good chemical quality and are suitable for most uses except for the James River, which receives the treated municipal wastes of Springfield through Wilson Creek.

Spring River Basin

The Spring River Basin is in southwestern Missouri and drains about 2,000 square miles of the State. The area is gently rolling to moderately hilly; much is excellent farmland. The principal tributaries to the Spring River are Center, Turkey, and Shoal Creeks, which enter the Spring River just west of the Missouri-Kansas State line. This area was once one of the world's largest zinc-mining

centers; the streams were important to the economy then, as they are now. The base flows of the streams are sustained by headwater springs which flow from the cherty, crinoidal limestone in the upper reaches. The main stem of the Spring River drains about 1,180 square miles of Missouri and is principally used for the development of power for mill operation, mainly in the Carthage area. Center Creek, which drains about 300 square miles, carries away industrial waste from plants that use springs, mines, or deep wells for water supplies. Turkey Creek, drainage area 48 square miles, is used to carry away the treated wastes of Joplin. Shoal Creek drains about 440 square miles in the State and is the source of municipal water supply for Joplin and the principal source for Neosho. Shoal Creek is used some for recreation.

Data on the flow of streams in the Spring River Basin are shown below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge	
				Maximum (cubic feet per second)	Minimum (cubic feet per second)
Spring River:					
At Larussell	306	7	167	16,300	15
Near Waco	1,164	40	828	103,000	4.2
Stahl Creek near Miller	3.86	9	1.92	1,150	0
Center Creek near Carterville	232	2		3,450	17
Turkey Creek:					
At Joplin	33	8	15.8	1,980	0
Near Joplin	41.8	2		3,520	3.4
Shoal Creek:					
Above Joplin	410	23	381	62,100	12
Near Joplin	439	17	386	54,000	[1] 1.5

[1] Regulated.

The surface waters in the Spring River Basin generally are moderately mineralized and fairly uniform in chemical characteristics. The streams drain limestone terranes and the water is a calcium bicarbonate type. The hardness of the waters ranges from 98 to 188 parts per million. The water quality of lower Center and lower Turkey Creeks is adversely affected by municipal and industrial wastes. Waters in Center Creek contain as much as 32 parts per million fluoride, 91 parts per million nitrate, 50 parts per million phosphorus as PO_4, and 25 parts per million organic and ammonium nitrogen.

GROUND WATER

(Dale L. Fuller and Robert D. Knight, Missouri Geological Survey and Water Resources, Rolla, Mo., and E. J. Harvey, U.S. Geological Survey, Rolla, Mo.)

INTRODUCTION

Much water is available from the ground-water reservoir in Missouri, but the distribution and quality are such that not all parts of the State are equally fortunate. For the purpose of this report the State is divided into three provinces as shown in figure 63b, and the yields available from typical wells that penetrate the various aquifers (water-bearing rocks) are shown in figure 63a.

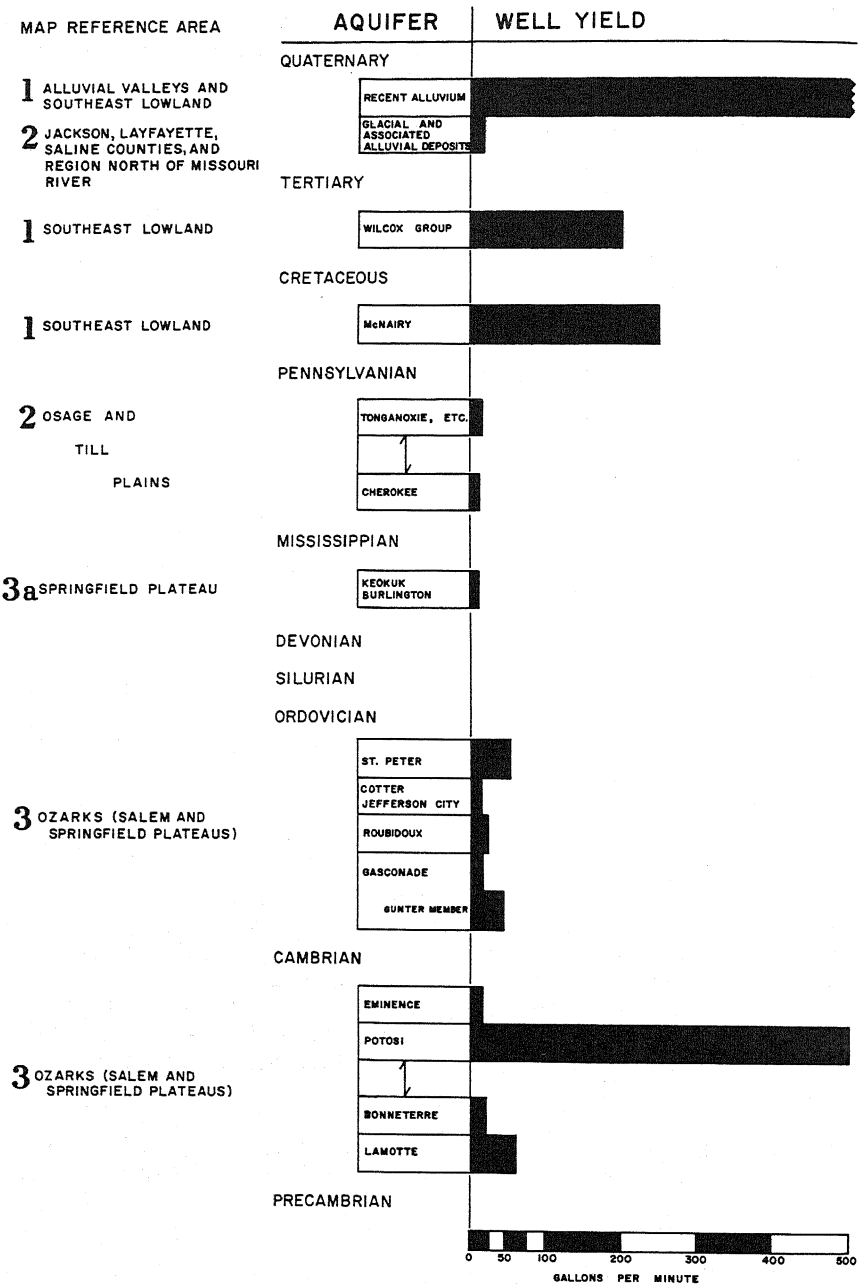


FIGURE 63a.—Typical yields of wells in principal aquifers of the three ground-water provinces.

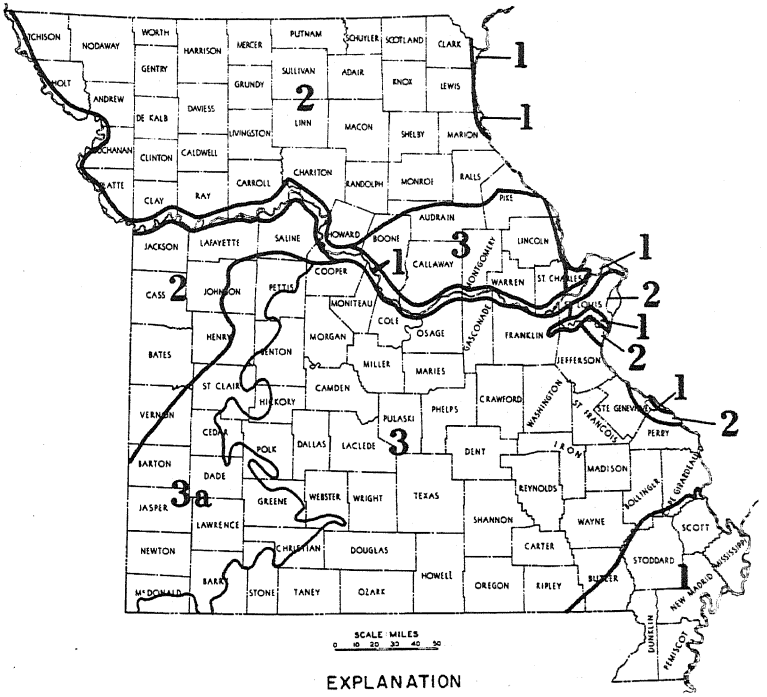


FIGURE 63b.—Ground-water provinces.

The most extensive area in the State for development of fresh ground water supplies is the Ozark area. It includes the Salem Plateau in the southeastern and south-central part of the State and the Springfield Plateau in the southwestern part. The reservoir in this area consists of a section of more than 2,000 feet of Cambrian and Ordovician dolomite and sandstone, overlain, on the flank, by Mississippian limestone. The diagrammatic section on figure 64, which extends from the Southeast Lowland through the St. Francois Mountains to the northwest, shows the thickness of the sedimentary section across the State and the increase in the mineralization of water with depth.

The geographic distribution of mineralized water in Paleozoic aquifers is shown also by figure 64. Northwest, east, and southeast of the Ozarks the water in these rocks increases in salinity until it is unusable.

In northern Missouri glacial deposits overlie the older consolidated rocks. The southern boundary of these deposits lies 3 to 25 miles south of the Missouri River in the western part of the State and conforms approximately to the course of the river in the eastern part (see inset map, fig. 2, p. 14). These glacial deposits contain sand beds which at present are developed largely for domestic and small municipal supplies, but they are capable of supplying larger quantities of water along the courses of buried glacial valleys. The glacial valleys have been defined by test drilling and areas are delineated where small, medium, and large water supplies can be expected.

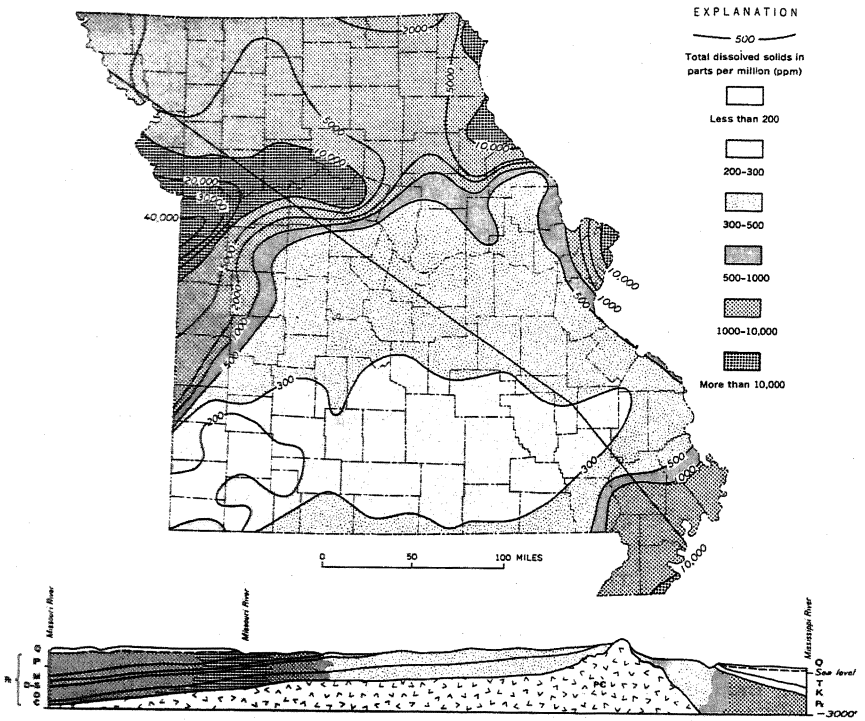


FIGURE 64.—Quality of ground water in the Paleozoic aquifers.

Unconsolidated or semiconsolidated deposits of sand and gravel yield copious supplies of water along the alluvial plains of the Mississippi, Missouri, and Meramec Rivers and in the Southeast Lowland. These areas are much less extensive (6,000 ± sq. mi.) than the areas of fresh water in Paleozoic rocks ((40,000 ± sq. mi.), but the quantities of water available per well from the unconsolidated deposits may be much larger. (See fig. 63.)

Since 1924, 25,000 well logs have been collected by the Missouri Division of Geological Survey and Water Resources. These well logs contain useful data on the thickness, composition, and depth to various formations that may yield water. Many of the well logs in-

clude insoluble-residue studies. Distribution of these logs by county is shown in figure 65.

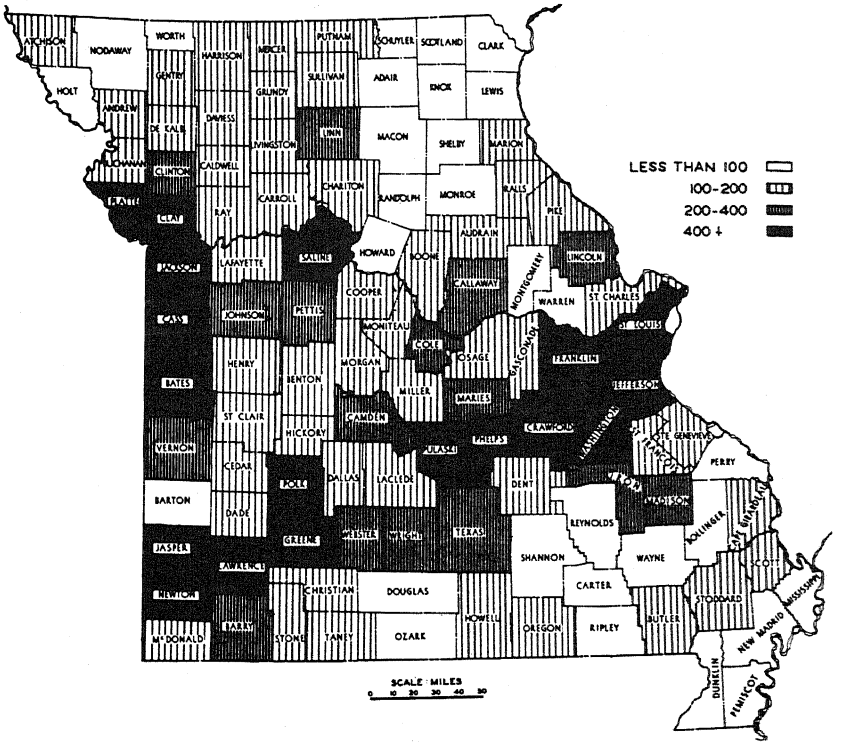


FIGURE 65.—Distribution of well logs per county.

Owing to the widespread development of karst topography in the Ozarks and the great depth of weathering, pollutants may find their way to considerable depths. To safeguard water supplies from pollution, wells are cased to a dense stratum below the surface and cemented to seal out possible pollutants. It may be necessary to install casing to considerable depth. At West Plains, Howell County, for example 1,000 feet of casing is set because of the depth of weathering. At Springfield 250 to 400 feet, and at Rolla about 400 feet of casing is required.

In the alluvial valleys, glacial terrane, and the Southeast Lowland where unconsolidated sand and gravel is the source of water, this danger is not so great. Wells are completed by cementing the casing and setting screen opposite the unconsolidated water-bearing sand.

It has become almost common practice for engineers to include in specifications for well construction in limestone and dolomite terranes, a clause providing for acidizing of wells if the water volume obtained does not meet production requirements. Generally acidizing the well will increase production. Production increases of more than

100 percent are common and few instances of no improvement are known. Hydrochloric acid is used to dissolve soluble rock material with an inhibitor added to prevent attack on the casing. The acid is forced under pressure into the crevices and bedding planes to increase the open area in the formation and hence the flow of water.

Water supplies for public use must be approved by the Missouri Division of Health. Approval of wells is based, in part, on examination of sample cuttings from the well under construction. Studies of the cuttings and determination of the depth at which casing should be set are made by geologists of the Missouri Geological Survey and Water Resources in Rolla.

THE OZARKS

The five principal fresh-water aquifers most likely to yield a dependable supply of water in the Ozarks region of Missouri are the Lamotte Sandstone, Potosi Dolomite, Gunter Member of the Gasconade Dolomite, Roubidoux Formation, and St. Peter Sandstone. However, owing to the soluble character of the rock sequence as a whole and the development of openings along bedding planes and joints, other intervals may contain a bountiful supply of water in one place or another. The positions of the five aquifers in the geologic column and their relationship to other geologic units are shown in figure 63. From the ground-water point of view the Ozarks Province includes all the Salem-Springfield plateaus south of the Missouri River, a strip north of the Missouri River, and the small part of the Osage Plains where fresh water is obtained from Ordovician and Cambrian rocks (map, fig. 63). The geologic section, shown in figure 64, ranges in thickness from zero at the igneous outcrop of the St. Francois Mountains to almost 2,000 feet in the western part of the State.

The depth to which a well in the Ozarks must be drilled depends on the amount of water required. Supplies of several hundred to more than 1,000 g.p.m. are available almost anywhere in the Ozarks except in and close to the igneous area of the St. Francois Mountains. No treatment of the water from these rock wells is normally required as the water will be potable if the well is cased properly.

All aquifers of the Ozarks crop out toward the eastern or central part of the area in concentric belts surrounding the St. Francois Mountains. The older formations crop out near the mountains and progressively younger formations crop out as distance from the mountains increases. The formations are recharged in the outcrop and also by the vertical movement of water through overlying formations. The recharge to these rock formations and the amount of water a well will produce is in a large measure dependent upon the permeability of the formation.

The specific capacity (yield in gallons per minute per foot of drawdown) of a well varies according to the ability of the aquifer or aquifers to yield water. Variations in specific capacity are shown in figure 66, a map based on data from many wells that penetrate one or more productive water-bearing zones.

Requirements of small industry needing up to 50 gpm (gallons per minute) can be provided for easily in the Ozarks. The water is usually obtained by wells penetrating the Gunter Member of the Gas-

conade Dolomite at an average depth of 500 to 600 feet. The wells that produce from this section are ideal for clubs, schools, small towns, and industries.

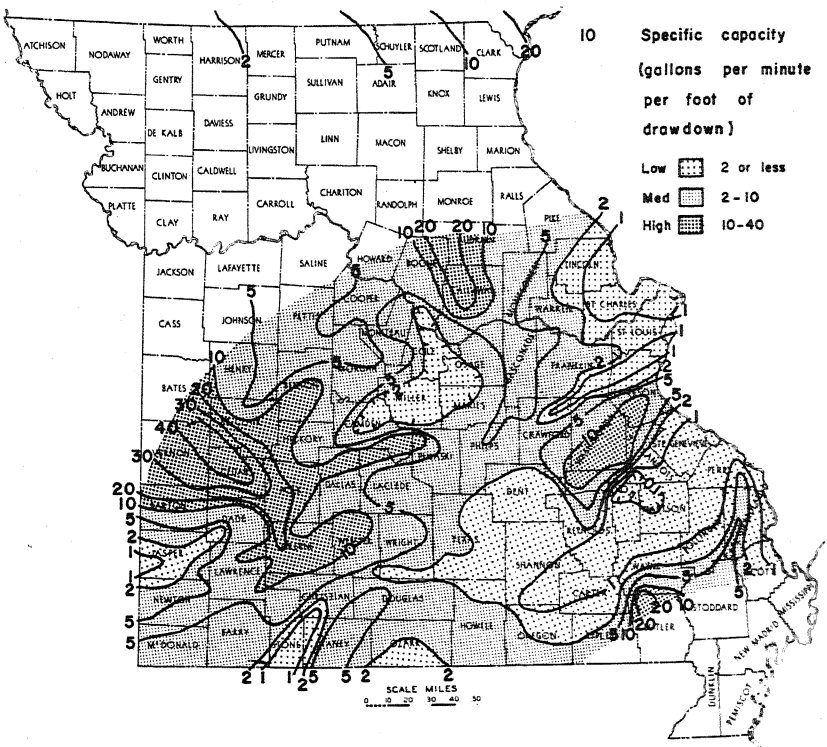


FIGURE 66.—Specific capacities of typical wells in the Ozarks.

Throughout the area numerous municipal and industrial wells yield 500 to 1,000 gallons per minute. These wells vary in depth. Wells that produce 300 to 500 gallons per minute average 1,000 to 1,500 feet in depth. Wells at Springfield in Greene County, for example, average 1,400 to 1,700 feet in depth and produce 500 to 1,000 gallons per minute. Wells at Rolla in Phelps County and Sullivan in Franklin County are 1,000 to 1,200 feet in depth and produce 400 to 600 gallons per minute.

Throughout the area requirements of 15 to 25 gallons per minute can normally be met by drilling to a depth of 300 to 350 feet through the Roubidoux Formation. This is usually an ideal depth for farm wells. Private wells for farms and dwellings in the central Ozarks average 300 feet in depth, whereas in the southwest part of the State the average depth to the Roubidoux is 800 feet.

Descriptions of aquifers

Lamotte Sandstone.—The Lamotte Sandstone is geologically the oldest aquifer in the State and is the basal unit of the Cambrian Sys-

tem. Its outcrop area is in the St. Francois Mountains and its thickness is as much as 500 feet in depressions between Precambrian knobs and ridges. Depth to the Lamotte ranges from 1,250 feet at Sedalia to 1,650 feet at Rolla and 2,000 feet in southwest Missouri. In the eastern Ozark area, where water from the Lamotte is used by municipalities, depths range from 100 to 500 feet.

The Lamotte Sandstone is generally a low-yield aquifer because of cementation of the sand grains. In some areas the Lamotte robs water from aquifers higher in the well. As an example, at Salem in Dent County, wells were drilled into the Lamotte Sandstone at a depth of 1,750 feet and produced approximately 125 gallons per minute. The wells were recased to the top of the Potosi Dolomite, plugged back to the base of the Potosi with neat cement and now the shallower wells produce more than 400 gallons per minute. Records of wells drilled at Rolla, Lebanon, Joplin, and other towns show that no substantial increase in production was achieved by drilling through the Potosi to the Lamotte. Wells at Sedalia which penetrated the Lamotte had a substantial increase in production over those wells penetrating the Potosi Dolomite. The city's well No. 9 tested only 351 gallons per minute at 1,000 feet in the Potosi and at 1,530 feet, after penetrating the Lamotte, produced 600 gallons per minute. Another city well produces 500 gallons per minute from a total depth of 1,517 feet. These wells, however, were treated with acid, which accounts for part of the increase.

At Farmington and Bismark in the St. Francois Mountains the Lamotte yields 200 to 250 gallons per minute per well. Near its outcrop these sands are the source of low-yield wells for farms and schools.

Bonneterre and Davis Formations and Derby-Doerun Dolomite.—Overlying the Lamotte are the limestone, dolomite, and shale of the Bonneterre, Davis and Derby-Doerun Formations. Generally supplies of water adequate for domestic use are available from the Bonneterre, but very little water is available from the Davis and Derby-Doerun units.

Potosi Dolomite.—The Potosi Dolomite is exposed in a broad area on the flanks of the St. Francois Mountains and in stream valleys leading away from the mountains. In most of the area the Potosi is drusy and vuggy. The vugs are interconnected and water is able to flow freely. This characteristic, together with its coarse crystalline texture and its wide outcrop area, make this formation one of the most reliable aquifiers in Missouri for municipal and industrial water supply.

The average thickness of the formation is 250 to 300 feet, although locally it is as much as 450 feet thick. In wells at Rolla the Potosi at a depth of 1,200 feet is 200 feet thick and the yield, which is principally from the Potosi, averages 500 gallons per minute. At Springfield the Potosi is approximately 1,700 feet in depth and averages 50 feet in thickness. The combined production from all units below the casing depth, usually 250 to 400 feet, is more than 1,000 gallons per minute. Among the reasons for the steady growth of Springfield is the availability to industry of a bountiful supply of water from the Potosi Dolomite.

Eminence Dolomite.—The Eminence Dolomite is medium to coarsely crystalline and locally very siliceous. As more wells were drilled through the upper 100 feet of the formation it became apparent that moderate quantities of water were present in the openings and fractures. And down the dip, this formation is being increasingly utilized for small industry and municipalities. In the outcrop area, adequate yields for farm and domestic supplies can be obtained.

The Potosi and Eminence Dolomites are also the source of many of the large springs in the Current and Black River valleys. Individual springs yield as much as 90,000 gallons per minute, an indication of the storage capacity of these rocks, and the surface streams draining the Potosi and Eminence have the highest base-flow yields in the State.

Gasconade Dolomite.—The basal unit of the Gasconade Dolomite is a sandstone and sandy dolomite named the Gunter Sandstone Member. It is the lowermost Ordovician unit in Missouri and overlies the Eminence Dolomite of the Upper Cambrian. The outcrop area of the Gunter Member is in the Lake of the Ozarks region in the northern part of the Ozarks and west of the St. Francois Mountains; optimum development of the sandstone facies is in the western part of the Ozarks. Figure 67 shows the variations in sand content of the Gunter Sandstone Member.

The depth of the Gunter Member in the vicinity of Rolla and to the south is 550 to 600 feet. At Columbia and Springfield the depth is 1,050 to 1,150 feet.

The Gasconade Dolomite above the Gunter Member is predominantly a light brownish gray, cherty dolomite averaging 300 feet thick. The upper 50 to 75 feet of the Gasconade is a dense and finely crystalline dolomite with very little chert. This dense rock forms a good sealing base for casing out the ground water from the upper strata.

The next 100 to 150 feet below the dense zone consists of chert and dolomite with the chert comprising 50 percent or more of this interval. This zone is a good aquifer whose yield is sufficient for farm and domestic use.

From Rolla south to the Arkansas line, wells drilled through the Gunter produce 40 to 50 gallons per minute and locally as much as 100 gallons per minute.

Wells in and near Columbia penetrating the Gunter Member produce as much as 1,000 gallons per minute. Similarly, at Springfield yields of 600 gallons per minute can be expected. Southwest of Springfield in Barry County the production averages 100 to 150 gallons per minute. Most of the yield of these wells is from the Gasconade Dolomite, and the Gunter Member is an important contributor.

Roubidoux Formation.—The Roubidoux Formation is the most reliable shallow aquifer for farm wells in the Ozarks.

The outcrop area of the Roubidoux is extensive in southern Missouri and the formation is present throughout nearly all the subsurface of the State. (See fig. 3 for areas where it has been removed by erosion.) Its thickness ranges from 100 to 250 feet, the greatest thickness being in the southwestern part of the Ozarks.

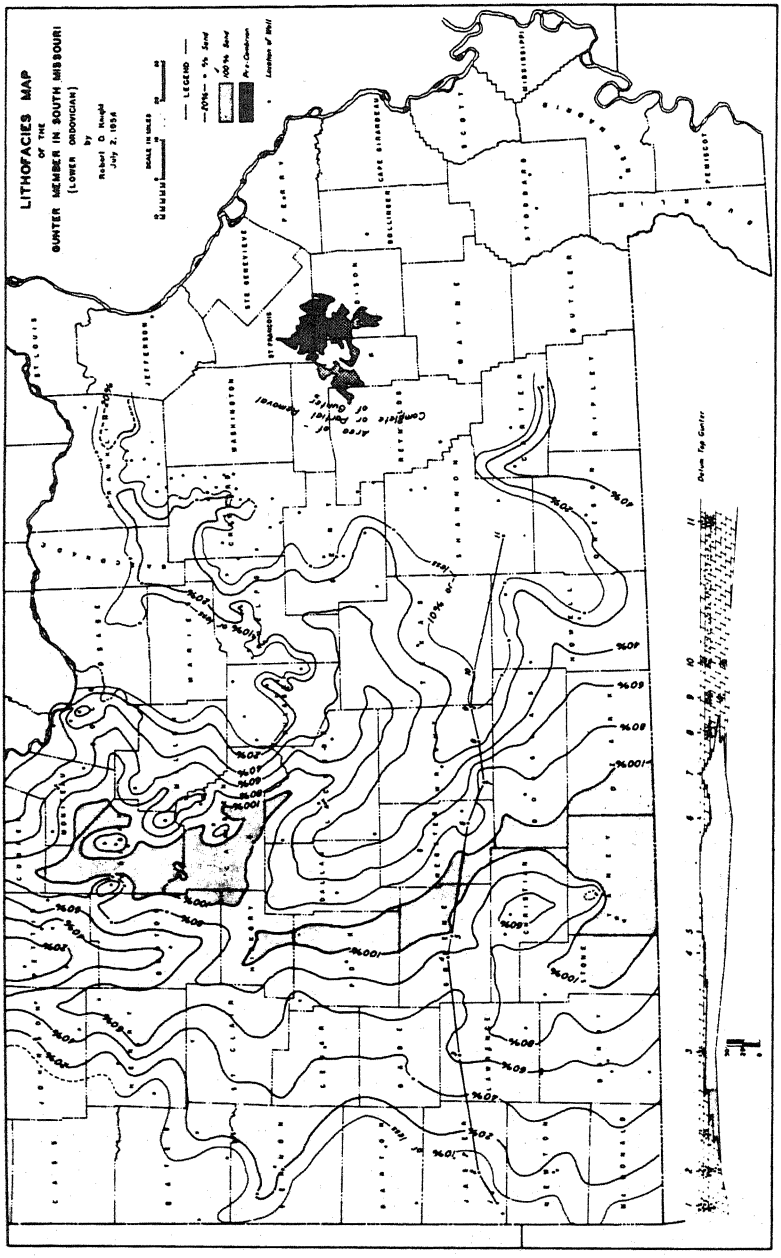


FIGURE 67.—Lithofacies map of the Gunter Sandstone Member in southern Missouri.

The formation consists of dolomite, sandstone, and chert. In the western part of Missouri, the formation contains distinct sandstone units near the base, the middle, and the top. Where sandstone is not present the formation may contain 50 percent or more chert.

Yields average 15 to 20 gallons per minute; however, in the extreme northern and western part of the Ozarks production is as high as 300 gallons per minute where its depth ranges from 800 to 1,000 feet.

Jefferson City and Cotter Dolomites.—The Jefferson City and Cotter Dolomites together have a thickness of as much as 550 feet and the base of the Jefferson City may be as much as 950 feet below the surface in some areas. Many rural wells stop in the Cotter and Jefferson City Dolomites where water apparently sufficient for domestic supplies is often obtained. However, after continued use the yield often declines.

In Greene County, sandstone locally referred to as the "Swan Creek Sandstone," a unit in the Cotter Dolomite, is the source of water in numerous wells; however, the water is considered polluted and should be cased out of the well.

St. Peter Sandstone.—The St. Peter Sandstone is a medium to coarse quartz sandstone which is found in a belt bordering the northeast and east side of the Ozarks. This sandstone is a good aquifer for small towns and industries where yields of 50 gallons per minute are adequate. East of Eureka in St. Louis County the water from the St. Peter becomes more mineralized with depth whereas west of Eureka and in the area north of the Missouri River the water is potable. In this area 20 to 25 gallons per minute is the normal yield. Locally in eastern Missouri the St. Peter produces 75 gallons per minute. At Barnhart and Imperial in Jefferson County, near the eastern margin of fresh water, it produces between 50 and 75 gallons per minute.

Mississippian aquifers.—The limestone of Mississippian age which underlies and forms the surface of the Springfield Plateau is a large reservoir of fresh water. As much as 450 feet of limestone may be present in the Springfield Plateau before the more heavily used Ordovician and Cambrian aquifers are reached at depth. The many springs, the streams which they feed, and many of the domestic farm wells have their source of water in these rocks. However, owing to development of underground drainage and karst topography, recharge of the aquifer is rapid and pollution is a continual threat, especially near populated areas or local sources of pollution. Yields of domestic wells range from 5 to 20 gallons per minute. At or near Joplin, some industrial wells yield 300 to 400 gallons per minute because of the highly fractured character of the rock. Abandoned mines in the Joplin area are the source for water for some industrial uses and yield as much as 1,000 gallons per minute.

Quality of water

Ground water from Paleozoic aquifers in the Ozarks is of excellent quality. The dissolved solids in the water is least along the Ozark uplift and increases to the north, south, and east as shown in figure 64. The mineralization pattern in the ground water conforms in a general way to the overall direction of movement of water.

Two types of fresh water occur in the Ozarks; hard calcium-magnesium bicarbonate water derived from the dolomite of the Cambrian and Ordovician rocks on the Springfield and Salem Plateaus, and hard calcium bicarbonate water from limestone of Mississippian age on the Springfield Plateau.

Water from the Mississippian limestone averages less than 300 parts per million total dissolved solids. Chloride is usually less than 10 parts per million but the sulfate content is generally higher and more variable. In Jasper and Newton Counties, where the Joplin mining district is located, the sulfate content in 34 well analyses ranged from 3.4 to 446 parts per million, the higher values indicating mixing with mine waters and water from the overlying Pennsylvania rocks.

Shallow aquifers are subject to pollution owing to the short distance through which surface drainage filters. The extent of pollution of shallow ground water is demonstrated in the highly developed agricultural land of the Springfield Plateau where many shallow domestic wells and springs in the Mississippian limestone have an abnormally high content of nitrate. If wells located near sewage disposal systems are not cased and sealed properly, surface water containing nitrates and other pollutants can percolate into the deeper ground-water reservoir. Concentrations of nitrate as high as 250 parts per million have been found where poor well construction exists.

Quality-of-water determinations for individual aquifers are generally unavailable in the Ozarks. Below the point at which the casing is set all aquifers penetrated may contribute to the well so that the water is a mixture from all water-bearing units below the casing. Water from the various aquifers is quite similar, as shown by representative analyses in table 38, and well within the standards of the Missouri Division of Health.

The chemical analysis of water from the Roubidoux Formation in Phelps County is typical of water from the Roubidoux throughout the Ozarks. Sulfate content is usually below 30 parts per million, although there are instances of higher content and the chloride content is usually below 10 parts per million. Iron averages 0.1 part per million or less, although it may be as high as 5 parts per million. Proper setting and sealing of casing ordinarily eliminates a large part of the iron.

Water representing a mixture from the Lamotte Sandstone, Potosi Dolomite, and the Gunter Member of the Gasconade Dolomite is of very good quality. At Sedalia total dissolved solids is 309 parts per million, the total hardness 270 parts per million, the sulfate 15 parts per million and the chloride 5 parts per million.

Water from the Potosi, the principal aquifer of the Ozarks, is usually of good quality. The total dissolved solids average 275 parts per million with a few supplies exceeding 300 parts per million. The total hardness averages about 275 parts per million also and is mostly carbonate hardness. The iron is usually 0.3 part per million or less and the sulfate and chloride average less than 15 parts per million.

The quality of the water from the Gunter is generally very good for industrial and municipal use. No treatment is normally required if casing is set deep enough to eliminate surface and shallow ground-water pollution.

TABLE 38.—*Chemical analyses of water from wells in Paleozoic aquifers in the Ozarks of central and southern Missouri*

[Analyses by M. E. Phillips of the Missouri Geological Survey and Water Resources and the Missouri Division of Health. Data in parts per million except pH]

PALEOZOIC AQUIFERS

County	Location [1]			Depth	Formations open to well [2]	Date sampled	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium as Na	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$		Alkalinity as $CaCO_3$	pH	Turbidity
	T.	R.	Sec.																Calcium, magnesium	Noncarbonate			
Dent	34	6	13	850	P	03-16-66	6.8	------	------	42	26.0	5.1	245	1.2	4.2	0.1	0.3	208	211	10	200	8.1	------
Greene	28	23	20	1,000	J-P	10-22-64	8.0	0.04	------	38	16.0	3.1	191	6.4	3.4	.1	.22	196	160	4.0	156	7.6	0.1
Howell	24	8	29	1,545	E-P	07-23-57	5.0	1.1	------	34	22.0	2.3	206	3.7	6.5	.1	.09	212	178	9.0	169	7.6	15.0
Newton [3]	26	33	5	100±	M	06- 8-65	9.5	.10	0.00	90	3.1	5.7, 1.0	268	11.0	11.0	.0	4.6	[4] 270	238	18	221	8.1	------
Pettis	45	21	33	1,465	E-L	08- 1-63	9.0	.55	------	56	32.0	5.6	317	15.0	5.0	.1—	0	309	270	10	260	7.4	1.0
Phelps	37	8	10	610	G	07- 2-63	------	.31	0	------	------	------	249	------	1.0	------	0	217	258	------	204	7.9	------
Do	34	9	1	280	A	06-20-66	4.2	.03	.00	27	16.0	4.6	123	11.0	6.0	.0	7.3	155	133	------	------	------	------
Do	37	8	10	1,135	P	11- 8-57	7.0	.2	------	50	30.0	4.7	274	21.0	5.2	------	0	295	246	21	225	7.4	.1
Do	37	7	7	203	R	09- 6-61	5.2	.12	0	59	36.0	5.7	341	17.0	3.0	.1	0	308	297	17	280	7.8	<1.0
St. Charles	46	1E	26	515	T	03- 3-61	3.8	.13	0	55	31.0	16.0	307	19.0	2.5	1.2	.3	289	263	12	252	7.4	<1.0
St. Francois	36	5E	36	622	L	08- 9-61	17.0	.03	------	49	39.0	5.6	320	9.7	8.2	.1—	5.1	379	284	26	258	7.3	.1
Texas	28	11	12	1,350	P	01-27-62	10.0	.25	------	48	30.0	2.2	289	2.3	5.2	.1	.35	268	242	9.0	233	7.3	.1

[1] Townships are all north. Ranges are west except where noted.

[2] Geologic units open to well between bottom of casing and total depth: (A) Gasconade Dolomite; (E) Eminence Dolomite; (G) Gunter Member of Gasconade Dolomite; (J) Jefferson City Dolomite; (L) Lamotte Sandstone; (M) Mississippian System; (P) Potosi Dolomite; (R) Roubidoux Formation; (T) St. Peter Sandstone.

[3] Analysis by U.S. Geological Survey.

[4] Includes 1.5 parts per million zinc.

Well location is of utmost importance near the boundary between saline and fresh water (see fig 64). Wells should be located as far from the boundary as economically feasible and should not be overpumped. At Warrensburg in Johnson County, for example, wells on the west side of town have saline water and those on the east side have fresh water. Overpumping will cause encroachment of saline water in situations such as this.

Although potable water can be obtained at Barnhart and Imperial, there are wells in the vicinity in which the water in the St. Peter Sandstone is highly mineralized, the chloride being as high as 1,500 to 1,700 parts per million.

At Sturgeon in northern Boone County the wells are close to the boundary and the northern limit of fresh water in the Roubidoux is just north of town. To the north and west the sulfate content increases rapidly. An overdraft at Sturgeon is causing encroachment, and the sulfate content of the water has increased to almost 600 parts per million.

The town of St. Peters in eastern St. Charles County is the northeast limit of fresh water in the Roubidoux. A well drilled just east of St. Peters found fresh water at a depth of 1,520 feet in the Roubidoux Formation. When the underlying Gasconade Dolomite was penetrated the water became unpotable. The concentration of chloride and sulfate increased to 2,773 parts per million and 1,260 parts per million respectively. North and east of St. Peters mineralized water is found in formations above the Roubidoux, and the depth to saline water diminishes rapidly to the northeast.

Mine water in the Bonneterre lead mining area of eastern Missouri has been used for municipal supplies. The dissolved-solids content of the water ranges from 419 to 976 parts per million and the zinc content is less than 0.6 parts per million. Mine water in the Joplin zinc district of southwestern Missouri is used by industries. The water is a hard calcium sulfate type with a dissolved-solids content ranging from 329 to 2,200 parts per million and zinc content ranging from 0.5 to 35 parts per million.

Use of ground water

Nearly all cities in the Ozarks obtain their water supplies from Ordovician and Cambrian aquifers. About 250 towns pump 30 million gallons per day from wells to furnish water to a population of 330,000. Rural and stock water supplies are derived from wells, springs, spring-fed streams, and ponds. It is estimated that in 1965, 15 million gallons per day of ground water was pumped in rural areas.

On the Springfield Plateau in southwest Missouri most farms and rural homes have shallow wells to 300 feet in depth which obtain sufficient water from the Mississippian limestone and chert. With the availability of water from both shallow and deep aquifers and the large number of springs, the plateau is well suited to stockraising. However, owing to the opportunity for pollution, water from wells of this depth range in the Mississippian limestone and the upper part of the Ordovician dolomite may not be safe for drinking without treatment.

The extensive new mining developments in the western extension of the southeast Missouri lead district in Crawford, Iron, Reynolds,

and Washington Counties will increase the use of water for mining and milling operations. Much of the water supply will be derived from the mines but supplemental supplies will be obtained from wells, streams, and reservoirs. It is estimated that water use will average about 25 million gallons per day when all of the projected mines, mills, and smelters are in operation.

In the original lead-mining district of St. Francois County water from the mines was the source of supply for Bonneterre and other mining towns in the vicinity. About 1 million gallons per day was pumped. Recently these towns have converted to wells.

In the Joplin area of Jasper County, where the zinc mines are mostly shut down, mine water is being pumped for industrial purposes including washing of crushed rock from the lead and zinc mine waste piles. At times pumpage is at the rate of 3.5 million gallons per day. Mine yields range from 100 to 1,000 gallons per minute. If mining is resumed dewatering would necessitate conversion to other sources of industrial water supply unless the mine water is delivered to the present users.

In 1965 about 1,900 acres of land were irrigated from wells. Most of the irrigated acreage is in Jasper and Newton Counties on the Springfield plateau where the water is obtained from Mississippian limestone. Pumpage amounted to 930 acre-feet or 0.8 million gallons per day based on a 90-day irrigation season.

Industrial use of fresh water from Paleozoic aquifers in the Ozarks is estimated to be about 15 million gallons per day. This estimate does not include water supplied to industry from municipal waterplants. A considerable part of the industrial pumpage is centered at Springfield and Joplin.

In summary, it is estimated that about 60 million gallons per day of fresh ground water is pumped for all purposes from wells and mines in Paleozoic rocks in the Ozarks. With the addition of pumpage in the development of new mines in eastern Missouri the total will soon reach 85 million gallons per day.

THE SALINE GROUND-WATER PROVINCE

Consolidated aquifers

For this report ground water containing 1,000 parts per million or more of dissolved solids is considered saline. The saline ground water province is defined as that area in which the total dissolved solids exceed 1,000 parts per million in consolidated aquifers capable of yielding adequate water volumes to municipalities or industries. This does not preclude the existence at shallower depths of fresh ground water in sufficient volume to meet municipal, industrial, and domestic needs from the alluvium and glacial drift. Supplies of 5 to 10 gallons per minute also can usually be obtained in this area from Pennslyvanian sandstone and Mississippian limestone at depths ranging from 250 to 400 feet.

Approximately one-third of Missouri is underlain by consolidated rock aquifers which contain saline water. The saline-fresh water boundary generally coincides with the limit of the Pennsylvanian rocks in northern and western Missouri (see fig. 64 and fig. 2).

Stratigraphic and quality-of-water data for the saline area are derived mainly from oil tests. For the most part ground water data are available only adjacent to the saline-fresh water boundary. These same formations which are good aquifiers in the Ozarks are present throughout the Saline Ground Water Province (see fig. 63).

Total thickness of the sedimentary column ranges from 1,200 feet to more than 4,000 feet. Figure 68, a generalized portrayal, shows by contours the slope and form of the Precambrian surface. Using the land surface elevations, also shown on the map, the thickness of the sediments can be determined.

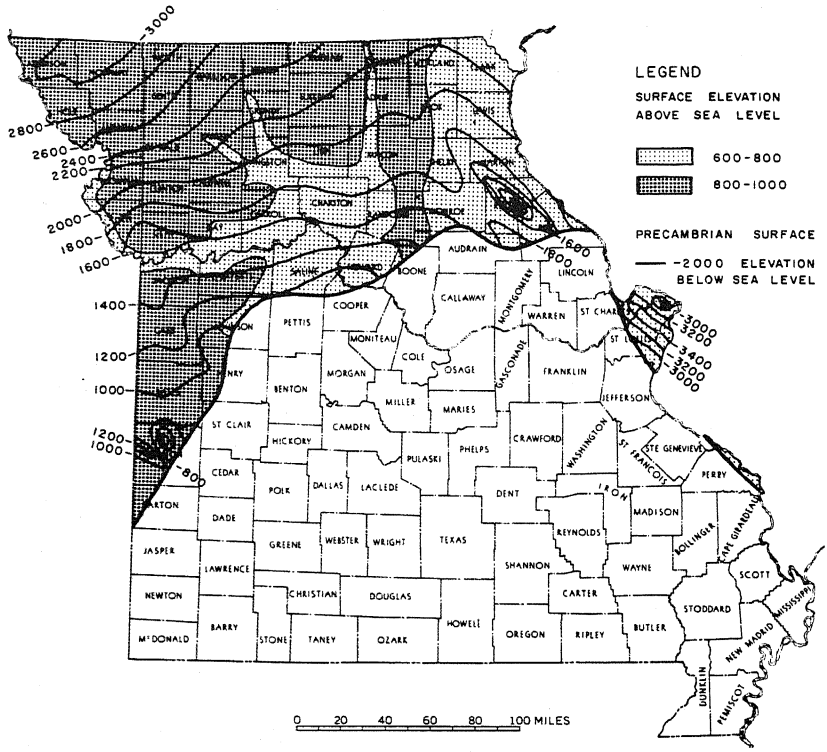


FIGURE 68.—Map showing contours on the Precambrian surface in northern Missouri. Precambrian control from "Configuration of the Precambrian surface showing major structural lineaments," by William C. Hayes, 1962.

In the saline province where surface-water supplies are limited and aquifers containing fresh water are not widely distributed, the new developments in desalination and the large quantity of saline water in storage in the Paleozoic aquifers assume increased importance. The ability of the consolidated aquifers to yield water in the saline area is probably comparable to that of the bordering fresh-water areas of the Ozarks (fig. 63) further attesting to the potential of the aquifers.

The low permeability of the Pennsylvanian strata impedes ground-water movement both laterally and vertically. Because of this, there is very little opportunity for ground water recharge and discharge. Production would probably be largely from storage and, as a consequence, water levels would decline. This is in contrast to the Ozark area in which recharge from precipitation occurs rapidly by vertical and lateral movement. As would be anticipated, observation wells in Ordovician and Cambrian aquifers in Barton, Vernon, St. Clair, Lafayette, Cooper, and Shelby Counties, all within the saline area, show essentially no seasonal fluctuations or responses to precipitation. Because of the low permeability of the Pennsylvanian strata, recharge would be largely by lateral ground-water movement within the deeper aquifers. Research is currently underway to determine the origin of the saline water. At present the supposition prevails that this is modified sea water, trapped in ancient times.

Unconsolidated aquifers

Within part of the saline ground water province, ground water is available from the sands and gravels of the glacial drift, and from alluvium. Glacial drift covers most of the State north of the Missouri River (see fig. 1, inset map fig. 2, and table 3).

Of some value as aquifers, but limited in yields, are the outwash sands and gravels which were deposited on uplands. For the most part, the preglacial channels with their fill of glacial sand and gravel are the dominant source of ground water. In part, the main filled channel is parallel to or is overlain by the present channel of the Grand River. Tributaries, however, to this main drift-filled channel are, for the most part, divergent from the modern drainage (fig. 69.).

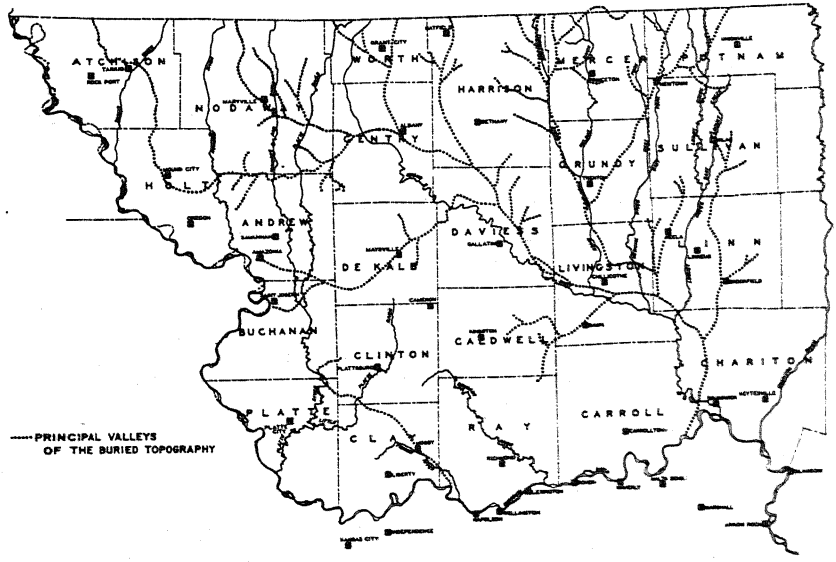


FIGURE 69.—Preglacial drainage pattern of northern Missouri.

Thickness of the glacial drift ranges from zero to about 400 feet. Typically, well depths vary between 100 and 250 feet. In general, the cleaner and coarser sands are in the basal part of the drift.

The area, as shown in figure 69, was test drilled by the Missouri Geological Survey. Test holes were spaced at 1-mile intervals along profiles which were 6 miles apart. This basic pattern was modified as needed to give better control. Of these test holes, many flowed.

Two observation wells are in glacial drift. The record from the well in northwest Grundy County displays no response to precipitation nor does it display a seasonal pattern. The other observation well is in Kahoka, Clark County, and is sufficiently close to pumping wells to exhibit interference. The records from the Clark County well show quick recharge in response to precipitation.

Yields of 500 to 1,000 gallon per minute with 10 to 20 feet of drawdown are anticipated in the most favorable areas. Figure 70 is a gen-

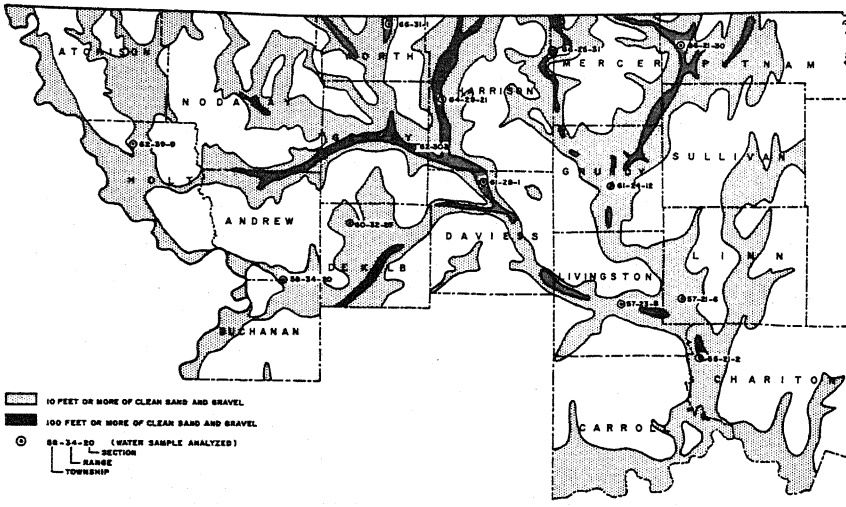


FIGURE 70.—Isopachous map of clean sands in the glacial drift and alluvium in northern Missouri.

eralized map showing those areas having 10 to 100 feet of clean glacial drift sands and those having more than 100 feet. In general, those areas having 10 feet or more of clean sand are capable of yielding sufficient water to supply rural domestic needs. Those areas having 100 feet or more of clean sand should have a yield ample for municipalities, industrial needs, and irrigation. The sand particles tend to be rather angular. Because of the mode of deposition, great variations in clay content occur in but a few feet laterally.

Quality of water

The dissolved-solids content of the ground water in the aquifers of Paleozoic age ranges from the minimum as defined for saline water (1,000 ppm) to a maximum in excess of 50,000 parts per million.

Variations in chemical quality are shown in figure 64. The quality of ground water in northern Missouri varies widely depending on the location and depth of the well sampled. Changes of water quality with depth are shown in figure 71.

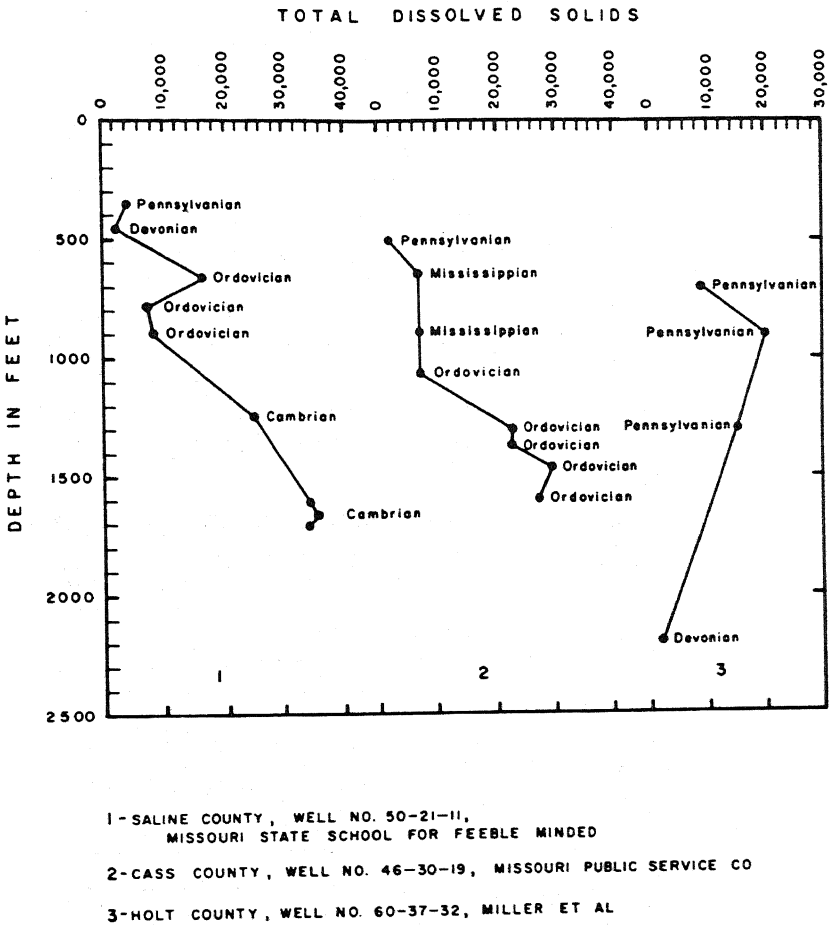


FIGURE 71.—Graphs relating depth to changes in chemical quality of ground water in Paleozoic aquifers in northern Missouri.

Often the most saline water occurs in the sediments of Pennsylvanian age. In some localities, however, such as Clark County, the most saline water occurs in the Lamotte Sandstone of Cambrian age where an exploration drill hole encountered water at a depth of 2,800 feet which contained 52,360 parts per million of total dissolved solids. Table 39 is a tabulation of chemical analyses of the water from selected wells drilled into the Paleozoic aquifers and glacial drift within the area.

TABLE 39.—*Chemical analyses of water from Paleozoic aquifers and the glacial drift in northern Missouri*

[Analyses by M. E. Phillips, R. T. Rolufs, and Henry Collier of Missouri Geological Survey and Water Resources and by the Missouri Division of Health. Data in parts per million except pH]

PALEOZOIC AQUIFERS

County	Location [1]			Depth	Geologic unit [2]	Date sampled	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium as Na	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$		Alkalinity as $CaCO_3$	pH	Turbidity
	T.	R.	Sec.																	Calcium, magnesium	Noncarbonate			
Adair	62	15	18	1,623	J	12/—/39	10	------	------	45	112	968	323	19	598	1,120	----	------	3,120	570	289	281	----	------
Andrew	60	35	28	1,375	T	—/—/37	10	[3]0.15	------	30	16	1,170	647	13	557	1,120	4.7	0.0	3,420	141	0	533	----	------
Atchison	64	40	33	2,242	----	12/22/58	5.0	------	------	82	25	995	382	0	922	695	----	.0	2,860	306	0	313	8.0	------
Bates	40	31	15	1,140	R	08/26/36	6.4	2.3	------	143	80	1,510	422	1	165	2,520	----	.0	5,060	868	------	199	----	------
Caldwell	55	29	28	1,375	D	08/19/44	----	------	------	306	154	2,540	250	0	1,520	3,850	----	------	8,680	1,400	1,190	205	----	------
Carroll	55	24	21	1,335	T	—/—/52	3.7	------	6.7	306	162	3,140	244	0	1,280	4,690	----	------	10,300	1,430	1,230	200	7.8	------
Cass	46	30	19	1,600	G	07/01/55	11	.09	.0	891	792	9,960	181	0	824	18,100	----	.0	34,700	5,490	5,340	149	7.6	------
Chariton	53	18	35	919	O	08/07/39	4.5	------	------	425	201	3,020	180	0	1,270	5,060	----	------	11,600	1,890	1,740	147	----	------
De Kalb	58	30	2	1,341	D	—/—/52	7.5	12.0	------	242	115	1,960	207	0	1,600	2,580	----	------	6,940	1,080	908	170	7.6	------
Gentry	64	33	13	1,600	D	—/—/47	13	.03	------	66	30	1,710	382	0	1,390	1,650	----	------	5,090	291	------	313	7.0	------
Harrison	64	27	3	1,178	----	—/—/60	10	1.2	------	98	33	1,520	491	0	1,650	1,150	2.0	.0	5,120	380	0	403	7.5	8.0
Holt	60	37	32	2,195	D	12/02/43	----	------	------	29	18	842	668	3	447	672	----	------	2,580	148	------	550	----	------
Howard	49	16	32	2,000	L	2/13/33	3.2	138	------	1,120	440	7,670	30	0	1,280	12,800	----	.8	26,600	4,600	------	24	----	------
Jackson	48	33	36	1,569	J	—/—/34	6.8	69	------	1,380	817	11,900	139	0	1,160	22,100	----	.0	46,100	6,800	------	114	----	------
Do	50	31	19	1,481	J	—/—/36	10	[3].20	------	691	384	6,360	236	0	1,100	10,600	1.0	.0	22,600	2,890	------	193	----	------
Johnson	45	28	11	1,049	R	—/—/34	5.6	2.2	------	68	34	598	445	7	62	834	----	.0	1,910	311	------	365	----	------
Knox	63	12	26	2,125	C	----	----	------	------	149	86	2,320	----	60	2,540	2,150	----	------	7,300	728	557	171	----	------
Lafayette	50	24	36	955	R	—/—/34	5.2	8.1	------	167	79	1,100	307	0	92	1,980	----	11	3,960	742	------	252	----	------
Lewis	60	7	17	896	T	—/—/40	3.6	------	------	232	117	1,940	250	0	1,080	2,910	6.0	------	7,200	1,060	855	205	----	------
Livingston	58	23	22	1,225	T	—/—/39	32	------	------	328	192	2,580	394	0	1,480	3,730	3.8	------	9,320	1,610	1,280	323	----	------
Mercer	65	24	30	2,125	R	—/—/40	2.8	------	------	64	88	1,600	197	8	1,750	1,400	3.2	------	5,240	522	354	168	----	------

Monroe	54	10	13	782	T	—/—/39	5.2	.38	------	40	20	806	498	1	477	654	3.0	1.6	2,100	180	------	410	----	------
Nodaway	65	36	10	2,030	M, D	—/—/46	30	[3].00	------	7	9.6	1,180	492	300	693	699	----	------	2,840	63	0	792	----	.0
Perry	36	11E	23	665	V	—/—/55	24	3.0	.0	367	446	2,81	209	0	256	5,710	----	.0	12,000	2,750	2,579	172	7.8	------
Pike	54	1	18	1,275	------	—/—/34	8.0	[3].05	------	402	171	2,980	289	0	1,000	4,550	3.2	.0	9,580	1,710	------	237	----	------
Platte	51	13	19	1,050	S	—/—/46	2.0	------	------	223	132	7,750	315	0	130	12,500	----	------	20,200	1,100	785	315	----	
Putnam	65	19	26	1,779	J	—/—/39	7.2	------	------	159	59	875	315	0	1,010	852	5.6	------	3,120	640	382	258	----	------
Ralls	55	5	34	1,685	P [4]	12/12/58	5.0	.53	.0	531	255	3,450	360	0	1,040	6,630	----	.0	13,500	2,380	2,080	296	7.9	------
Randolph	52	14	22	1,185	R	—/—/40	5.2	------	------	164	88	702	494	0	876	723	2.2	------	3,000	771	------	405	----	------
Ray	52	26	25	784	T	—/—/34	7.6	[3].30	------	444	220	4,120	386	0	1,300	6,310	----	.0	13,600	2,010	1,700	317	----	------
St. Louis City	45	7E	13	2,199	J	—/—/34	10	3	------	563	210	2,920	267	11	614	5,110	4.2	.2	11,200	2,270	------	219	----	------
Saline	50	21	11	1,715	A	—/—/40	7.6	------	------	1,480	610	10,200	173	----	1,620	17,800	.9	------	37,200	6,210	------	142	----	------
Schuyler	65	15	21	1,505	O	—/—/40	0.8	------	------	90	50	862	200	0	1,260	542	2.0	------	2,870	429	265	164	----	------
Shelby	59	11	35	800	T	—/—/41	13	------	------	136	95	1,400	558	0	881	1,650	----	------	4,700	731	274	457	----	------
Vernon	35	31	5	1,100	E	—/—/57	8	.1	------	82	39	347	268	0	62	610	8	.4	1,530	364	144	220	7.4	0.2

GLACIAL DRIFT

Andrew	58	34	20	125	------	06/12/57	19	0.57	0.26	115	24	30	391	0	85	3.3	0.2	0.1	487	385	65	320	7.5	4
Charlton	55	21	2	139	------	04/18/57	15	.54	.03	58	22	144	422	0	33	103	.3	1.5	576	238	0	346	7.6	3
Daviess	61	28	1	150–175	------	11/06/56	14	5.3	.19	84	30	124	490	0	147	8.5	.4	8.4	649	335	0	402	7.8	25
De Kalb	60	32	28	165	------	11/20/56	12	1.4	.00	101	38	289	290	0	683	52	.8	6.8	1,390	408	170	238	8.0	10
Gentry	62	30	3	178	------	07/30/56	16	2.4	.00	79	26	104	427	0	138	10	.4	.1	618	302	0	350	7.5	10
Grundy	61	24	12	242	------	09/09/55	12	5.8	.00	250	83	360	255	0	1,380	24	----	3.7	2,410	965	756	209	7.2	10
Harrison	64	29	21	282	------	06/28/56	7	14	.00	114	38	452	356	0	796	58	.8	.2	1,610	441	152	289	7.2	95
Holt	62	39	9	212	------	----------	20	.23	.00	66	24	92	396	0	19	74	.3	2.8	507	264	0	325	7.2	2
Linn	57	21	6	85	------	02/04/57	13	.38	.05	70	26	106	539	0	16	21	.3	1.2	515	280	0	442	7.5	2
Livingston	57	23	8	135	------	08/28/56	19	2.6	.18	99	25	51	496	0	25	4.0	.3	.0	475	349	0	406	7.3	100
Mercer	66	25	31	290	------	12/22/55	16	[3].82	------	107	32	138	908	0	14	2.5	----	.1	432	402	0	744	7.4	------
Putnam	66	21	30	150	------	03/23/56	13	.82	.00	136	43	116	513	0	291	17	.3	2.2	933	515	94	420	7.5	6
Worth	66	31	1	216	------	08/07/56	11	.46	.00	112	32	388	245	0	975	50	.7	.2	1,800	412	212	200	7.5	------

[1] Townships are all north. Ranges are west except where noted.
[2] Geologic unit: (A) Davis Formation; (B) Bonneterre Formation; (C) Cambrian System; (D) Devonian System; (E) Eminence Dolomite; (G) Gunter Member of Gasconade Dolomite; (J) Jefferson City Dolomite; (L) Lamotte Sandstone; (M) Mississippian System; (O) Cotter Dolomite; (P) Precambrian rocks; (R) Roubidoux Formation; (S) Salem Formation; (T) St. Peter Sandstone.
[3] Iron in solution when analyzed.
[4] Well drilled to Precambrian; water is from Paleozoic formations above.

The suitability of water from glacial drift for irrigation depends not only on the dissolved constituents in the water but also on the drainage characteristics of the lands, permeability of the soil, chemical reactions in the soil solution, the amount of water to be applied, and the type of crop to be grown. Generally, water used for irrigation should have a moderate to low dissolved-solids content. The percent sodium in the dissolved solids should not exceed 50 to 60, depending on the total dissolved solids. Although satisfactory quantities of water may be available from the glacial drift for irrigation needs, the analyses given in table 39 indicate that in some areas the high dissolved-solids and sodium content make the water generally unsuitable for irrigation use. The data plotted in figure 72 indicate that much of the water from glacial drift is classed as good to permissible, but, because of the areal variability of the dissolved-solids and sodium contents of water from glacial drift, an evaluation of water from a particular source should be made before it is used for irrigation.

The quality of the water from the glacial drift is quite variable. In general, it is hard, high in total iron, total dissolved solids, and in sulfate, but is low in chloride. Water from the glacial drift is a mixed calcium bicarbonate-sodium sulfate type that ranges from 432 to 2,413 parts per million of total dissolved solids.

Use of water

In the Saline Ground Water Province most municipal ground water supplies are obtained from wells in alluvium but only a few are derived from glacial drift. About 150 towns have well supplies and use 22 million gallons per day. It is estimated that about 25 percent (9 million gallons per day) of water in rural areas for domestic and livestock use is taken from aquifers. Irrigation and industry is concentrated along the Missouri River where the supply of water from the alluvium is much larger than the demand. About 2,200 acre-feet of water (8 million gallons per day) was pumped from the alluvium and glacial deposits along the Missouri River during the 90-day irrigation season in 1965. A total for industrial use in the saline province is not available, but individual supplies along the Missouri River have wells each capable of yielding more than 1,000 gallons per minute. Industrial use of ground water is concentrated at St. Joseph, Kansas City and vicinity, and Weldon Springs in St. Charles County.

The large cities along the Missouri River in the saline province treat and use river water. Independence, North Kansas City, Marshall, and many small towns use water from the alluvium and glacial deposits. In the Osage Plains and Dissected Till Plains towns having a few hundred inhabitants use shallow aquifers in the alluvium or glacial drift where it is available. Others use impoundment or surface sources. Larger towns of 1,000 or more population depend chiefly on treated surface water from rivers or impoundments.

Some cities near the saline-fresh water boundary are using saline ground water from the consolidated Paleozoic aquifers for their municipal water supply. Most of these cities are in west-central Missouri. The three most saline supplies in use contain 2,435, 3,633, and 5,125 parts per million of total dissolved solids. The combined average use of water at these three towns is 44,000 gallons per day. Industrial use of saline water is small. Probably the largest user is

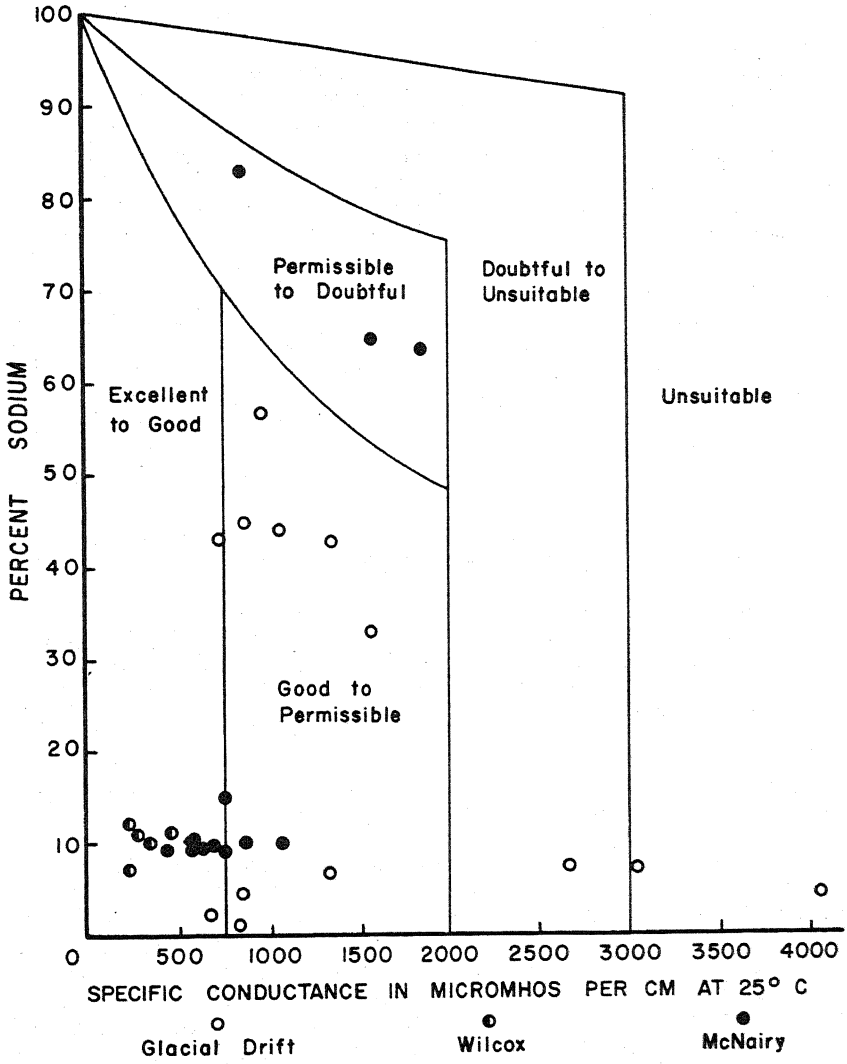


FIGURE 72.—Classification of ground water from glacial drift, the Wilcox Group, and the McNairy Formation for irrigation purposes. (Diagram after Wilcox, 1948.)

the coal industry, which uses saline water as wash water in processing and grading plants.

Probably the use of saline water in the rural areas for domestic and livestock needs exceeds that of all other uses. The most evident deficiency of saline water is the short life of household water-using equipment. Not so evident is the detrimental effect on livestock. It has been generally accepted that water having a salinity of up to 10,000 parts per million of total dissolved solids could be consumed

by livestock. Current research is leading to the conclusion, however, that detrimental syndromes which are difficult to diagnose result from the consumption of such water.

Without the advent of economically feasible desalination processes, the consumption of saline water will probably decline. Within the saline ground water province new water supplies are being developed by constructing surface impoundments, and from wells in alluvium and glacial drift. This is equally true for farm water supplies.

The marginal quality of the water from glacial drift is a restrictive influence on its use. It will probably remain little used for industrial purposes, except for cooling, without extensive treatment. Presently the drift is used extensively to supply water for agricultural needs, excluding irrigation. Although few wells have been constructed for irrigation purposes, a many fold increase is anticipated. An appreciable withdrawal is being made for municipalities. Including demands for water districts, this type of use will increase. Drift ground water is being used for flooding water fowl preserves. While an increase in use is anticipated for this purpose it will be very limited as compared to the increase for irrigation and public water supplies.

PROVINCE OF SOUTHEAST MISSOURI LOWLAND AND THE ALLUVIAL VALLEYS OF THE MAJOR STREAMS

The province of the Southeast Missouri Lowland and the alluvial valleys of the major streams contain three principal aquifers: the alluvium, the Wilcox Group, and the McNairy Formation (Ripley of the local vernacular). The aquifers are discussed in the order of their potential yield.

Alluvium

The alluvium occurs as valley fills of the major rivers and as the cover formation of the southeast Missouri Lowland (Mississippi Embayment), excluding Crowley's Ridge.

The embayment area is the most extensive alluviated plain in the State. Along the Mississippi and Missouri Rivers are alluviated areas of much importance locally because water in large volume is available. The part of the Missouri River alluvial plain in Missouri ranges in width from 1½ to 12 miles and extends 400 miles from the Iowa-Missouri line to the river's mouth near St. Charles. (The river travels a distance of 575 miles through the plain.) All of the flood plain can be considered available for development of ground water supplies from the alluvial deposits. The alluvial plain along the Mississippi River in Missouri is as much as 6 miles wide, and segments extend for distances of 5 to 50 miles along the river in uninterrupted reaches. The Meramec valley has alluvial deposits capable of significant ground water development for a distance of 75 miles upstream from its mouth. The width of its flood plain and terraces in St. Louis and Jefferson Counties is about 1 mile; they narrow upstream to one-quarter to one-half mile. The geologic age of the deposits ranges from Pleistocene to Recent.

The alluvium consists of clay, sand, and gravel. Although there are numerous exceptions, the sediments in general become coarser with depth. For the most part the sands and gravels are subrounded to rounded.

Thickness of alluvial fill in the Missouri River valley ranges from 80 to 90 feet near the Iowa-Missouri border to as much as 120 feet at the confluence with the Mississippi River. Thickness of the alluvium along the Mississippi River averages more than that along the Missouri River. As far north as Palmyra the thickness exceeds 110 feet. In the Southeast Lowland the two principal channels where deposits are thickest are located between the Ozark upland and Crowley's Ridge and in the broad area east of Crowley's Ridge. (See fig. 73).

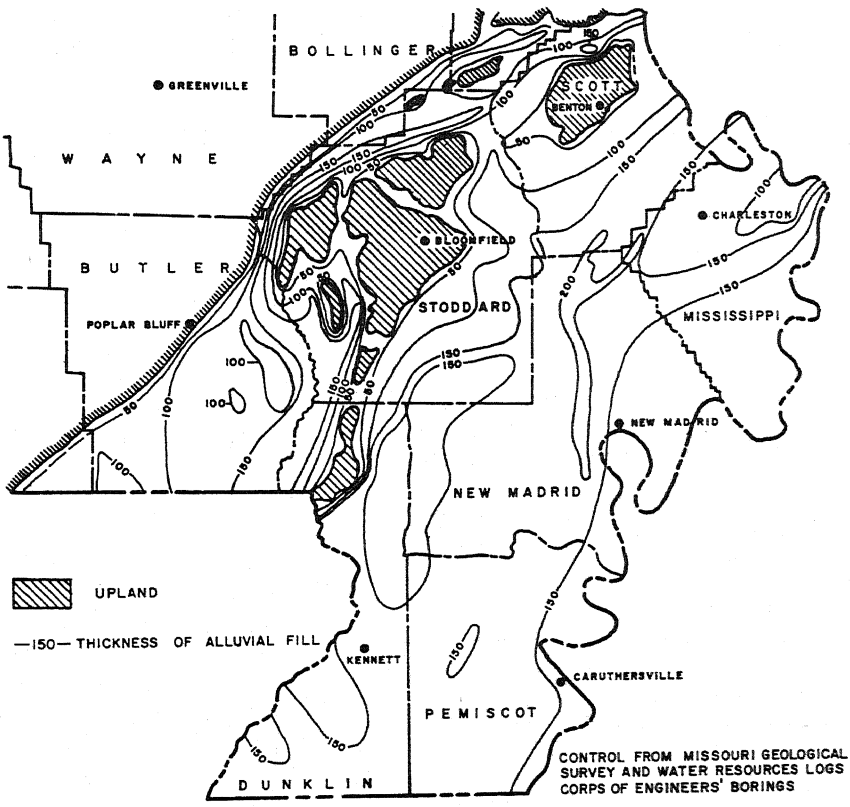


FIGURE 73.—Isopachous map of the alluvial fill in the Southeast Lowland, Mo.

Depths of wells along the Missouri and Mississippi Rivers and along the lesser streams such as the Meramec depend upon the thickness of the alluvium and the occurrence of beds of sand and gravel having suitable permeabilities. Because of the high permeabilities in southeast Missouri, wells in the alluvium average less than 100 feet in depth.

Water levels in the alluvium along the Missouri and the Mississippi Rivers fluctuate in response to changes in river stage. Recharge of the aquifer occurs during high, and discharge during low, river stages. The magnitude of the fluctuation is somewhat less than that of the river stages. Records from five observation wells equipped with re-

corders show varying time lags ranging from less than 1 to more than 30 days between river crests and the peaks in ground-water levels. Permeabilities of the river channel floor and bank probably exert the greatest control on the rate of response, but distance from the river is also a factor. Temperature fluctuations of the alluvial ground water is less than the tracking error of the recorder charts, and no temperature pattern has been detected. Recharge by local precipitation is not readily evident on the recorder charts.

In contrast, the recharge of the alluvium in southeast Missouri, as evident from the records from seven recorder-equipped wells, is derived from local precipitation. Unless there is a deficiency of soil moisture, water levels rise in less than 24 hours in response to rain. Water levels are generally highest in April and May and lowest in October and November. The fluctuations have an amplitude of 5 to 10 feet.

Water in the alluvium in the Southeast Lowland moves generally southward although locally it moves in other directions. This is shown by the water-table map, figure 74.

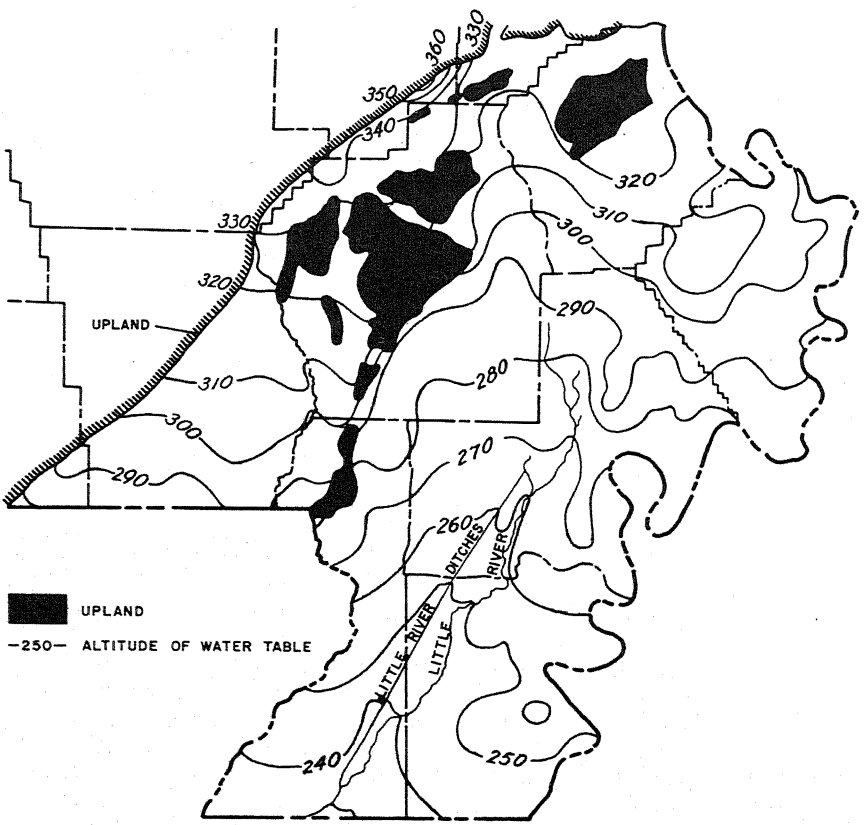


FIGURE 74.—Water-table map for the alluvium in the Southeast Lowland, Mo., October 1965.

Under normal conditions the water stands 10 to 20 feet below the land surface and discharges from the alluvium to the streams as indicated by the pronounced effect of the Little River ditches in Dunklin and Pemiscot Counties. Contour lines point upstream, reflecting ground-water movement to the ditches.

From the recorder data there is no evidence of long-term decline in ground-water levels along either the streams or in southeast Missouri.

Yields from the stream valley alluvium commonly range between 500 and 1,000 gallons per minute with some 10 to 20 feet of drawdown. The yield of the alluvium of southeast Missouri is somewhat more bountiful. Yields of 2,000 to 3,000 gallons per minute are not uncommon. Irrigation wells are usually constructed and equipped to give yields of 800 to 1,000 gallons per minute with drawdowns of 5 to 15 feet.

Wilcox Group

Because the "Lafayette" Gravel of the Pliocene (?) Series is not always differentiated from the Wilcox Group of the Eocene Series in the well logs, the two will be considered as one aquifer. The "Lafayette" is a permeable sand and coarse gravel. The Wilcox Group is substantially finer grained and has lower permeabilities. Particle sizes range from clays, in part bedded, through silt to coarse sand. Because the section thickens to the southeast, well depths range from less than 200 feet to as much as 1,400 feet.

The Eocene Series, which crops out along Crowley's Ridge in southeast Missouri, thickens to the east and southeast to more than 1,300 feet. Except at the outcrop, the series is covered by alluvium. Figure 75 shows by contours the elevations on the base of the Wilcox Group.

This map can be used to determine the depth to which a well would have to be drilled to fully penetrate the sands of the Wilcox. If the elevation of the base of the Wilcox is below sea level at a particular point, the land surface elevation is added to the elevation of the base of the Wilcox to determine the depth to drill.

Throughout a considerable part of the area, the alluvial sands and gravels rest directly upon the sands and gravels of the Eocene Series. In these areas recharge by precipitation is prompt and water levels are comparable to those of the alluvium. Where separated by clay horizons from the alluvium, water levels in the Wilcox may be either higher or lower than water levels in the alluvium. The volume of water removed by pumping is relatively small; declining water levels have not been noted and declines are not anticipated.

Wells have seldom been constructed to utilize the full yield potential of the Eocene Series. Thus, depending upon needs, wells with capacities ranging from 100 to more than 1,600 gallons per minute are in use. Permeabilities are less than those of the alluvium but the greater thickness makes it possible to have comparable yields.

McNairy Formation

The McNairy Formation of the Gulfian Series of the Cretaceous System occurs in the Southeast Lowland. Exposures are present in part of Crowley's Ridge. The formation dips to the southeast.

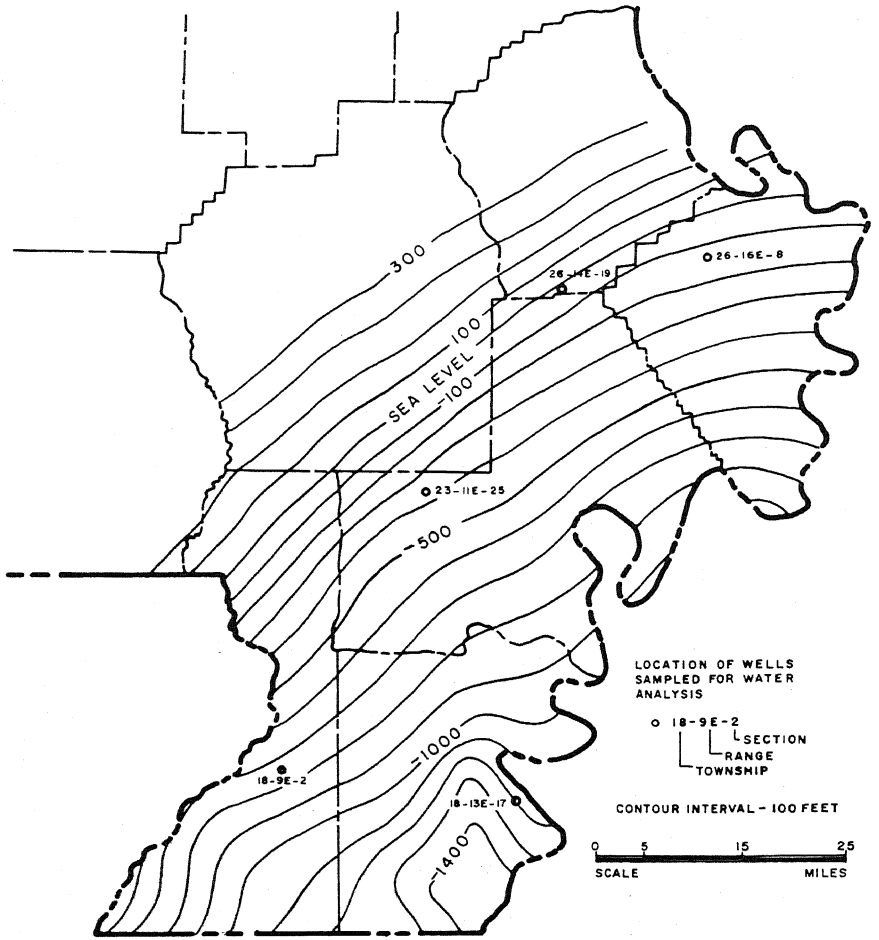


FIGURE 75.—Contour map of the base of the Wilcox Group in southeastern Missouri.

Except at the outcrop and where the McNairy Formation is near the surface and overlain by alluvium, the Midway Group of the Paleocene Series overlies the McNairy Formation and acts as an aquiclude.

Although the McNairy Formation is mainly a poorly consolidated, medium- to coarse-grained sandstone, it contains considerable clay which in places precludes the construction of productive wells. Two such locations are at Charleston in Mississippi County and at Steele in Pemiscot County.

Depths of wells range from 100 to 2,000 feet. Figure 76 shows elevations on the base of the McNairy Formation. This map can be used to determine the depth to which a well would be drilled to fully penetrate the McNairy Formation. If the elevation of the base of the McNairy is below sea level at a particular point, the land surface

elevation is added to the elevation of the McNairy to determine the depth to drill.

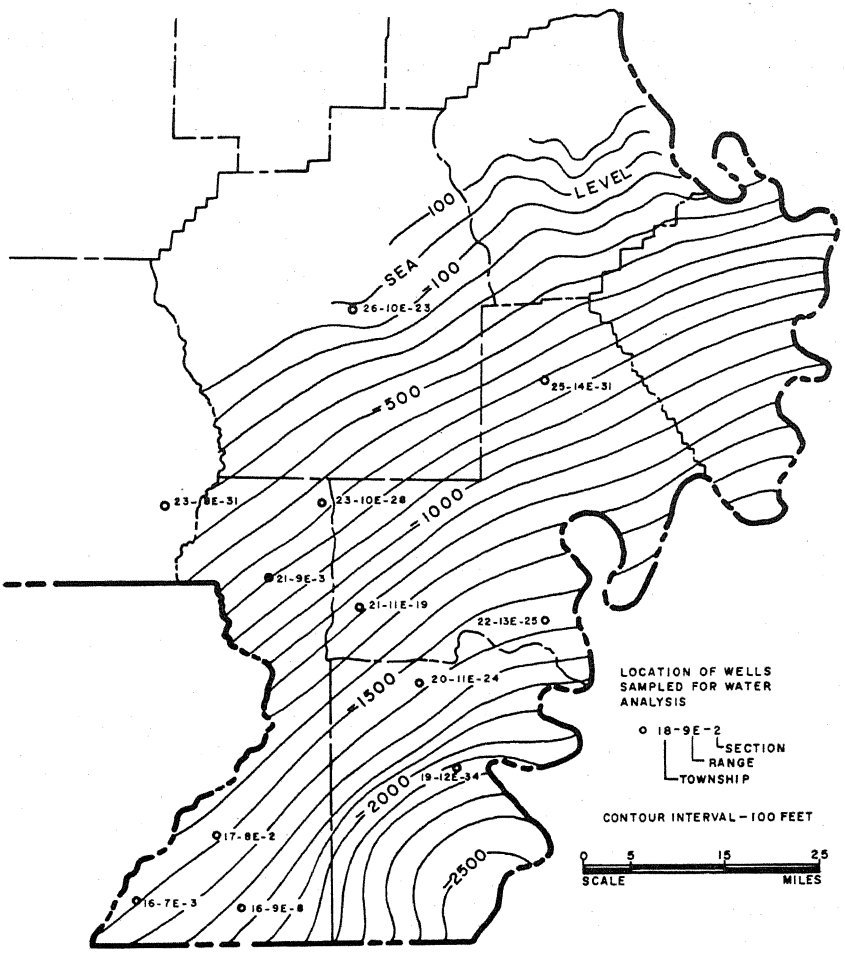


FIGURE 76.—Contour map of the base of the McNairy Formation in southeastern Missouri.

The land surface in the outcrop area in Crowley's Ridge is slightly above 400 feet and slopes to less than 250 feet above sea level in the southeast corner of Pemiscot County. This results in a large area of artesian flow in the lowland area bordering Crowley's Ridge. The McNairy Formation is an artesian aquifer confined above by the Porters Creek Clay and Owl Creek Formation and below by rocks of Selma age and Paleozoic sediments which have low permeabilities. In most areas away from the outcrop the hydrostatic head is sufficient to produce flowing wells. In some locations the head has declined 10 to 20 feet. Elsewhere wells which have been in service

an equally long time have shown no decline. Because of the manner of recharge, declines would result as a consequence of heavy pumpage.

Excluding leakage from the Paleozoic dolomites it seems that recharge must come from the outcrop area and from areas where the McNairy Formation is overlain by the alluvium. The higher amounts of chloride and total dissolved solids in the ground water from the McNairy in some locations suggests upward leakage of small magnitude of the more saline Paleozoic ground water.

Quality of water

Comparison of the analyses from the McNairy Formation, Wilcox Group, and the alluvium in the Southeast Lowland shows that although water from the McNairy is much softer than that from the other aquifers it is generally the most mineralized and has the highest chloride content. The total dissolved-solids content of water from the three aquifers is compared in the table below and water analyses for the three aquifers are given in table 40.

Total dissolved solids

[In parts per million]

Geologic unit	Number of analyses	Maximum	Minimum	Median
Alluvium	6	357	113	243
Wilcox	5	298	124	170
McNairy	12	1,109	251	446

The McNairy Formation typically contains ground water which is soft and low in total iron. This quality makes the water desirable for use by municipalities and some industries because water treatment plants are not needed. Chemical and physical characteristics which are detrimental to its use in some areas are temperatures in excess of 90 degrees and sodium, chloride, and total dissolved solids content above U.S. Public Health Service standards. Water in the alluvium is similar to that in the Wilcox in many respects except that water from the alluvium has a higher iron content.

No geographic trends in mineralization of water in the alluvium in the Southeast Lowland are apparent from the analyses. The mineralization of water in the Wilcox and McNairy Formations does not increase down the dip, but the hardness in the McNairy decreases markedly and there is an indication of decrease in hardness in water from the Wilcox. Mineralization of water in the McNairy Formation in the northern part of the lowland is increased by mixture with water from the underlying Paleozoic rocks.

In the Missouri River valley water from the alluvium is considerably more mineralized than that occurring in the Southeast Lowland. Water from the alluvium of the Mississippi River valley and some of its tributaries, North River in Marion County and Meramec River in St. Louis County, is similar to that of the Southeast Lowland. Analyses of water representative of the alluvium in these areas are given in table 40.

TABLE 40.—*Chemical analyses of water from wells in the McNairy Formation, Wilcox Group, and the alluvium in the Southeast Lowland and the alluvial fill of the major streams*

[Analyses by M. E. Phillips and R. T. Rolufs of Missouri Geological Survey and Water Resources and by the Missouri Division of Health. Data in parts per million except pH]

County	Location [1]			Depth	Date sampled	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium as Na	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$		Alkalinity as $CaCO_3$	pH	Turbidity
	T.	R.	Sec.															Calcium, magnesium	Noncarbonate			
McNAIRY FORMATION																						
Stoddard	26	10	23	286	02/26/58	12	1.8	------	50	21	9.3	262	915	6.9	------	0.4	251	210	0	215	6.8	5.0
New Madrid	25	14	31	894	07/29/64	7	.80	0.0	69	17	209	154	21	378	0.8	.0	950	242	115	127	7.6	7.0
Do	21	11	19	1,308	06/01/64	9	.08	------	7.2	1.9	117	270	7.4	44	.1	.0	342	26	0	221	7.8	.2
Do	22	13	25	1,658	07/23/64	9	1.3	.0	80	18	224	140	35	458	1.1	.0	1,110	276	161	115	7.3	30
Butler	23	8	31	325	01/—/65	8	.08	.0	21	5.3	172	272	13	132	.4	.0	509	74	0	224	7.9	.2
Dunklin	23	10	28	360	07/08/63	7	.14	------	12	3.4	153	264	10	102	.3	.0	446	44	0	217	8.2	.1
Do	21	9	3	935	02/24/64	10	.04	------	64	1.5	142	292	8.8	52	.2	.0	883	22	0	240	8.3	.1
Do	17	8	2	1,717	10/15/63	14	.03	------	1.6	.3	196	421	5.8	41	.4	.1	447	60	0	346	8.3	.1
Do	16	7	3	1,770	03/16/64	12	.06	------	3.2	.5	180	404	14	54	.3	.1	509	10	0	332	8.2	.2
Do	16	9	8	1,846	05/20/64	14	.06	------	2	.7	252	677	1.2	8.1	.6	.0	645	8	0	556	8.3	.2
Pemiscot	20	11	24	1,720	12/01/64	14	.08	------	5.2	1.2	142	345	4.5	21	.1—	.0	359	18	0	283	8.2	.1
Do	19	12	34	2,153	05/14/51	16	.20	------	7.3	1.1	112	262	6.0	27	------	.0	379	23	0	215	8.1	.1
WILCOX GROUP																						
Scott	26	14	19	350	11/15/61	11	1.0	------	31	8.3	6.9	141	2.1	5.4	------	0.2	134	112	0	114	7.0	20
Mississippi	26	16	8	400	08/13/63	10	1.5	------	34	7.3	6.4	142	4.9	6.0	0.2	.1	170	116	0	116	7.2	15
New Madrid	23	11	25	475	08/27/64	12	.70	0.0	44	13	11	205	.0	3.0	.2	6.3	207	162	0	168	6.8	10
Dunklin	18	9	2	------	09/08/53	12	5.5	------	57	12	20	213	31	15	.2	.0	298	193	18	175	7.3	30
Pemiscot	18	13	16	1,380	03/24/60	15	1.4	------	4.8	2.4	30	84	12	4.9	------	.3	124	22	0	69	6.3	10

See footnote at end of table.

TABLE 40.—*Chemical analyses of water from wells in the McNairy Formation, Wilcox Group, and the alluvium in the Southeast Lowland and the alluvial fill of the major streams*—Continued

[Analyses by M. E. Phillips and R. T. Rolufs of Missouri Geological Survey and Water Resources and by the Missouri Division of Health. Data in parts per million except pH

County	Location[1] T.	R.	Sec.	Depth	Date sampled	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium as Na	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Alkalinity as $CaCO_3$	pH	Turbidity
SOUTHEAST LOWLANDS ALLUVIUM																						
Scott	27	14	3	80	07/01/55	18	0.83	0.36	23	4.2	8.6	84	9.9	0.5	------	0.0	113	74	6	69	7.8	1
Stoddard	25	12	26	100	07/01/55	23	9.3	.73	69	18	24	291	35	7.8	------	.0	331	247	8	238	7.0	------
Mississippi	23	16	14	120	09/30/64	17	16	.71	74	32	13	394	.8	4.0	0.1	3.0	357	315	0	324	7.2	------
New Madrid	25	14	22	92	07/01/55	22	.59	.52	34	6.8	9.9	128	14	.3	.7	.0	157	113	8	104	7.8	1
Dunklin	22	10	15	--------	07/27/64	16	.20	------	31	5.8	8.2	101	22	7.2	.1—	.6	166	102	19	83	7.4	.2
Pemiscot	20	12	9	75	07/01/55	23	17	.94	53	12	16	218	19	4.8	.6	.0	243	182	3	178	7.0	------
Missouri River Alluvium																						
Buchanan	56	36W	1	86	06/12/57	22	16	1.4	150	46	19	688	2.2	7.0	0.2	1.2	597	563	------	564	7.4	------
Clay	----	----	----	--------	05/20/53	12	15	------	80	22	51	273	143	19	.4	.0	535	290	66	224	7.0	------
Callaway	44	11W	8	895	—/—/—	24	20	------	116	27	12	472	14	7.1	------	.4	452	402	15	387	7.2	------
Mississippi River Alluvium																						
Marion	58	6W	13	40	11/07/59	9	0.10	------	62	11	18	195	34	22	0.1	1.7	303	200	40	160	7.9	0.2
St. Charles	47	4	23	106	07/20/62	29	6.2	0.52	94	39	15	480	.2	3.0	.2	.1	417	395	1	395	7.0	30
Cape Girardeau	29	11	1	110	—/—/35	1.6	5.2	.12	29	12	6.6	169	.0	3.2	.6	.5	190	121	------	139	6.6	10
Meramec River Alluvium																						
St. Louis	44	5	18	60	12/09/64	8.0	1.7	------	48	17	13	191	34	19	0.15	0.2	250	190	34	156	6.6	10

[1] Townships are all north. Ranges are east except where noted.

Use of water

In recent years there has been a great increase in the use of water from the alluvium. While this has been predominantly for irrigation, industrial and municipal pumpage also has increased. Where water temperatures are important, as for cooling, the alluvium offers the coldest water with uniform temperature. Temperatures range from 55 to 62 degrees. Because of the readiness with which recharge occurs, a long-term supply of water is assured. It is anticipated that there will be a greater increase in use from this source than from all of the other aquifers of the State combined.

The principal users of ground water from the Wilcox Group are municipalities and industries. The Wilcox is unused for irrigation except near the outcrop area where alluvial ground water is not available. Only moderate increases of water consumption from this source are anticipated.

The principal use of ground water from the McNairy Formation is by municipalities, with a lesser amount being used by industry. A moderate increase in use is anticipated.

The principal use of ground water in the alluvial plain of southeastern Missouri is for irrigation. It is estimated that 83,000 acre-feet (300 million gallons daily based on a 90-day irrigation season) of ground water was pumped from the alluvium during the 1965 season. This quantity far exceeds water use for all other purposes in the area. Municipal use of ground water averaged 7.7 million gallons daily from the McNairy Formation, the Wilcox Group, and the alluvium. Rural and stock use averaged 4.6 million gallons daily. Industrial use of ground water is estimated to be 3 million gallons daily.

Use of ground water along the Missouri River is discussed in the section on the saline ground water province because of the close relationship of the alluvium to the glacial deposits discussed in that section.

Along the Mississippi River where water is available in the alluvium the use of water is a very small percent of that available. Irrigation use was 75 acre-feet, or 270,000 gallons a day based on a 90-day irrigation season. Municipalities drawing water from the alluvium of the Mississippi and tributary valleys exclusive of the Missouri River use about 6 million gallons daily. Rural domestic and stock use is slight.

SPRINGS

(E. J. Harvey, U.S. Geological Survey, Rolla, Mo.; Jerry D. Vineyard, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Springs are an important part of the water resources of Missouri, particularly in the Ozarks, where some of the world's largest springs are located. Only a minor part of the discharge of Missouri springs is used directly for municipal and domestic water supplies, medicinal purposes, and for commercial fisheries, but they contribute indirectly to the economy by sustaining the flow of streams and by serving as focal points for scenic and recreational developments. Wise development of the springs demands a clear understanding of the hydrology of springs.

The springs of the Ozarks are in a very scenic part of the State. Attempts to preserve the esthetic qualities of the springs, their sur-

roundings, and the rivers into which they flow have culminated in the establishment of the Ozark National Scenic Riverways. The Current River and its principal tributary, Jacks Fork, are included in this new national park.

GEOGRAPHIC DISTRIBUTION

The Ozark Plateaus contain the largest and greatest number of springs in Missouri (Beckman and Hinchey, 1944). Springs with appreciable year round flow occur at altitudes as high as 1,500 feet above sea level. Most Ozark springs are outlets for subterranean streams intersected by surface streams as the latter deepen their valleys. The interconnected solution channels forming spring supply systems, filled or partly filled with water, are caves in various stages of formation. Similar openings, now above the water table, comprise the large cave systems for which the State is noted, and show that the Ozarks have had a long history as a major spring area. The combination of considerable relief, repeated uplifting of a sequence of more than 1,000 feet of carbonate rocks, and the fracturing resulting from the uplifting and other stresses has created the conditions necessary for the development of an extensive spring and cave system.

The springs are located at many points along the streams and add much to the beauty of the streams. Among these streams are Current River and its tributary Jacks Fork, Eleven Point River, North Fork River and its tributary Bryant Creek, the White and James Rivers, and Shoal Creek, Spring River, the lower Osage, Gasconade, Big Piney and Meramec Rivers, and the Black and St. Francis Rivers, all well known to float trippers, fishermen, and those who merely enjoy the scenery.

In areas bordering the Salem Plateau springs generally are small by comparison, but many are large by standards of other states. These springs typically drain karst topography developed in the soluble limestone bedrock, but solution channels are not so well developed in this region as in the Salem Plateau. The Mississippian limestone of the Springfield Plateau in southwest Missouri supports many small springs, and some with discharges of as much as 10 to 20 cubic feet per second.

Streams crossing the Osage Plains of western Missouri and the Dissected Till Plains of northern Missouri have minimum flows of zero to 0.001 cubic feet per second per square mile, whereas the spring-fed streams of the Ozarks have flows up to 0.40 cubic feet per second per square mile. Springs in northern and western Missouri are small and generally intermittent.

In Greene County on the Springfield Plateau where a survey has been made to locate and measure all known but previously unmeasured springs, many springs have been found which have substantial year-round flow. Prior to the survey of Greene County, records of only four springs were available. In the fall of 1964, 56 additional springs were located which had measurable flow. A few large springs (10 cubic feet per second or more), formerly unrecorded, have been found in Greene and other counties in such surveys. It is believed that the record of the number of springs having an average discharge of 1 cubic foot per second or more would be increased by 25 percent if

a comprehensive survey of the Ozarks were made. This is based on the premise that the flow of known springs accounts for about one-half to three-quarters of the base flow of a spring-fed stream such as the Current River. Undoubtedly there must be many other springs.

The absence of surface flow in a stream valley does not indicate that springs of considerable magnitude may not exist upstream. Some springs discharge and flow in the spring branch or stream valley for a short distance only to disappear into the ground at faults, in subterranean cavities hollowed out of the carbonate rocks, or into the coarse gravel fill of the alluvial valley.

GEOLOGIC DISTRIBUTION

The most favorable environment for the development of large spring systems is the thick sequence of Cambrian and Ordovician dolomites of the Ozarks. There are more than a thousand feet of flat-lying medium- to coarse-grained carbonate rocks in central and southern Missouri. The major cavernous formations in the Ozarks are the Gasconade, Eminence, and Potosi Dolomites, which have similar lithologies. Ground water moves freely through these formations, and, where deeply buried, they are good aquifiers.

Water-well temperature and drilling data show that in some areas ground water may circulate through interconnected solution openings to depths of 800 feet below the land surface. Investigation of spring supply systems has shown that major subterranean streams flow at depths as great as 260 feet below the local water table, and drill holes have penetrated solution openings at much greater depths.

Throughout much of the Ozarks the Roubidoux Formation, which contains several sandstone units, overlies the dolomite strata and impedes the development of karst topography. The permeable sandstone filters ground water passing through it, producing spring water which, though hard, is of good quality.

Springs in the Pennsylvanian rocks of western and northern Missouri are small and many are highly mineralized. Sedimentation in the Pennsylvanian Period was cyclic and produced thin rock units of varying lithology. In this area there are no thick sections of carbonate rocks, only thin limestone beds with intervening layers of shale, sandstone, siltstone, clay, or coal. There is no opportunity for the development of large integrated solution channels characteristic of large spring supply systems. The dissimilar rock layers impede the movement of ground water and produce only small contact springs.

EBB AND FLOW SPRINGS

Periodic or "ebb and flow" springs are of little economic value, but they are of considerable scientific interest. Of 23 ebb and flow springs known in the United States in 1944 (Beckman and Hinchey, 1944, p. 44), five were in Missouri. Since 1944, three additional ones have been discovered in the State. Recent study of ebb and flow springs has not revealed the mechanism of periodicity, but observations suggest that periodicity is a function of spring discharge. Records show that ebb and flow springs cease to fluctuate at higher discharges. Critical dis-

charge ranges probably exist for each spring outside of which the spring will flow normally.

There is no evidence to disprove the widely held theory that the ebb and flow effect is caused by siphons in the spring supply systems (Bridge, 1923). Recent study of spring supply systems has shown that siphons are often present in spring systems in a transitional stage from completely water filled solution channels to air-filled caves. It is believed that more ebb and flow springs will be found as continuous flow records on Missouri springs become available.

DISCHARGE

More than 1 billion gallons of water flows on the average day from the 15 largest springs in the State. Data on the large springs are given in table 41. The order of magnitude is changed from that given by Beckman and Hinchey (1944, p. 16), because of the availability of longer records. Blue Spring in Wayne County, inundated by Wappapello Reservoir, and Mammoth Spring because it is located in Arkansas, are omitted in the revised list. (Beckman and Hinchey included Mammoth Spring because the recharge area is in Missouri although the spring outlet is immediately south of the Missouri-Arkansas line.) North Fork Spring in Ozark County and Round Spring in Shannon County have been added to the list.

Up to 1966, 474 springs had been located and measured in Missouri, and all of the large ones are in the Ozarks. Although many more springs exist, all large ones probably have been measured. Figure 77 shows the geographic distribution of springs with discharge of more than 1 cubic foot per second (648,000 gallons a day). The discharges of the 474 springs measured in the course of 40 years are as follows: no flow one or more times when visited, 44; minimum flow more than zero and less than 1 cubic foot per second, 265; minimum flow of 1 cubic foot per second or more, 165.

Some springs have unusually large flows immediately after a heavy rain and cease flowing entirely in a short time. Others increase after rain but have well-sustained low flows.

QUALITY OF WATER

Spring water in the Ozarks is of very good quality. On the flanks of the Ozarks the mineral content is higher, corresponding in a general way with the higher mineral content exhibited by water from deep wells and streams. Owing to the easy entrance of water locally, considerably more variation in the quality is evident in the springs than in deep wells. Springs in metropolitan and industrial sections of the State show the effects of urbanization in the higher mineral content of spring water.

Basically two types of water discharge from the springs of the Ozark Plateaus. On the Salem Plateau where the aquifers are dolomite and sandstone, calcium-magnesium bicarbonate water predominates. On the Springfield Plateau, springs that issue from the Mississippian limestone are of the calcium bicarbonate type.

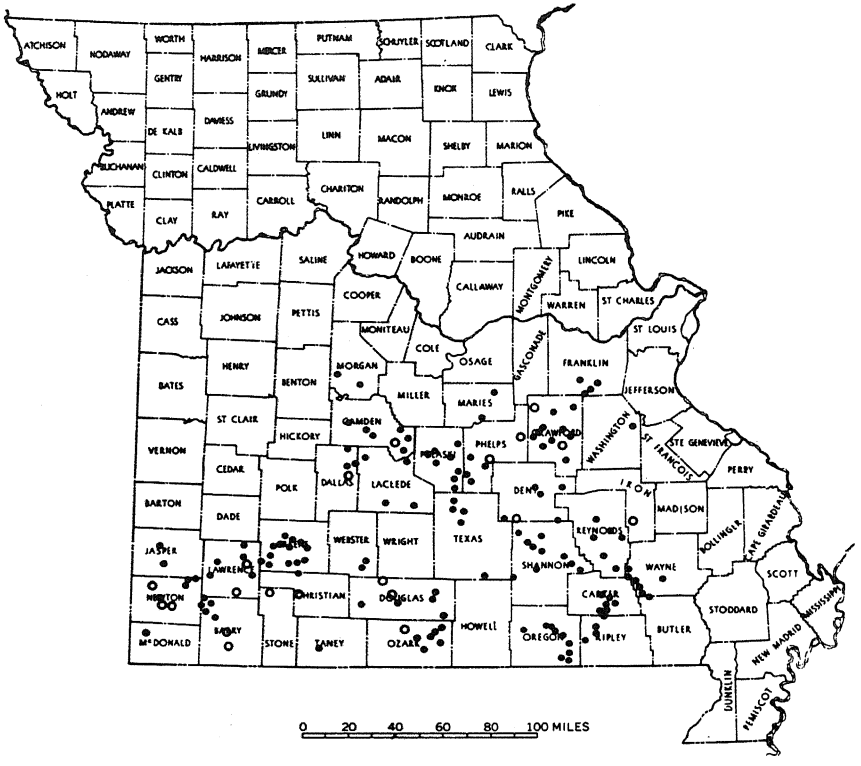
TABLE 41.—*Discharges of large springs in Missouri*

[In gallons per day]

Name of spring	County	Location	Average discharge	Maximum measured		Minimum measured	
				Discharge	Date	Discharge	Date
Big	Carter	SW¼NE¼ sec. 6, T. 26 N., R. 1 E	276,000,000	840,000,000	June 1928	152,000,000	Oct. 6, 1956.
Greer	Oregon	SE¼SW¼ sec. 36, T. 25 N., R. 4 W	214,000,000	583,000,000	May 26, 1927	67,000,000	Nov. 16–19, 1956.
Double	Ozark	NE¼NE¼ sec. 32, T. 24 N., R. 11 W	[1] 100,000,000	150,000,000	Apr. 7, 1965	30,000,000	Nov. 16, 1964.
Bennett	Dallas	SE¼NW¼ sec. 1, T. 34 N., R. 18 W	100,000,000	[2]		36,000,000	Nov. 13, 1934.
Meramec	Phelps	NW¼SE¼ sec. 1, T. 37 N., R. 6 W	96,000,000	420,000,000	1927–28	36,000,000	Aug. 1, 1934.
Blue	Shannon	NE¼SE¼ sec. 21, T. 29 N., R. 2 W	[1] 90,000,000	153,000,000	Apr. 24, 1964	40,000,000	Oct. 10, 1932.
Alley	do	NW¼SE¼ sec. 25, T. 29 N., R. 5 W	81,000,000	[2]		35,000,000	Oct. 1934.
Welch	do	SE¼SE¼ sec. 14, T. 31 N., R. 6 W	[1] 75,000,000	214,000,000	June 22, 1924	45,000,000	Aug. 24, 1964.
Bolling	Pulaski	SE¼NW¼ sec. 33, T. 37 N., R. 10 W	[1] 68,000,000	45,000,000	Oct. 26, 1963	36,000,000	Jan. 21, 1964.
Blue	Oregon	NW¼SE¼ sec. 16, T. 22 N., R. 2 W	[1] 61,000,000	65,000,000	July 18, 1935	35,000,000	Aug. 13, 1936.
Montauk	Dent	SE¼NE¼ sec. 22, T. 32 N., R. 7 W	[1] 53,000,000	79,000,000	May 15, 1939	25,000,000	Aug. 13, 1934.
Hahatonka	Camden	NE¼SW¼ sec. 2, T. 37 N., R. 17 W	48,000,000	123,000,000	June 19–20, 1924	28,000,000	Feb. 23, 1923.
North Fork	Ozark	SW¼SW¼ sec. 28, T. 24 N., R. 11 W		49,000,000	July 6, 1966	43,000,000	Apr. 8, 1966.
Round	Shannon	SW¼NW¼ sec. 20, T. 30 N., R. 4 W	26,500,000	336,000,000	May 1933	6,500,000	Dec. 1937.
Hodgson Mill	Ozark	SW¼SE¼ sec. 34, T. 24 N., R. 12 W	[1] 24,000,000	29,000,000	Aug. 18, 1934	15,000,000	Aug. 29, 1925.

[1] Estimated.
[2] Peak flows affected by runoff upstream from spring, after heavy rains.

Springs outside the Ozarks are generally higher in dissolved solids and exhibit chemical features characteristic of the area in which they are located. Springs north of the Missouri River are moderately mineralized but more mineralized than those of the Ozarks, and they contain considerably more sulfate. Spring water in northern Missouri is not as a rule as mineralized as well water from the same strata.



• Springs with average discharge over 1 cfs (648,000 gal. per day).

o Springs used for fish hatcheries and and rearing ponds.

FIGURE 77.—Springs of Missouri with average discharge more than 1 cubic foot per second.

There is a noteworthy concentration of salt springs in Saline County which gives the Blackwater River a noticeably higher natural mineral content than any other stream in the State. The geochemistry and origin of the saline ground water in that county are being studied as a project of the Water Resources Research Center at the University of Missouri. Saline springs are also known in other areas of the State. Springs having concentrations of several thousand parts per million

of total dissolved solids are known in Marion, Pike, Jefferson, Perry, Pettis, St. Clair, and Clay Counties. Those in Jefferson and Perry Counties are the only known saline springs in the Ozarks.

The dissolved mineral content of spring water increases as the discharge of the spring declines seasonally. Seasonal variations in chemical quality are due to land use in the recharge area of the spring, kind of rock, and the length and character of the conduits through which the water travels to its orifice. Owing to the ease with which precipitation reaches the ground-water reservoir variations in chemical quality are to be expected. For this reason pollution of springs is rapid if sources of pollution are present in the recharge area. On the basis of one analysis a spring may appear to be of satisfactory bacteriological quality but it may be unsafe at another time of the year or in later years.

The presence of nitrate in concentrations much greater than the local average may suggest pollution. The source of the nitrate may be decaying organic matter, legume plants, sewage, nitrate fertilizers, nitrates in soil and rock, and deposits of bat droppings in caves. Practically all springs sampled in the Ozarks showed some nitrate content which is normal. Generally the content was less than 10 parts per million. However, as shown in the table below, in certain areas of the State the nitrate content of a majority of the springs exceeds 10 parts per million. Rarely does the concentration exceed 45 parts per million.

Basin	Number of samples	Percent of samples having more than 10 p.p.m. NO_3
White River	22	68
Sac River	27	63
Spring River	40	35
Osage River	4	25
Pomme de Terre-Niangua Rivers	20	10
Eleven Point River	24	4
North Fork River	28	4
Gasconade River	72	3
Meramec River	69	3
Black-St. Francis Rivers	31	0
Current River	52	0

The drinking water standards (U.S. Public Health Service, 1962b) recommend that the nitrate content not exceed 45 parts per million as there is evidence that higher concentrations may cause methemoglobinemia in infants.

Springs on the Springfield Plateau have abnormally high nitrate concentration. The area is drained principally by the White, Sac, Spring, and Osage Rivers. The terrain on the plateau is gently rolling with extensive areas of karst topography. Interior drainage increases the possibility of pollution from surface sources. Domestic sewage disposal systems are common and dairy farming and stock raising are widespread. Thus, the requirements for pollution are present and it is well displayed by the sharp contrast in the occurrence of nitrate in spring water on the Springfield and Salem Plateaus.

In the table below are given summaries of some of the chemical characteristics of spring water, in parts per million, in two basins, the Spring River that drains limestone terrane on the Springfield

Plateau and the Current River that drains dolomite terrane on the Salem Plateau. These basins are considered representative of the two areas of the Ozarks. Spring water from limestone varies more in hardness, nitrate, and total dissolved solids, is generally softer, and has about the same total mineralization as spring water from dolomite. The iron content of spring water in the two basins is low and no significant difference was noted. Total iron ranged from 0.0 to 1.5 parts per million with most analyses showing less than 0.10 parts per million.

Basins	Number of samples	Hardness (parts per million)			Nitrate (parts per million)			Total dissolved solids (parts per million)		
		Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median
Spring River	31	397	92	146	17.0	.0	8.9	520	123	184
Current River	29	315	129	188	5.8	.0	.3	301	136	183

USE OF SPRINGS AND SPRING WATER

The springs of Missouri have figured importantly in the history and development of the State, and many of the towns contain the word "spring" in their names. Three overlapping eras in the development of the State can be distinguished in the use of spring water. In the earliest days of the pioneers the springs served as a source of water for people and stock as they moved westward, and, perhaps more importantly, certain springs served as sources of salt when availability of salt depended on local manufacture at the salt springs. The important salt springs are in Saline, Howard, and Perry Counties.

Following this earliest use of water the larger fresh-water springs became important as a source of power for grist mills and other manufacturing and mining establishments in rural Missouri. As recently as 1944, at least eight grist mills situated at springs were still in operation (Beckman and Hinchey, 1944). Within the past two decades most of the grist mills have ceased operation until in 1966 only three were in business.

Following the decline in the importance of the saline springs as a source of salt they were gaining importance for the medicinal qualities of the water. This was the era of the great spas when large hotels, pools, and bath houses were built at many of the mineral springs. The only spa of importance remaining in Missouri today is Excelsior Springs 10 miles east of Kansas City.

With the increase in recreational and commercial fishing, trout and bait hatcheries have been increasing production and facilities. Resorts have been built, not for the medicinal qualities of the mineral waters, but to afford recreation to the trout fisherman. Many lakes have been built in the Ozarks to utilize the high sustained flow of the streams for hydroelectric power and water-based recreation.

The principal use of spring water at the source is for rearing trout and other game fish and bait. Owing to the uniform temperature and good quality of the water the springs are ideal for both sport fishing and commercial fisheries. Information on some of the fish-rearing establishments open to the public and details on the spring flow are

given in table 42. Locations are shown on figure 77. It is estimated from a recent study that about 100 million gallons of water a day is used at the hatcheries and fishing facilities. This quantity does not include the total spring flow at the largest hatcheries; it comprises only 5 to 30 percent of individual flows at some of the larger springs.

TABLE 42.—*Yields of representative springs used by the fish-rearing industry of Missouri*

County	Ownership	Name of spring or springs	Demand or spring flow (million gallons daily)
Barry	Private	Crystal	5–11
Do	State of Missouri	Roaring River	6–8
Camden	Private	Wet Glaize	5–8
Christian	do	Montague	2
Crawford	do	McDade	1
Do	do	Westover	7
Dallas	State of Missouri	Bennett	19–25
Dent	do	Montauk	5–6
Douglas	Private	Bryant	½–1
Do	do	Crystal	7–10
Iron	do	Speer	¾
Lawrence	State of Missouri	Chesapeake	1–2
Do	Private	Spring River	3
McDonald	do	Kelley	½
Morgan	do	Gravois Mills	3
Newton	U.S. Government	Hearell, Elm, Bartholic, and McMahon.	3
Do	Private	Ozark Trout Farm	1
Ozark	do	Rockbridge, Morris	7–15
Phelps	do	Meramec	2–4
Do	do	Yancy Mills	½–2
Stone	do	Brown	6–7

At the present time the town of Mill Spring, Wayne County, is the only community solely dependent on a spring for its water supply. Arcadia, Iron County, and Springfield, Greene County, have springs incorporated in their water supply systems which are drawn on intermittently or which supplement water from other sources. However, springs determined the locations of numerous towns in the days when Missouri was first settled. Generally there was a grist mill at the larger springs and the spring served as a water supply and source of power. Meramec Spring, Phelps County, provided the water and power supply for the first economically successful iron works west of the Mississippi River, established in 1829. Scotland Spring in Jasper County is today an important source of water supply for the complex of chemical industries located east of Joplin.

Another important use of the springs of Missouri is stock water. Many of the cattle ranches in the Ozarks have one or more springs that furnish a water supply for stock and when dammed and stocked with trout also serve as private fishing lakes.

SUMMARY

The importance of the springs in the future of Missouri lies in their fairly uniform mineral content, generally low suspended-solids content, uniform cool temperature (56°–59° F.), and large quantities of water available. The chief drawback to their widespread use at the source is the inaccessibility of many of them.

Studies made in other States have shown that springs can provide adequate and reliable water supplies of good quality for municipal and industrial uses (Gurnee and others, 1961; Sun and others, 1963). The use of springs as water supplies must be accompanied by adequate water treatment facilities and delineation and protection of the spring recharge areas to minimize pollution hazards. A spring flowing 1 cubic foot per second can supply a city of 6,500 population, assuming average per capita water use of 100 gallons per day. Missouri has 165 known springs which have minimum flows of 1 cubic foot per second (646,000 gallons per day) or more.

SUMMARY OF WATER USE

(E. J. Harvey, U.S. Geological Survey, Rolla, Mo., with a discussion of Irrigation by Herman J. Hall, University of Missouri, Columbia, Mo.)

Withdrawal of water for purposes other than the production of hydroelectric power is a little over 2,000 million gallons per day, a small percentage of the available supply. In 1960, hydroelectric power production, located principally on the Osage River in central Missouri and on tributaries of the White River in the southern Ozarks (see fig. 80), required 13,000 million gallons per day. Being nonconsumptive, this use does not affect other uses of the same water, except in the control of reservoirs and the incidental effect that storage has on water quality. Nonwithdrawal uses such as navigation, recreation, and propagation of fish and wildlife, although not easily evaluated in terms of volume, are very important to Missouri.

Industrial water supply in Missouri is derived principally from streams, according to a nationwide study in 1960 (MacKichen and Kammerer, 1961, p. 20). About 60 million gallons per day is pumped from wells and 1,410 million gallons per day is from surface sources. About 1,300 million gallons per day of this self-supplied industrial water is used for cooling in fuel-electric plants. The remainder is used principally in the chemical industry, food industry, and primary metals industry. In addition to self-supplied water, industrial and commercial establishments obtained 180 million gallons per day, not including that used for air conditioning, from public supplies.

Many more towns in the State are dependent on ground water supplies than on surface supplies. However, the quantity pumped from surface sources and the population served far exceed that pumped from wells and the population served.

	Number of supplies		Population served		Average pumpage (million gallons daily)	
	Number	Percent	Population (thousands)	Percent	Pumpage	Percent
Surface water	102	18	2,617	77	414	86
Ground water	492	82	771	23	67	14
Total	594	100	3,388	100	481	100

In many locations bountiful supplies from both ground and surface sources are available, but for economic or other reasons one or the other is developed. Springfield, Kirkwood, Sedalia, and St. Charles have developed both sources with one source held in reserve. The 10 principal cities of the State and their sources of supply are as follows: surface water—St. Louis and the surrounding cities in St. Louis County, Kansas City, Springfield, St. Joseph, Joplin, Jefferson City, and Cape Girardeau; ground water—Columbia, Independence, and St. Charles.

The source of water in rural areas for domestic and stock water supplies excluding irrigation water is wells, springs, streams and ponds. It is estimated that 150 million gallons per day are used, and of this, 28 million gallons per day or 20 percent is pumped from wells. A large part of the domestic supply is pumped from wells, but 75 percent of the stock water is from streams and ponds (McNabb, written communication, December 1965).

Missouri depends almost altogether on rainfall to provide moisture for crop production but drought periods develop renewed interest in irrigation. During the drought in the 1930's several thousand acres of crops were irrigated. Interest dropped when the drought ended and the practice was abandoned except for some commercial vegetable operations.

The drought period beginning in the early 1950's brought renewed interest. This time the interest continued past the drought period and still continues to increase. This is especially true in areas where water supplies are readily available. Since 1954, from 24,000 to 64,000 acres per year have been irrigated in Missouri. The number of acres irrigated each year depends on the rainfall distribution with more acres being irrigated during a dry year. Another general drought period would undoubtedly cause a material increase in the practice.

The total acreage irrigated during 1965 was 75,900 acres. About 22,900 acres of this was by sprinkler and about 53,000 acres by surface methods.

Most of the water used for irrigation in Missouri comes from wells with streams and impoundments also being used.

The principal crops irrigated in Missouri in order of acreage are corn, cotton, rice, fruit and vegetables, pasture, soybeans, and alfalfa.

The principal area of irrigation is in the Southeast Lowland. Other areas are along the alluvial plains of the Missouri and Mississippi Rivers and the rolling upland on the Springfield Plateau in southwestern Missouri. Ground water is pumped for irrigation of truck farms in the vicinity of Kansas City and St. Louis. Row crops planted in the broad flood plain along the Missouri River between the Iowa line and Howard County are irrigated but not with the seasonal regularity reported in the Lowland, where rice, cotton, and soy beans are irrigated regularly. Pasture irrigation is increasing in the dairy and stock raising country on the Springfield Plateau.

The distribution of irrigated land in the State is shown in figure 78. The greatest concentration is in the Southeast Lowland where the land is flat, the climate is suitable for growing rice and cotton and a large quantity of water is available at low cost. Irrigated land in the

Missouri River flood plain is concentrated in the western part of the valley where it is 10 miles wide and water is easily obtained. The concentration of irrigation in southwestern Missouri conforms quite closely to the extent of the Springfield Plateau. Water is easily obtained from well sustained streams. Springs are numerous; ground water can be obtained from shallow wells drilled into the Mississippian limestone. In addition, much of the surface of the Springfield Plateau is rolling to gently sloping. Although large quantities of water are available from streams on the Salem Plateau, much of the land is too hilly to be easily irrigated.

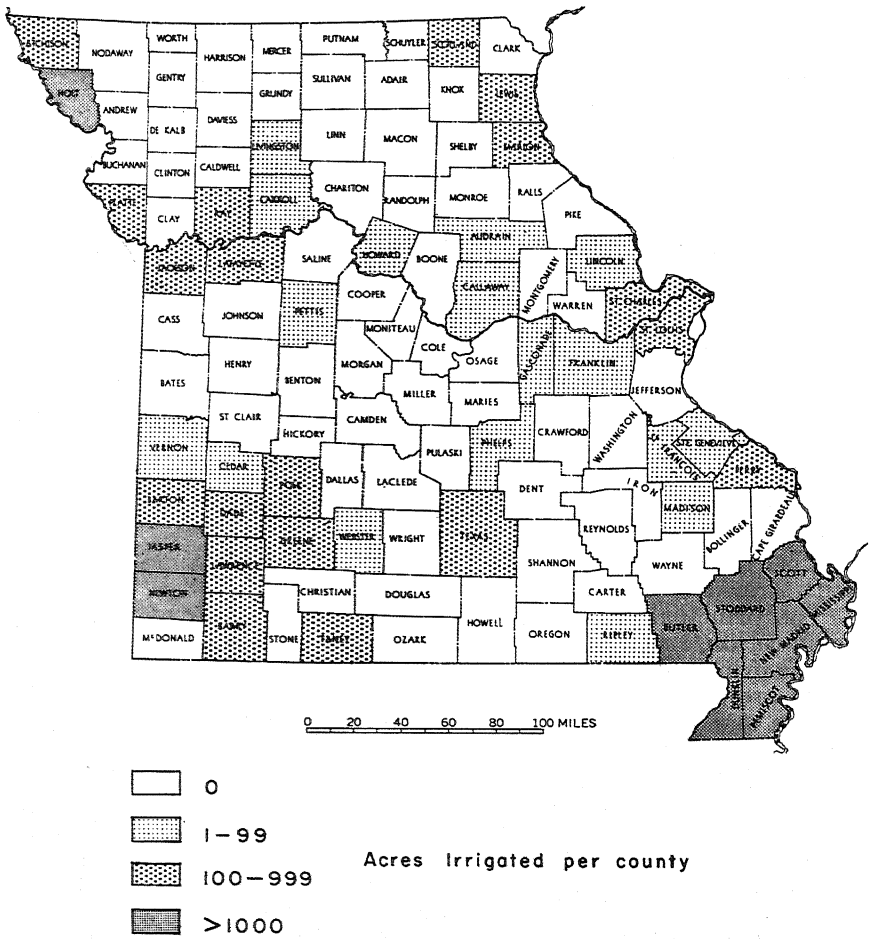


FIGURE 78.—Distribution of irrigated acreage in Missouri, 1965.

Based on a 1965 survey of water use for irrigation in the Lowland area and on a 1965 statewide survey of irrigated acreage by the Extension Division of the University of Missouri, it is estimated that about 76,000 acres of land were irrigated in 1965 and over 90,000 acre-feet of water were applied. Aquifers supplied 95 percent of the water; streams and ponds supplied 5 percent.

In the Lowland 64,000 acres were irrigated, 98 percent from alluvial wells and 2 percent from streams and ponds. This required 83,000 acre-feet of ground water and 1,700 acre-feet of surface water. Along the Missouri and Mississippi Rivers 4,800 acres (80 percent of the irrigated acreage) were watered from alluvial wells and 1,100 acres (20 percent) from surface sources. Assuming application of one-half acre-foot per acre, it is estimated that 2,400 acre-feet of ground water and 600 acre-feet of surface water were used.

In the remainder of the State 6,300 acres were irrigated, 70 percent from surface sources and 30 percent from wells, requiring 2,200 acre-feet of surface water and 900 acre-feet of ground water.

WATER RESOURCES FOR RECREATION

(By Hadley K. Irwin, Recreation Supervisor, Missouri State Park Board, Jefferson City, Mo.)

Since the time of early settlement of Missouri, water resources have played a very important part in the State's history and development. This valuable resource must be protected for many reasons, and one of the most important is for the recreation it provides.

Outdoor recreation has become deeply embedded in the American way of life, and the majority of the people or vacationers wish to be near water areas and to engage in water-associated activities such as swimming, fishing, water skiing, boating, hunting, camping, and picnicking. Our expanding population, with more leisure time, more purchasing power, and better highways, continues to seek more opportunities to enjoy the outdoors. The demand for outdoor recreation will continue to become greater and greater each year.

In the beginning, only rivers and springs provided water-related recreational opportunities in Missouri. In 1931 the Lake of the Ozarks was completed by the Union Electric Co. This was followed by the construction of other large reservoirs by the U.S. Corps of Engineers, such lakes as Table Rock, Pomme de Terre, Lake Wappapello, Clearwater, and Stockton Reservoir which is now under construction. Parts of Bull Shoals and Norfolk Reservoirs are in Missouri. They also furnish recreation for millions of people.

There are other reservoirs such as Kaysinger Bluff, Cannon and the dams in the Meramec Basin, all of which will furnish water-related recreation.

The benefits or recreational opportunities furnished by the multiple use of land and water-resource development projects have become an important product of the Corps of Engineers' civil works program. For that reason, recreation as a purpose is now given full consideration along with other purposes in planning of water-resource development projects.

The economic impact created by these manmade lakes is reflected by the figures from the Lake of the Ozarks Association. Bank deposits in the area were $59 million in 1965. There are 403 resorts on the lake with a total of 23,000 beds. There are 23 heated fishing docks and 14 major marinas, four golf courses, and five caves that do a good business from the many visitors to the lake area. There were 2,300,000 overnight guests in the immediate area during the 1965 season.

As reported by the Corps of Engineers the number of visitors at Clearwater was 483,000; Pomme de Terre, 1,133,000; Table Rock, 2,872,000; and Lake Wappapello, 1,164,000. Besides these large reservoirs, many smaller ones have been constructed such as Lake Jacomo in Jackson County and Forest Lake in Thousand Hills State Park.

Missouri has many miles of streams and rivers which furnish outdoor recreation in the form of fishing, floating, and swimming. The recently created Ozark National Scenic Riverways, which encompass most of the Current River and Jacks Fork, will be available to the public from now on. Of particular interest to the recreation-minded public is the Wild Rivers Measure, which would establish a national system of streams to be preserved in free-flowing condition for their conservation, scenic, fish, wildlife, and recreation use.

During 1966 in excess of 10 million visitor-days were reported at the State parks of Missouri, pointing to the fact that catering to the needs of the tourists is a major industry in the State, and lakes, springs, and rivers are a valuable resource in fulfilling the needs of these vacationers.

CAVES

(Jerry D. Vineyard, Missouri Geological Survey and Water Resources, Rolla, Mo.)

Caves are neither water resources nor mineral resources, but they result from subsurface ground water activity and their secondary mineral deposits provide scenic and esthetic values enabling their development as tourist attractions. Missouri is fortunate in having many caves. Currently it leads the Nation in the number of caves open to the public (26 in 1966). In 1956 the Missouri Geological Survey published "Caves of Missouri," describing 437 caves known at that time (Bretz, 1956). Subsequently the number of known caves has risen to nearly 2,000, a figure second only to the State of Virginia. Internationally there are few areas equal to Missouri in number and size of caves. Perhaps the greatest caves of all remain nearly inaccessible to man, for they comprise the supply systems for the large limestone springs of the Ozarks.

Because of the moderate relief in the cavernous areas of the State, most cave systems are low-gradient underground stream channels that probably originated at or below the water table, and later were modified by free surface streams. Deep shaft caves are present in several cavernous areas of the State, but this type of cave is comparatively rare. Missouri caves range in size from small, pipe-like tunnels a few tens of feet long to large, integrated cavern systems running for tens of miles.

Most Missouri caves are in the Ozarks, where thick Paleozoic carbonate rocks and abundant ground water constitute an ideal environment for the development of cavern systems. Few caves are found in

the thin Pennsylvanian limestones of northern and western Missouri, but the thicker Mississippian limestones of central, southwestern, and northeastern Missouri are highly cavernous.

Secondary mineralization is present to some extent in nearly all Missouri caves. Generally speaking, those caves having scenic secondary mineral deposits are best suited for development as tourist attractions. Numerous caves now in a natural state contain scenic values suitable for commercial development.

Calcite and its chemically identical twin, aragonite, are the chief secondary minerals found in caves. Gypsum, manganese minerals, and a few other minerals occur in small quantities in caves. Cave onyx (calcite-aragonite travertine deposits) was mined from Missouri caves for decorative dimension stone for a short period in the late 1800's, but the industry never attained more than minor importance.

Extensive clastic deposits in some cave passages have no economic value and actually hinder development of caves. Red clay, silt, sand, and gravel derived from weathering of overlying rocks and from the host rock form the clastic sedimentary fills in caves. Debris from roof collapse, called breakdown, is found in many caves, but there is little evidence to suggest that earth tremors are a major cause of roof failure. However, severe shocks would cause breakdown in areas already weakened by other processes.

Caves developed for public viewing must be inspected and approved annually by the State Division of Mine Inspection.

The Potosi-Eminence-Gasconade sequence of massive, medium-grained dolomite is the most cavernous lithologic group in the State, followed closely by the Mississippian Burlington and Keokuk Limestones. The largest known cave in the State is a cave-spring complex developed in the Gasconade Dolomite (Ordovician) in Camden County. Second largest known system is an integrated karst drainage network in Perry County, developed in the Joachim Dolomite (Ordovician). A karst drainage system in the Burlington Limestone (Mississippian) in Boone County probably ranks third largest. None of the three largest caves is open to the public.

Inventory of the State's cave resources is maintained by the Missouri Geological Survey in cooperation with the Missouri Speleological Survey, Inc., a nonprofit, volunteer organization devoted to the study of speleology. Cave data on file at the Missouri Geological Survey include information on most of the 2,000 known caves and detailed maps of more than 250 caves.

WATER RESOURCES PROGRAMS AND PROJECTS OF THE SOIL CONSERVATION SERVICE

(J. M. Dale, U.S. Soil Conservation Service, Columbia, Mo.)

In carrying out the conservation of soil and water resources in Missouri, the Soil Conservation Service works closely throughout the State with individuals and small groups of landowners in locally organized Soil and Water Conservation Districts. Landowners have formed their own Soil and Water Conservation Districts which are organized primarily on a county basis in 65 counties. As of December

31, 1965, some of the accomplishments dealing with soil and water conservation work have been recorded as follows:

Accomplishments	Unit	Quantity
Farm conservation planning	Acres	8,893,490
District cooperators	Number	33,370
Soil surveys	Acres	10,453,051
Terraces and diversions	Mile	24,580
Grassed waterways	Acres	31,116
Farm ponds	Number	61,962
Structures—stabilization, floodwater retarding, multiple purpose, and water control.	do	18,178
Irrigation reservoirs	do	14
Sprinkler irrigation systems	do	353
Surface irrigation systems	do	813
Irrigation water management	Acres	62,072
Land leveling, grading, and smoothing	do	243,767
Drainage ditches—main, lateral, and field	Miles	10,891
Pumping plants	Number	981
Spring development	do	450
Pipelines	Miles	315
Floodways	do	283
Stream channel improvement	do	312

In planning a water-disposal system for upland areas, excess rainfall moving from the fields is controlled by a system of terraces, grassed waterways, structures, and floodways. As the need arises for more water, excess runoff is stored in ponds and reservoirs.

Terraces control excessive runoff so it either moves off the upland fields at a slower rate or has more opportunity to soak into the soil. When the movement of water is slowed down or the total runoff is reduced, there is less soil erosion. Grassed waterways and grade stabilization structures provide a means of carrying excess runoff from the upland fields down the natural drainage ways at safe velocities that decrease gully erosion.

Further downstream, floodways and stream-channel improvements convey the runoff through adjacent bottomland areas, thereby reducing flooding of the bottomland fields and eliminating most of the streambank erosion and bottomland scouring. Diversions convey excess runoff from upland fields by diverting the water from eroded areas and from bottomland fields which might be flooded. In addition, diversions convey runoff into ponds or reservoirs where water may be stored for useful purposes.

Farm ponds, spring development, and associated pipelines provide storage and distribution of runoff and spring water for such purposes as stock water, spraying, irrigation, and firefighting. Ponds are also used for recreation such as fishing, boating, and swimming. Floodwater-retarding structures temporarily store and control runoff water for the pupose of reducing downstream floodwater damages to agricultural crops, fences, buildings, roads, and bridges, and municipalities.

IRRIGATION

In the overall planning of an irrigation system, the soil-plant-water relationship is given full consideration. Best use is made of the avail-

able soil and water resources. Land leveling corrects the unevenness of bottomland fields and flat upland fields, thereby providing better distribution of water in surface irrigation systems. Irrigation water is stored in a reservoir strategically located either in a natural drainage-way where runoff water can be impounded or near a stream or underground source of water from which the water may be pumped into the reservoir. Pumps are used to distribute water from reservoirs, wells, or streams to surface or sprinkler systems.

Main, lateral, and field ditches, and land grading and smoothing serve the purpose of draining excessive ground water and runoff from bottomland fields where crops have been damaged due to wet conditions. Field ditches are also used to provide drainage on flat, wet upland fields. On bottomland fields which have properly designed drainage systems, small structures are used to control the flow of water from these fields. They are also used for the distribution of water to surface-irrigated fields.

WATERSHEDS

In 1954 the Watershed Protection and Flood Prevention Act (Public Law 83–566) was enacted. It provided for a new project-type approach to soil and water resource development, use, and conservation.

Under the act, each project is a local undertaking with Federal help, not a Federal project with local help. This act places full responsibility for starting small watershed projects on local people who act through their own organizations. The Secretary of Agriculture is authorized to give technical, cost-sharing, and credit aid to local organizations in planning and carrying out works of improvement for (1) flood prevention, (2) agricultural water management, including irrigation and drainage (3) nonagricultural water management, including municipal or industrial water supply and fish and wildlife development, and (4) recreation. The Soil Conservation Service has the primary responsibility for carrying out the Watershed Protection and Flood Prevention Act.

The upstream watershed program supplements both the present soil and water conservation program and the programs for development and flood protection of major river valleys. The act bridges the gap between these two types of programs and greatly enhances the ultimate benefits of both. Federal help is made available only to assist the local organizations plan and install needed flood prevention, water management, and recreation measures that cannot feasibly be installed under other current Federal conservation programs.

It is estimated that there are over 300 potential small watershed projects in Missouri. Figure 79 [Status of Public Law 566 Watershed Projects in Missouri and Watershed Data Tabulation] summarizes the status of watershed projects in Missouri as of January 1, 1966.

Watershed data

[Letters and numbers on fig. 79]

Name	*Acres*
A. Lost Creek	10,304
B. East Branch of South Fork Blackwater	12,613
1. 102 River Tributaries	19,301
2. Logan Creek	148,880
3. East Fork of Big Creek	52,084
4. Big Creek (Daviess)	10,880
5. Panther Creek	22,035
6. Platte River Tributaries	12,800
7. Hoover-Frankum	18,307
8. Sinking Creek	60,110
9. Tabo Creek	84,895
10. South Fork of Blackwater	65,579
11. Callahan Creek	22,170
12. Loutre Township	31,794
13. Bear Creek	33,395
14. Wellington-Napoleon	19,130
15. Big Creek Tributaries	134,000
16. Grindstone-Lost-Muddy Creek	209,100
17. West Fork of Grand	183,370
18. Fourche Creek	68,480
19. Lost Creek	38,919
20. North Wyaconda	52,185
21. Willow Creek	17,802
22. Indian Creek	24,500
23. Durgens Creek	26,160
24. Brownwood-Jenkins Basin	12,800
25. St. John's Bayou Basin	249,447
26. Ten Mile Pond	64,783
27. Clarence Cannon Memorial	28,770
28. Middle Fabius	123,680
29. Little Sni-A-Bar	22,860
30. Black Creek	4,720
31. Little Black	239,117
32. Buck-Doe Run	26,816
33. Hickory Creek	27,640
34. Little Dry Wood Creek	111,344
35. Cane Creek	218,080
36. Kinney-Rollins Creek	25,010
37, Spring River	203,310
38. Williams Creek	16,000

RIVER BASINS

A program of comprehensive river basin planning studies is progressing in Missouri. The plans developed from these studies will provide (1) economic projections of economic development (2) translation of such projections into demands for water and related land resource uses, (3) hydrologic projections of water availability, both as to quantity and quality, and (4) projections of related land resource availability. These studies outline the characteristics of projected water and related land resource problems and the general approaches that appear appropriate for their solution.

Planning efforts are coordinated closely between Federal, State, and local agencies and organizations that are concerned with the development, utilization, and management of water and land resources. Full consideration is given to the desires and objectives of local interests.

The major river basins in Missouri and their boundaries are shown in figure 79.

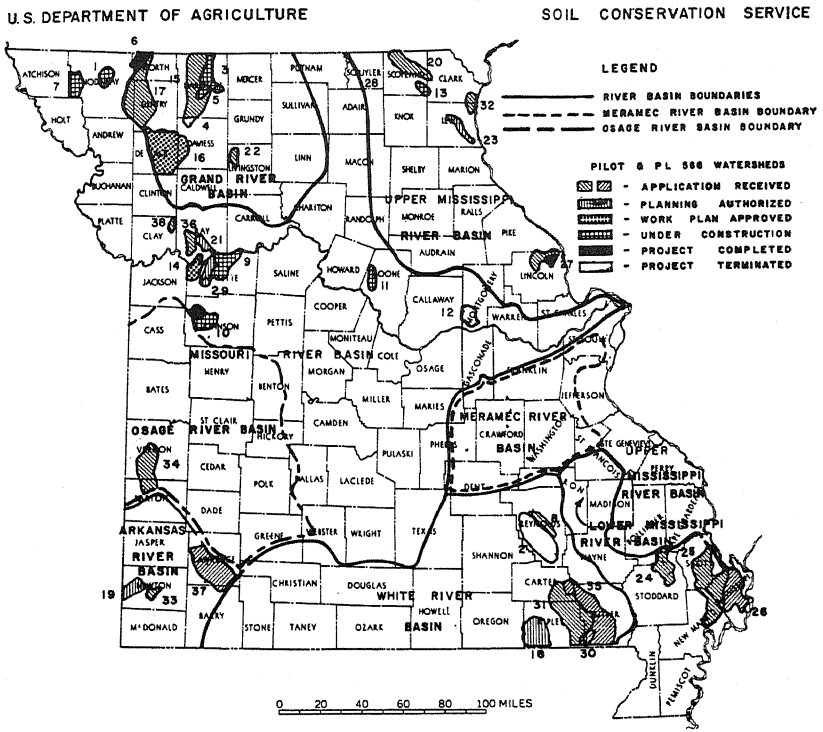


FIGURE 79.—Status of Public Law 566 watershed projects in Missouri, January 1, 1966.

RESOURCE CONSERVATION AND DEVELOPMENT

The Food and Agriculture Act of 1962, section 102, Public Law 87–702, authorized the Secretary of Agriculture to assist in developing and carrying out plans for a program for the orderly development, improvement, conservation, and utilization of natural resources through locally sponsored resource conservation and development projects. These projects are initiated through local leadership such as Soil and Water Conservation Districts and other entities of State or local government. They will provide urgently needed acceleration of the planning and carrying out, project by project, of the type of conservation activities necessary to achieve the development, improvement, conservation, and wise use of the natural resources and thereby increase the economic opportunities to the people of the area.

To expand this program throughout the country, 10 pilot projects were authorized nationwide so that the conservation objectives of the U.S. Department of Agriculture, the locally controlled Soil and Water Conservation Districts, and other conservation agencies and groups can be accelerated to meet growing local, State, and National needs.

Accomplishments in the pilot projects resulted in approval of 10 additional projects, one of which is the "Top of the Ozarks Rivers"

resource conservation and development project involving five southeast Missouri counties, Texas, Dent, Shannon, Howell, and Oregon, covering an area of 2,970,880 acres.

Local people are in the process of planning this project. Assistance in project planning is being provided by the Soil Conservation Service, Forest Service, Economic Research Service of the Department of Agriculture, and the University of Missouri Extension Service. This project will have an "open end" work plan in that it can be adjusted and expanded.

Local sponsors have listed four problems that are of prime concern to the area:

1. Inadequate water supplies for municipal, industrial, recreational, and private uses.
2. Pollution of streams from sewage and industrial disposal.
3. Flooding of valuable agricultural lands and recreational facilities.
4. Scouring and sediment deposition on many of the clear streams.

The installation of the measures included in the coordinated work plan will accelerate the development, use, and conservation of the natural resources of this five-county area.

A second R.C. & D. project named Spring River is pending. This consists of seven southwest Missouri counties with land draining into Spring River and its tributaries plus Cedar and McDonald Counties. The problems and needs of Cedar and McDonald are so similar to those found in the Spring River Counties of Barry, Barton, Dade, Jasper, Lawrence, Newton, and Stone that all nine counties, covering 3,376,000 acres, are being included in this project.

WATERPOWER

(By L. F. Pease, U.S. Geological Survey, Washington, D.C.)

Waterpower is a renewable resource derived from the flow of water. The power potential of a site depends upon the weight of water, usually measured by volume, and the head, the usable vertical distance between intake and discharge points of the plant installed to utilize it. Flow in an uncontrolled stream varies tremendously with the season and from year to year, thus the greatest sustained power can be obtained if a sufficient storage capacity (reservoir) is provided to equalize the flow to the generators and enable the flow to be utilized at a constant rate.

As hydroelectric energy is commonly used to supplement that generated in thermal plants (coal, oil, gas, and, recently, nuclear), installations ordinarily store water in time of low demand and release it to provide power at times of peak demand. Hence the installed capacity ratings of hydroelectric generators usually exceed the gross theoretical power of their sites.

Generator capacity is measured in kilowatts (1,000 watts, equal to 1.34 horsepower) or more commonly in megawatts (MW). Energy actually produced is measured in kilowatt hours (KWH) or megawatt hours (MWH); the relation of energy produced to generating capacity is a measure of total utilization of the installation during the period

under consideration. Energy generated from hydroelectric plants in 1965 (802,522 MW) was 23.3 percent of the capacity of the State's hydroelectric generators.

Installed capacities of thermal and hydroelectric plants in the United States and Missouri are shown below:

Installed capacity, 1965

Type of plant	United States		Missouri		Missouri as percent of United States
	Megawatt	Percent	Megawatt	Percent	
Thermal	191,884.9	81.4	3,379.2	89.6	1.8
Hydro	43,792.2	18.6	392.6	10.4	.9
Total	235,677.1	100.0	3,771.8	100.0	1.6

Generation of electric power in 1965 is summarized as follows:

Generation of electric power, 1965

Type of plant	United States		Missouri		Missouri as percent of United States
	Megawatt-hours	Percent	Megawatt-hours	Percent	
Thermal	861,341,822	81.7	15,969,011	95.2	1.9
Hydro	193,448,125	18.3	802,522	4.8	.4
Total	1,054,789,947	100.0	16,771,533	100.0	1.6

The gross theoretical power of a powersite is the total potential output at 100-percent system efficiency calculated as though the average flow (Q mean) is available continuously for generation of power. It is equal to, in kilowatts (KW), 0.085 Qh, where Q is measured in cubic feet per second and h is the head in feet. The theoretical power is also calculated for flows of Q95 and Q50, those available 95 and 50 percent of the time, respectively.

The gross theoretical waterpower of Missouri, at its developed and potential sites, is 4,317 megawatts. This is 1.6 percent of the national total and ranks Missouri 16th in order of the States. Five hydroelectric powersites have been developed, which have a total installed generating capacity of 392.6 megawatts and place Missouri 23d among the States.

DISTRIBUTION

Waterpower depends on flow, head, and suitable sites for plants and especially on impoundments to stabilize flow and provide feasible installations. The U.S. Geological Survey, in its inventories of waterpower potential, lists all developed or undeveloped sites with installed capacity or gross theoretical power potential of 1 megawatt or greater. The World Power Conference (1962) defines an undeveloped site as one having "such gradient, flow, and physical condition that its development for the production of power may reasonably be assumed to be eventually practicable."

TABLE 43.—*Developed and undeveloped waterpower in Missouri, Dec. 31, 1965*

Principal drainage area and subdivisions	Drainage basin index number	Developed waterpower sites					Undeveloped waterpower sites				Total gross theoretical power (MW), developed and undeveloped sites, based on mean flow
		Number of sites	Gross theoretical power (MW), gross head (100-percent efficiency) flows at—			Installed capacity (MW) [1]	Number of sites	Gross theoretical power (MW), gross head (100-percent efficiency) flows at—			
			Q95 [2]	Q50 [2]	Q mean			Q95 [2]	Q50 [2]	Q mean	
Mississippi River Basin:											
Iowa River to Des Moines River	5-H						1	1.6	7.8	19.6	19.6
Des Moines River to Illinois River	5-J						2	0	1.5	14.1	14.1
Illinois River to Ohio River	5-M						2	309.8	904.4	1,002.4	1,002.4
Missouri River to Red River	7-G						13	10.6	39.0	102.7	102.7
Missouri River Basin:											
Platte River, Nebr. to Kansas River	6-P						6	194.9	577.6	644.3	644.3
Kansas River to mouth (excluding Missouri River)	6-S	3	4.5	33.7	85.3	176.6	16	13.4	78.0	201.3	286.6
Missouri River	6-S						(3)	516.1	1,451.6	1,973.6	1,973.6
White River Basin	7-H	2	13.9	57.7	98.0	216.0	18	34.7	96.5	175.7	273.7
Total		5	18.4	91.4	183.3	392.6	3 58	1,081.1	3,156.4	4,133.7	4,317.0

[1] MW equals megawatts equals 1,000 kilowatts.
[2] Q(*x*) equals flow in stream *x* percent of the time.
[3] Block of power in Missouri River from Kansas City to mouth—unspecified number of sites.

Missouri's waterpower potential is available principally from the major rivers, the Missouri and Mississippi, but the only developed waterpower sites are on tributaries. Figure 80 shows the location of all developed sites regardless of size and the undeveloped sites having a minimum of 5 megawatts potential at mean flow except that possible sites along the Missouri River between Kansas City and the mouth are not specified. The gross theoretical power by drainage basin subdivisions is shown on table 43. The installed power capacity in megawatts at developed sites is the total of the manufacturer's nameplate ratings of all generating equipment.

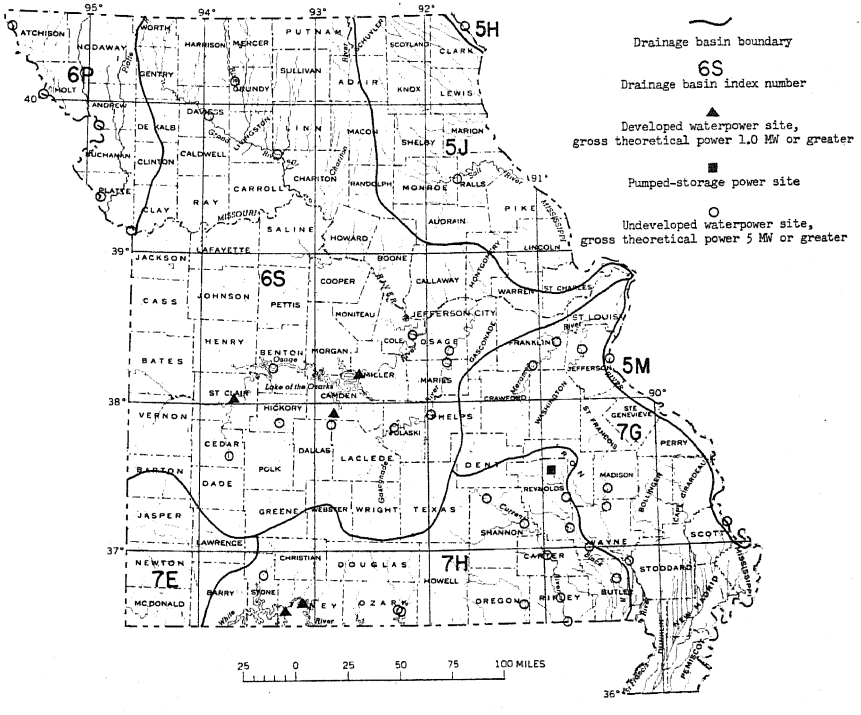


FIGURE 80.—Waterpower sites in Missouri.

Details of the five sites that have been developed are shown in table 44.

TABLE 44.—*Developed waterpower sites in Missouri*

Name	Stream	Installed capacity (megawatts)	Percent of total	Average annual generation (megawatt-hours)	Percent of total
Osceola	Osage River	1.6	0.4	7,000	0.7
Niangua	Niangua River	3.0	.8	13,000	1.3
Ozark Beach	White River	16.0	4.1	60,000	5.9
Bagnell	Osage River	172.0	43.4	440,000	43.4
Table Rock	White River	200.0	51.3	493,000	48.7
Total		392.6	100.0	1,013,000	100.0

Power available at the 58 undeveloped waterpower sites is summarized in table 45.

TABLE 45.—*Undeveloped waterpower sites in Missouri*

Size	Number of sites	Gross theoretical power (megawatts) [1]	Percent of total
Under 5 megawatts (not shown on fig. 80)	18	59.50	.4
5 to 10	17	127.57	3.1
10 to 100	16	329.91	8.0
100 and over	[2] +7	[2] 3,616.56	[2] 87.5
Total	[2] +58	4,133.54	100.0

[1] Based on mean flow.
[2] Includes Missouri from Kansas City to mouth (number and size of sites unspecified but assumed in excess of 100 megawatts each).

Missouri powersites are located in three geographic regions: the Mississippi River and those tributaries above St. Louis; the Missouri River Basin north of the river; and streams flowing out of the Ozark Plateau.

The Mississippi River forms 500 miles of the eastern border of the State. Above St. Louis the Mississippi River is completely controlled for navigation by dams and seven locks, none having facilities for power development (see fig. 81). Power development at these sites is not currently feasible.

Three undeveloped sites are situated within the Mississippi River Basin above St. Louis—one each on the Des Moines River, the Salt River, and Bear Creek—with a combined theoretical power of 34 megawatts. The Clarence Cannon Dam and Reservoir Project on the Salt River, currently under construction by the U.S. Army Corps of Engineers, will produce 12 megawatts of power.

Two powersites on the Mississippi River below St. Louis have a combined gross theoretical power of 1,002 megawatts. The Riverside site, 25 miles downstream from St. Louis, has a power potential of 489 megawatts. The Commerce site, 20 miles up the Mississippi Rver from the mouth of the Ohio River, has a potential of 513 megawatts. Both of these sites are on the boundary with Illinois but in this section are treated as though they were entirely within Missouri.

The Missouri River falls 345 feet as it flows eastward for 375 miles across the State from Kansas City to St. Louis. In this stretch of the river no waterpower sites have been specifically identified; but installation of generators, if feasible, at navigation dams and locks similar to those along the Mississippi River above St. Louis could provide 1,974 megawatts of continuous electric power, which would constitute 46 percent of the total waterpower potential of the State.

The Missouri River forms the northern 200 miles of the western boundary of the State. The river has a fall of 240 feet in this stretch and contains five undeveloped sites with a combined power potential of 641 megawattts. Although these sites are located on common boundaries with Nebraska or Kansas, they are treated here as though they were entirely in Missouri.

The Missouri River Basin, exclusive of the main stem, includes the Platte River Basin and the Grand River Basin, which flow south into the Missouri River. Four sites on these rivers have a combined potential of 32 megawatts.

All the developed powersites (table 44) and 44 of the 58 potential sites in the State are located in or around the periphery of the Ozark Plateau, where streams drop rapidly as they descend its slopes. Three reservoirs have been built at the base of the plateau for flood and navigation purposes, but they do not have power facilities. The undeveloped sites of this area are as follows:

Stream basin	Number of sites	Gross theoretical power, megawatts
Missouri River drainage:		
Osage River	9	113.4
Gasconade River	4	59.6
Mississippi River drainage:		
Meramec River	8	72.3
St. Francis River	5	30.4
White River drainage:		
Black River	5	35.1
Current River	8	103.0
Upper White River	5	37.5
Ozark Plateau	44	451.4

Future power development at three of the undeveloped sites would require the addition of electric generation facilities at existing dams. The Pomme de Terre project on the Pomme de Terre River is a flood control reservoir constructed in 1963 without power generating facilities. The site has a theoretical power of 6 megawatts. The Clearwater project on the Black River was built for flood control and navigation in 1948. It has an undeveloped potential of 9 megawatts of power. The Wappapello project on the St. Francis River, completed in 1941 for flood control, has a potential of 8 megawatts.

The gross theoretical hydroelectric energy at the undeveloped sites is estimated at more than 36 million megawatt hours annually; however, the amount eventually developed will undoubtedy be considerably less because of unfavorable geologic conditions at some damsites, competitive uses of storage areas, and prior water rights for agricultural, industrial, and municipal purposes.

A pumped-storage project in Missouri is included by some in the category of waterpower, but it is not so considered here. It is the Taum Sauk installation in Reynolds County, shown by a special symbol in figure 80. A brief description will explain the reason for excluding it. Excess, off-peak power generated by steam in St. Louis, 90 miles away, is transmitted to reversible pump-turbines at a site on the East Fork of the Black River. The turbines lift water 800 feet from a lower reservoir to an upper one on top of Proffitt Mountain, whence it is released back through the turbines at periods of peak load. Generating capacity is 350 megawatts, but more energy is consumed in pumping than is recovered, and the economics of the installation depend on the relative cost and value of off-peak and peak-load power.

STATE LAWS, POLICY, AND PROGRAMS PERTAINING TO WATER AND RELATED LAND RESOURCES

(By Clifford Summers, Executive Secretary, Missouri Water Resources Board, Jefferson City, Mo.)

PROPERTY RIGHTS IN WATER

Missouri law regarding property rights in water is neither extensive nor well defined. Except for the assignment of regulatory and development responsibilities, statutory law on the subject of water is practically nonexistent, and for the most part the Common Law of England and judicial decisions of Missouri courts constitute the only authority on this facet of the water problems.

A review of Missouri Court Decisions indicates that the Court interprets percolating water to be a part of the soil and that adjoining property owners have no absolute or natural right therein, and can acquire no perspective right thereto. However, the courts have ruled that one's right is not absolute and is limited to the restriction that the owner of the land must use the water beneficially or for the betterment of the land and cannot divert the water merely for the purpose of injuring adjoining proprietors.

In regard to surface waters, Missouri had adopted the common enemy doctrine which provides for no natural easement or servitude in favor of the higher land, but permits one to do as he pleases with his property regardless of the effect on surface water. Later decisions have ruled that one may not obstruct a natural watercourse without liability for ensuing damages to others, but that one may treat surface waters as a common enemy and obstruct their flow without liability for ensuing damages so long as it is done in a reasonable manner and not recklessly or negligently.

The riparian doctrine is applicable in the State of Missouri, even though the courts have not specifically interpreted the application of this doctrine. The term "natural flow" has been used in many court decisions, but these determinations were not necessary to the decision. The natural flow theory of the riparian doctrine as viewed in Missouri is one under which a riparian owner can take all the water he needs for livestock and household purposes, but for other purposes, such as irrigation, he cannot take water if the taking would sensibly diminish the flow.

The Supreme Court of Missouri has also ruled that all rivers and streams in the State useful to the public are public waters. The court has further ruled that public rights to these public waters include boating, fishing, wading, bathing, and also reasonable use of the beds and banks thereof as incidental and necessary for such purpose without unreasonably damaging the property of the riparian proprietor.

The general assembly has enacted legislation concerning water control and administration in connection with such subjects as drainage, flood protection, establishment of conservancy districts, pollution control, supervision of public water supplies, preservation of game and fish, disposal of accreted lands, disposal of swamp lands, regulatory health measures, authorities delegated to incorporated cities, towns, villages, and select statutory offenses against the state. Under the police powers of the State, the legislature may pass laws to deal with

the regulation and preservation of streams, water bodies and adjacent lands.

POLICY

The Water Resources Board, assigned the responsibility for preparing a comprehensive plan for the utilization and management of the water resources, has adopted as policy the general provisions of Senate Document No. 97. These provisions include equal consideration of water needs and uses for domestic, municipal, agricultural, and industrial water supplies; navigation facilities, hydroelectric power where its provisions can contribute advantageously to a needed increase in supply; flood control and prevention measures to protect people, property, and productive lands; land stabilization measures where feasible; drainage measures where best use of land would be justifiably obtained, watershed protection and management measures; outdoor recreation and fish and wildlife opportunities; and the preservation and protection of nonreplaceable resources to insure availability for their best use when needed.

The well-being of the people is the overriding determinant in considering the best use of water and related land resource.

It would be misleading to leave the impression that complete unanimity exists among the several water use interests within the State. Divergent views and cross purposes appear in the considerations of each project or proposal for development. The final decision on interpretation and application of policy as it affects the use of water and related land resources is through the administrative authority of the chief executive.

PROGRAMS

In general, cooperation with the assistance to other related water programs prevails within each agency. Several interagency committees and councils have been formed, both through formal and informal arrangements. The agencies of State government involved in water programs and the purpose of each is as follows:

Water Resources Board

A relatively new agency, the water resources board is charged with coordinating the collection of water data and with the preparation of a long-range comprehensive plan for development of water resources. The board represents the interests of the State in interstate and Federal water projects, as well as promotes local interest and participation in water conservation measures.

Division of Geological Survey and Water Resources—

At the time of its organization in 1853 this division was charged with the responsibility of surveying the water resources of the State. Information gained from ground water hydrologic research, readings from recorded water levels throughout the State, and data provided by 25,000 statewide well logs enable the Survey to advise municipalities, industries, homeowners, and other agencies regarding ground water supplies.

Streamflow data covering over 4,500 station-years and water quality data are available through continuing cooperative programs established with the U.S. Geological Survey in 1921. Other cooperative

programs with the U.S. Geological Survey involve special ground water studies and investigations of the springs of Missouri.

Water Pollution Board—

Controlling the discharge of waste to the waters of the State in a manner that will prevent the creation of nuisance, protect the public health, and permit subsequent reasonable uses of water in streams and lakes is a function of the Water Pollution Board. Protection of ground water from waste discharges is also considered a responsibility of this board. Control is exercised through a system of permit issuance and supervision of construction and operation of sewage and industrial waste works.

Division of Health

Public water supplies, defined as those water supply systems furnishing water to more than a single service connection whether or not for gain, are under the supervision of the Division of Health. Standards of quality, operation, and construction have been established for such supplies. Control is exercised through a procedure of permit of approval issuance, plan review, and supervision of construction and operation of public water supplies. Advisory services are available for owners of private and industrial water supplies.

Conservation Commission

Maintaining suitable water for fish and wildlife habitat and providing water areas for public recreational use associated with fishing and hunting are the primary responsibilities of the Conservation Commission. Maintenance of water quality is achieved through aid in water pollution control and the application of improved land use practices including forest management, fire control, and through the development of cover to protect land from erosion.

State Park Board

The function of this department is to acquire, protect, preserve, develop and interpret for the inspiration, use and enjoyment of the people of the State a well-balanced system of areas of outstanding scenic, recreational, and historic importance.

Division of Commerce and Industrial Development

Water for industry and expansion of Missouri as a vacation land through promotion of recreational areas is the goal of this agency in regard to water resources. Industrial needs include not only water of good quality necessary for complex processes but also sufficient water to dilute treated liquid waste from industry. Adequate harbor facilities, channel depth, and clearances are of extreme interest to industry shipping by water. This agency cooperates closely with the U.S. Corps of Engineers and river communities on these matters.

Department of Agriculture

Agricultural interests are concerned with control of runoff, water for livestock, and with water for irrigation. Agricultural needs for water, particularly for irrigation, are expected to expand in the future.

Highway Department

Highways, roads, bridges, and other related structures must be designed with the control of water in mind. In cooperation with the

U.S. Geological Survey, the Highway Department conducts studies of runoff of drainage areas of all sizes and designs and maintains highway structures to control or carry the storm water.

University of Missouri

The functions of the University of Missouri include research on problems concerning soil and water conservation and dissemination of the information obtained. These are carried out by the Agricultural Experiment Station, the resident instruction program on the campus, and the teaching program conducted throughout the State by the Extension Division.

Boat Commission

The boat commission administers the watercraft laws of the State and promotes boating safety. It also maintains and operates watercraft facilities.

Council for Outdoor Recreation

The Council, composed of the exectuive heads of the 11 State agencies responsible for recreation planning, development, or administration, is charged with distributing land and water conservation fund money to agencies and political subdivisions. The Council is also responsible for maintaining a recreation plan and determining the outdoor recreation needs of the State.

Public Service Commission

The commission has general supervision over privately owned utilities that furnish water to the general public. The powers and duties of the Commission extend to the supply, service and facilities, rates, and all relationships between the utility and the consumers. The water is furnished for domestic, commercial, and industrial uses, conditioned as to quality and in adequate amounts to meet present requirements, keeping in mind the expected future demands as the needs of each community grow.

State Soil and Water Districts Commission

The State Soil and Water Districts Commission is composed of five members. Three are farmer members, who are landowners and are appointed by the Governor of the State of Missouri; two ex-officio members include the Directors of the Experiment Station and the Agricultural Extension Service, University of Missouri. The Commission determines policies and procedures in the organization of Soil and Water Conservation Districts in Missouri.

State Department of Education

Local, State, and Federal agencies are cooperatively responsible for the provisions of educational opportunities for all who can benefit from them. The public school is a particular function of the State. The responsibility for its direction is assigned by law to the State department of education—a service agency of the State. Because the solutions to the problems pertaining to soil and water conservation depend in a degree upon the education of the public, the State department of education is responsible for disseminating such information through the public schools of the State.

POLLUTION ABATEMENT

(By Jack K. Smith, Executive Secretary, Missouri Water Pollution Board, Jefferson City, Mo.)

In 1957, the legislature enacted a comprehensive water pollution law. Previous to this the legislature had enacted laws for the protection of fish and wildlife. In 1963 the 72d General Assembly enacted the marine toilet law. In 1965 the 73d General Assembly enacted a law which prohibits the disposal of trash and refuse in or near waters of the State. Since 1956 the Congress, through the Federal Water Pollution Control Act, has made grants to cities for construction of sewage treatment plants. As of December 31, 1965, over 175 Missouri cities have received Federal grants. This incentive program has been successful. The 89th Congress amended the Federal water pollution law. The act is now called "The Water Quality Act of 1965." Under this law the States are required to establish by June 30, 1967, water quality criteria on all interstate streams. The act also provides that States develop means for monitoring these streams and seek corrections where indicated.

All major cities in Missouri have sewage treatment plants in operation, under construction, or bonds have been voted for waste treatment facilities. During the period January 1, 1958, through December 31, 1965, Missouri municipalities voted more than a quarter of a billion dollars for sewerage improvement. On January 1, 1966, only 10 cities, total population 21,870, had sanitary sewers which discharge raw sewage and had not arranged the necessary financing for sewage treatment. There were 370 cities, total population 3,144,000, that had sanitary sewer systems. The percent of people living in cities with sanitary sewers that had treatment plants in operation, under construction, or financed was 99.3.

The Missouri Water Pollution Board has established the following objectives for the Missouri and Mississippi Rivers.

1. All raw municipal waste discharges to the Missouri River will be treated by January 1, 1967.
2. All raw municipal waste discharges to the Mississippi River will be treated by January 1, 1968.

All major sources of industrial pollution with direct discharge to the Missouri and Mississippi Rivers are satisfactory. By January 1, 1967, Missouri River water quality below Kansas City will be greatly improved, and the quality of water in the Mississippi River should be improved below St. Louis by January 1, 1968.

A warning system for notification of spills and accidents has been organized and placed in operation. To protect surface waters, groundwater regulations have been adopted by the Missouri Water Pollution Board.

A program for correction of pollution from acid mine drainage has been developed. Over 200 miles of streams in Missouri are affected by acid mine drainage. The first phase of correcting an acid mine drainage in Cedar Creek (Boone-Callaway Counties) has been completed. When phase 2 is completed, 35 miles of the stream will be improved. Remedial work in other areas of the State affected by acid mine drainage has resulted in improved water quality in 9 miles of stream. All current coal-mining operations are conducted in a

manner to prevent pollution. Gravel washers are required to provide settling ponds.

A comprehensive water quality survey program is carried out by the Water Pollution Board. Field work has been completed on the Meramec, Big, Bourbeuse, Spring, Elk, and James Rivers, and Shoal and Turkey Creeks, and the Lake of the Ozarks. The Water Pollution Board, in cooperation with the Corps of Engineers, the Federal Water Pollution Control Administration, the Missouri Department of Conservation, U.S. Geological Survey, Union Electric Co., Missouri Boat Commission, and the Missouri Division of Health, completed a 1-year water quality study of the Lake of the Ozarks. The study included four separate surveys, one made during each season of the year.

As a result of the study, these general statements of water quality may be made. No visible pollution was observed during the surveys. The chemical and bacteriological analyses show very little, if any, pollution in the main channel of the lake. Local pollution is present in coves used for swimming, or storage of cabin cruisers, and where there are large concentrations of people either in private homes or resorts. The main channel of the lake revealed coliform and fecal streptococcus counts of less than 10 organisms per 100 milliliters with one exception. During the last survey conducted July 30 through August 3, 1965, the coliform count just above Warsaw was 240 per 100 milliliters. This count was probably due to the runoff from heavy rains.

Seventeen water quality monitoring stations have been established in Missouri. Continuous monitoring of specific conductance and dissolved oxygen has been started on the Missouri River at St. Joseph. Monthly samples are collected at eight locations on the Mississippi River. Detailed information on water quality is now available on streams where studies have been completed.

Special studies on pollution problems are carried out for the Water Pollution Board at the University of Missouri. The annual cost of these studies is approximately $50,000.

Enforcement of the State and Federal water pollution laws has been given due consideration by the Missouri Water Pollution Board. When education and persuasion fail, enforcement procedures as outlined in State and Federal laws have been taken. The Board has participated in Federal action at Sioux City, Iowa, Omaha, Nebr., St. Joseph, Mo., Kansas City, Mo., and St. Louis, Mo. Under the provisions of the State law, the Board has taken three legal actions; two have resulted in completion of approved abatement works and the third is still in litigation.

Water in Missouri streams is in general of good quality, but there are areas of obvious pollution. Water quality objectives have been developed by the Water Pollution Board for the Missouri, Mississippi, and Blue Rivers. Procedures for establishing water quality criteria have been approved by the Water Pollution Board, and plans are underway for the adoption of water quality criteria for all interstate streams by June 30, 1967.

While much has been accomplished by the Water Pollution Board, with the help of the Missouri Department of Conservation, the Missouri Division of Health, the State Geologist, the University of

Missouri, the Department of Agriculture, and the Attorney General, much remains to be done. Very briefly these needs may be summarized as follows:

1. More emphasis must be placed on inspection of existing waste treatment plants. There are approximately 1,250 plants and approximately 150 new plants are constructed each year. For the treatment plants now in use 16 full-time inspectors would be required to make a minimum of two inspections per year.

2. More emphasis must be placed on water quality; improved operation of waste treatment plants and additional treatment, in some instances, will be required. Greater emphasis must be placed upon the proper use of agricultural chemicals and improving agricultural practices, including the proper disposal of animal waste.

3. The stream survey program to determine existing conditions and to measure trends in water quality should be expanded. Unless the stream program is increased, an additional 10 or 12 years will be required to complete the survey of all the drainage basins in the State.

4. There is a need to modify the Missouri water pollution law for emergency pollution problems. The spills from broken pipe lines, tank cars, et cetera, are increasing. During 1965 an average of one major accident per month occurred. The possibility of accidents is better appreciated when following facts are considered:

Acres of water surface	639,990
Total stream miles	19,086
Number of waste treatment plants as of June 30, 1965 (150 new plants each year)	1,236
Stream crossings of petroleum lines	75
State Highway mileage	32,000
Local roads mileage	64,000
City street mileage	10,000
Railroad mileage	7,000
Reported pollution-caused fish kills in 1964 (137,600 fish killed)	35

5. The disposal of solid waste from cities and industries must be improved. The anti-littering law, which became effective on October 13, 1965, needs the support of all citizens.

SELECTED REFERENCES

Anderson, Keith E., 1963, Water well handbook: Rolla, Mo., Missouri Water Well Drillers Assoc., 2 ed., 281 p.

Beckman, H. C., 1927, Water resources of Missouri 1857–1926; Missouri Bur. Mines and Geology, ser. 2, v. 20, 424 p.

——— 1940, Surface waters of Missouri (streamflow records) 1927–1939: Missouri Div Geol. Survey and Water Resources ser. 2, v. 26, 900 p.

Beckman, H. C., and Hinchey, N. S., 1944, The large springs of Missouri: Missouri Div. Geol. Survey and Water Resources, ser. 2, v. 29, 141 p.

Bolon, H. C., 1952, Surface waters of Missouri (streamflow records) 1940–1949: Missouri Div. Geol. Survey and Water Resources, ser. 2, v. 34, 934 p.

Boswell, E. H., and others, 1965, Cretaceous aquifers in the Mississippi Embayment with discussions of quality of the water by H. G. Jeffery: U.S. Geol Survey Prof. Paper 448–C, 37 p.

Bretz, J Harlen, 1956, Caves of Missouri: Missouri Div. Geol. Survey and Water Resources, ser. 2, v. 39, 491 p.

Bridge, Josiah, 1923, Ebb and flow springs in the Ozarks: Missouri School Mines and Metallurgy Bull. Tech., ser. 2, v. 7, no. 1.

——— 1930, Geology of the Eminence and Cardareva quadrangles: Missouri Bur. Mines and Geology, ser. 2, v. 24, 228 p.

Fishel, V. C., and others, 1953, Water resources of the Kansas City area, Missouri and Kansas: U.S. Geol. Survey Cir. 273, 52 p.

Fuller, D. L., and others, 1956–1960, Water possibilities in the glacial drift of 18 counties in northern Missouri: Missouri Div. Geol Survey and Water Resources, Water Resources report series, no. 1–18, as follows:

1. 1956, Grundy County, 7 p.
2. 1956, Mercer County, 11 p.
3. 1956, Harrison County, 14 p.
4. 1956, Putnam County, 8 p.
5. 1956, Worth County, 6 p.
6. 1956, Livingston County, 14 p.
7. 1956 Gentry County, 10 p.
8. 1957, De Kalb County, 12 p.
9. 1957, Daviess County, 13 p.
10. 1957, Sullivan County, 7 p.
11. 1957, Linn County, 10 p.
12. 1957, Chariton County, 14 p.
13. 1957, Carroll County, 20 p.
14. 1957, Buchanan County, 10 p.
15. 1957, Andrew County, 10 p.
16. 1959, Nodaway County, 24 p.
17. 1960, Holt County, 21 p.
18. 1960, Atchison County, 20 p.

Gleason, C. D., 1935, Underground waters in St. Louis County and City of St. Louis, Mo.: Missouri Div. Geol. Survey and Water Resources, Bienn. Rept. of State Geologist 1933–34, app. 5, 24 p.

Grohskopf, J. G., 1945–46, Ground water supplies in Missouri: Jour. Missouri Water and Sewage Conf., v. 16 no. 4, p. 54–58 October 1945; pt. 2, v. 17, no. 2 p. 46–57 April 1946.

——— 1955, Subsurface geology of the Mississippi Embayment of Southeast Missouri: Missouri Div. Geol. Survey and Water Resources, ser. 2, v. 37, 133 p.

Gurnee, Russell, and others, 1961, The Barton Hill project, a study of the hydrology of limestone terrane, Schoharie, New York: Natl. Speleolog. Soc. Bull. v. 23, pt. 1, 30 p.

Jordan, P. R., 1965, Fluvial sediment of the Mississippi River at St. Louis, Missouri: U.S. Geol. Survey Water-Supply Paper 1802, 89 p.

Knight, Robert D., 1954, The Gunter Member of the Gasconade Formation (Lower Ordovician) in southern Missouri *in* Guide book of Seventeenth Regional Field

Conference, The Kansas Geol. Society, southeastern and south-central Missouri: Missouri Div. Geol. Survey and Water Resources R. I. no. 17, p 57–59.
Krinitzsky, E. L. and Wire, J. C., 1964, Groundwater in alluvium of the lower Mississippi valley (upper and central areas): U.S. Army Engineer Waterways Experiment Station, Corps of Engineers, Tech. rept. 3–658, 2 vols., 100 p.
MacKichan, K. A., and Kammerer, J. C., 1961, Estimated use of water in the United States, 1960: U.S. Geol. Survey Circ. 456.
McGuiness, C. L., 1963, The role of ground water in the national water situation: U.S. Geol. Survey Water-Supply Paper 1800, 1122 p.
Meinzer, O. E., 1927, Large springs in the United States: U.S. Geol. Survey Water-Supply Paper 557, p. 17–27.
Missouri Division of Health, 1962, Census of public water supplies in Missouri: Missouri Div. Health, 76 p.
Missouri Speleological Survey, 1959–, Missouri Speleology (quarterly):
Peterson, M. S., 1965, Floods of June 17–18, 1964 in Jefferson, Ste. Genevieve and St. Francois Counties, Missouri: Missouri Div. Geol. Survey and Water Resources, Water Resources, Rept. 19, 20 p.
Robertson, Charles E., and others, 1963, Groundwater maps of Missouri: Missouri Div. Geol. Survey and Water Resources 23 p., 4 maps.
Schweitzer, Paul, 1892, A report on the mineral waters of Missouri: Geol. Survey of Missouri, v. 3, 262 p.
Searcy, J. K., and others, 1952, Water resources of the St. Louis area Missouri and Illinois: U.S. Geol. Survey Circ. 216, 55 p.
Searcy, J. K., 1955. Floods in Missouri, magnitude and frequency: U.S. Geol. Survey Circ. 370, 126 p.
Shepard, E. M., 1904, Water resources of Missouri: U.S. Geol. Survey Water-Supply Paper 102, p. 389–440.
——— 1905, Water resources of Missouri: U.S. Geol. Survey Water-Supply Paper 114, p. 209–219.
——— 1907, Underground waters of Missouri their geology and utilization: U.S. Geol. Survey Water-Supply Paper 195, 224 p.
Skelton, John, 1966, Low-flow characteristics of Missouri streams: Missouri Div. Geol. Survey and Water Resources, Water Resources Rept. 20, 95 p.
Smith, W. S. T., 1905, Water resources of the Joplin district, Missouri-Kansas: U.S. Geol. Survey Water-Supply Paper 145, p. 74–83.
Smith, W. S. T., and Siebenthal, C. E., 1907, Description of the Joplin district (Missouri-Kansas): U.S. Geol. Survey Geol. Atlas, Folio 148.
Speer, P. R., and others, 1966, Low-flow characteristics of streams in the Mississippi Embayment in Northern Arkansas and in Missouri with a section on quality of the water by H. G. Jefferey: U.S. Geol. Survey Prof. Paper 448–F. 25 p.
Sun, P-C. P., and others, 1963, Large springs of east Tennessee: U.S. Geol. Survey Water-Supply Paper 1755, 53 p.
Taylor, C., T., 1964, Chemical quality of Missouri surface water: Missouri Dept. Public Health and Welfare Water Pollution Board, 28 p.
U.S. Corps of Engineers, 1957, Suspended sediment in the Missouri River, daily record for water years 1955–59: U.S. Corps of Engineers Omaha Div., 118 p.
U.S. Geological Survey, 1955, Compilation of records of surface waters of the United States through September 1950; pt. 7, lower Mississippi River basin: U.S. Geol. Survey Water-Supply Paper 1311, 606 p.
——— 1958, Compilation of records of surface waters of the United States through September 1950; pt. 6–B, Missouri River basin below Sioux City, Iowa: U.S. Geol. Survey Water Supply Paper 1310, 619 p.
——— 1959, Compilation of records of surface waters of the United States through September 1950; pt. 5, Hudson Bay and upper Mississippi River basins: U.S. Geol. Survey Water-Supply Paper 1308, 708 p.
——— 1964, Compilation of records of surface waters of the United States, October 1950 to September 1960; pt. 5, Hudson Bay and upper Mississippi River basins: U.S. Geol. Survey Water-Supply Paper 1728, 576 p.
——— 1964, Compilation of records of surface waters of the United States, October 1950 to September 1960; pt. 6–B, Missouri River basin below Sioux City, Iowa: U.S. Geol. Survey Water-Supply Paper 1730, 514 p.
——— 1964, Compilation of records of surface waters of the United States, October 1950 to September 1960: pt. 7, lower Mississippi River basin: U.S. Geol. Survey Water Supply Paper 1731, 552 p.
——— 1965, Water resources investigations in Missouri 1965: U.S. Geol. Survey water folder.

U.S. Public Health Service, 1959, National water quality network annual compilation of data Oct. 1, 1958–Sept. 30, 1959: U.S. Public Health Service Pub. 663, 323 p.
——— 1961, National water quality network annual compilation of data Oct. 1, 1960–Sept. 30, 1961: U.S. Public Health Service Pub. 663, 545 p.
——— 1962a, National water quality network annual compilation of data Oct. 1, 1961–Sept. 30, 1962: U.S. Public Health Service Pub. 663, 909 p.
——— 1962b, Drinking water standards, revised 1962: U.S. Public Health Service Pub. 956, 61 p.
——— 1963, Water Pollution Surveillance System annual compilation of data Oct. 1, 1962 to Sept. 30, 1963: Upper Mississippi River Basin, v. 6, 112 p.
U.S. Weather Bureau, 1959, Climates of the States—Missouri: Climatography of the United States no. 60–23, 16 p.
Vineyard, Jerry D., 1964, Catalogue of the caves of Missouri: Rolla, Mo., Missouri Speleolog. Survey, 99 p.
Wilcox, L. V., 1948, The quality of water for irrigation use: U.S. Dept. Agriculture Tech. Bull. 952.
Wood, H. W., Jr., and Short, J. A., 1950, Water resources in Missouri, its resources, people and institutions: Columbia, Curators of the Univ. of Missouri p. 58–78.
World Power Conference, 1962, Survey of Energy Resources, 1962: Central Office of the World Power Conference, London, 39 p.

77–278 O—67——23

SUPPLEMENT

WATER RESOURCES DEVELOPMENT IN MISSOURI

BY

DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS

PREPARED BY

KANSAS CITY DISTRICT

April 1966

WATER RESOURCES DEVELOPMENT IN MISSOURI

INTRODUCTION

The Nation's water resources are subjects of increasing importance and attention. There is a growing shortage of water for municipal, industrial, and agricultural use, while substantial losses are experienced through wasteful practices and failure to conserve available supplies. As the population of the Nation expands and society becomes more complex, there is an ever increasing need for sound development and more efficient utilization of these vital resources. Missouri is no exception.

The history and the development of Missouri have been closely linked with its water resources. Early explorers discovered Missouri by following its waterways, and most early settlements were river towns. The State has suffered from disastrous floods and droughts; it has enjoyed a normal rainfall conducive to a bountiful agriculture; and it has been able to attract water-using industry and water-seeking people. Its drainage pattern is formed by a number of tributary basins which discharge directly into the Mississippi River or indirectly through the Missouri, St. Francis, White, and Arkansas Rivers. Some of these basins lie entirely within the State, while others are affected by upstream or downstream water resources developments in other States.

This section of the report is concerned primarily with water resources development in Missouri. The discussion is organized according to major drainage basins and subbasins in Missouri to facilitate the compilation and presentation of information. In view of the interrelationship between the various types of water uses, and since many projects, both public and private, serve more than one purpose, no attempt has been made to arrange the discussion by the specific purposes served. Background information is provided in a brief history of Missouri's economic and population growth, a summary of the concepts of water resources development, and a résumé of the coordinated activities of the various agencies involved in water resources development in Missouri.

ECONOMIC HISTORY OF MISSOURI

The area which is now the State of Missouri, having been under French control for about a century and under Spanish control for about 30 years, became U.S. territory as a part of the Louisiana Purchase of 1803. At that time the population of the present Missouri area was estimated to be about 10,000, concentrated largely in river towns. The physiographic and climatic features of the area, its geographic situation, particularly with respect to major rivers, and its natural resources provided attractions for settlement and, later, for

industrial development. In the early periods of development, the Mississippi and Missouri Rivers provided the roadways for exploration, westward migration, settlement, and commerce. The river lowlands, which comprise about one-fifth of the land area of Missouri, were settled first because they were fertile and readily accessible. The wooded areas along the streams provided timber for building materials and fuel. The Ozark Highlands, while less productive for agricultural purposes, attracted early French settlers who exploited the rich mineral deposits. St. Louis and St. Charles were established as fur trading centers during this period, and Ste. Genevieve, the first permanent settlement in Missouri, dating from about 1735, owes its early existence largely to salt springs and lead mines in the area.

Conditions stipulated in the Louisiana Purchase Treaty of 1803 laid the groundwork for the formation of the State and opened the territory to the American settler. Settlement of the Missouri Territory accelerated after this treaty and American frontiersmen from Virginia, Kentucky, Tennessee, and North Carolina moved into the territory. The population doubled in the first 6 years of American control, and tripled in the next decade. After much controversy over the slavery issue, the State of Missouri was admitted into the Union in 1821. The settled regions of the State at that time were primarily along the Mississippi, Missouri, Gasconade, Osage, White, Current, Chariton, Grand, and Salt Rivers.

During the 1820's and 1830's, a series of treaties ended Indian claims to the area, and immigrants from northern Europe began to settle and till the rich agricultural lands of the Glacial Plains north of the Missouri River and the Old Plains area south of the Missouri River along the Kansas border. The population continued to expand rapidly until about 1860. Many rural trading and marketing centers were established during this period, and commerce began to flourish along the rivers as the westward movement gained momentum. Early riverboat ports were located at Cape Girardeau, St. Louis, St. Charles, and Ste. Genevieve, and newer ports were established at Hermann, Jefferson City, Glasgow, Brunswick, Lexington, Independence, and St. Joseph.

St. Louis emerged as the manufacturing, marketing, and shipping giant in the State. Major industrial activities included smelting of lead and iron, manufacturing leather products, and the brewing of beer. Franklin, Mo., and later Independence, Mo., became the starting points for the trading expeditions of the Santa Fe Trail. The outfitting point for the Oregon Trail was originally at Independence, and with the founding of Westport (Kansas City) in 1833, a new point of transfer from water route to overland route was established. During the gold rush of 1849 and 1850, the great armies of people bound for California and other western areas passed through Missouri. Industry and business at Independence, Kansas City, and St. Joseph profited greatly as these were the major outfitting points for the gold seekers. Lexington, Mo., became an important freighting center for the west in the 1850's and in 1860 contracts were obtained by one of the freight companies there to start the Pony Express route from St. Joseph. By 1860, the 10 most populous cities, shown in the following table, were located along the Mississippi and Missouri Rivers.

1860 census of Missouri's 10 most populous cities

St. Louis	160,773	Carondelet	3,993
St. Joseph	8,932	St. Charles	3,239
Hannibal	6,505	Independence	3,164
Kansas City	4,418	Jefferson City	3,082
Lexington	4,122	Cape Girardeau	2,663

A substantial decline in Missouri's population during the Civil War was regained immediately afterward as many of those who had fled the State returned along with a new influx of northerners and foreign immigrants. In 1870, Missouri ranked fifth in the Nation with a population of 1,721,295.

With the introduction of the railroads and the expansion of the western frontier, the characteristics of Missouri's population growth began to change after 1870. The population grew steadily, but at a diminishing rate, as more new settlers arrived while many Missourians left the State to settle elsewhere. In addition, the urban population growth began to outpace the rural growth. In 1880, 78 percent of the population was rural and, in 1910, the percentage of rural population had dropped to 58 percent.

The population increased only slightly from 1910 until after World War I. Then, in the postwar decade, there was a moderate acceleration of the growth rate. Diminishing farm income along with rising operating costs forced many farmers to the larger cities where industry offered better opportunities. The shift away from farms temporarily halted during the depression of the 1930's but continued during and after World War II. By 1960, the urban population accounted for 61 percent of the State's total.

In the latter half of the 19th century, agriculture in Missouri progressed from a self-sufficiency type of farming to a mechanized industry, using improved new techniques and machines. Market production resulted from these new techniques, and in addition to the major crops—corn, wheat, oats, hay, and cotton in the boot-heel areas—other fields such as livestock raising, dairying, poultry production, and fruit growing were introduced into the agricultural economy. Land in farm production increased from 45 percent of the State's total land area in 1860 to 70 percent in 1890. Producing for the market subjected the farmers to many economic factors and price fluctuations. To reduce the risks, several farmer organizations were formed and State-operated education and experimental facilities were established. As early as 1892, and during subsequent decades, drainage districts were organized and extensive ditches and channel improvements were constructed in the wide alluvial valleys.

The droughts and depression of the 1930's deteriorated the farmer's position in the economy. Federal agricultural programs, including purchases of surplus farm commodities, seed and feed loans, subsistence grants, and public works projects, alleviated some of the agricultural problems. Inflationary pressures during World War II drove agricultural incomes upward in the 1940's, and prices have generally remained fairly stable since then. Today, highly mechanized farming operations in Missouri have continued the trend to larger farms but, except for the introduction of soybeans and a decline in oat production, the main crop types are about the same today as they were at the turn of the century.

Industry has played a major role in developing Missouri's economy. St. Louis emerged from the frontier days as a diversified industrial and commercial center, and other cities began to grow more rapidly after the Civil War. Kansas City, located near the confluence of the Kansas and Missouri Rivers, developed into a major center for meatpacking and flour milling. By 1900, Kansas City was reported to be the second largest railroad center in the Nation. St. Joseph also developed major meatpacking and milling industries. Following the arrival of the Atlantic and Pacific Railroad in the 1870's, Springfield became a nucleus for cotton and woolen goods, as well as supply point for settlers. Other cities such as Joplin and Carthage developed from mining and quarrying operations during the latter part of the 19th century. Diversified industrial expansion, particularly in the larger cities, continued until the depression of the 1930's and, in 1929, Missouri ranked 11th in the Nation in value of products manufactured. During the 1930's, Federal programs initiated under the Civil Works Administration, Public Works Administration, and the Work Projects Administration eased the depressed economy in Missouri's cities. In the field of water resources, the projects included drainage and flood control works and water supply impoundments. Much of Missouri's industry was diverted to the war effort during World War II with considerable expansion of facilities. These, in turn, were converted to consumer production in the postwar years and many new plants moved in, mostly to the larger cities having adequate water supplies. Presently, Missouri's diversified economy is noted for wheat marketing, milling, meatpacking and distribution, car and truck assembly, milk and cheese processing, aircraft assembly, manufacture of soap products, chemicals, steel, electronic equipment, spacecraft and rocket engines, and many other industrial fields. Mining of various minerals constitutes a major economic activity in some of the smaller communities of the State, and lumber is harvested for commercial use in the Ozark region. Except during severe drought periods, Missouri's water resources have thus far been adequate to support its agricultural and economic growth.

The prospects for continued economic expansion in Missouri appear favorable. The urban population continues to gain in percentage over rural population, but the State retains its dual agricultural and industrial nature. Mechanized farming and use of modern techniques is expected to further enhance the agricultural production. Missouri's major cities are favorably situated for trade and manufacturing activities and the location of the State with respect to navigation on the Mississippi, Missouri, and Ohio Rivers continues to be an important factor in its development. Federal flood control projects protect vast amounts of farmland and major industrial districts. The variety and abundance of Missouri's natural resources, and its river, rail, and air transportation are all conducive to future economic growth.

WATER RESOURCES DEVELOPMENT CONCEPTS

The history of water resources development in the United States has been one of adaptation to the demands for use of water by an expanding population and growing economy. Early in the Nation's

history, water resource development was principally concerned with navigation and water transportation; however, as the country grew and other needs developed, the scope of water planning and development was broadened to satisfy additional demands such as flood control hydroelectric power, irrigation, water supply, water quality control, recreation, and related uses. The guiding principle of water resource development has become that of "the greatest good for the greatest number of people." If the water and related land resources are to fulfill the needs of future generations, it is imperative that this principle be continued.

The ultimate development of these resources requires a realistic program of coordinated policy and comprehensive water resource planning which gives consideration to all of the land and water problems within river basins. In the past, many developments were designed and constructed to meet the need of a single project purpose such as local flood control, drainage, irrigation, water supply, or power. More recently, however, water resource developments have been conceived as multiple-purpose undertakings with a view to providing for as many project purposes and needs as possible. This approach permits the most efficient utilization of damsites and assures that maximum benefits will be realized for the costs involved.

AGENCIES CONCERNED WITH WATER RESOURCES

The conservation, utilization, and development of Missouri's water resources, because of their vast complexity and the wide diversity of interests, involve numerous governmental agencies from the Federal level to the local level. Although various forms of water resource development had been practiced for many years, it was not until the 1940's that the need for coordinating divergent interests and needs became manifest. The importance of this coordination has become even more apparent since that time as a result of the additional need for, and increased interest in, water resources development.

An example of this coordination occurred in 1944 when two Federal agency proposals for the Missouri River Basin, one recommended by the Corps of Engineers in the summer of 1943 and the other recommended shortly thereafter by the Bureau of Reclamation, were presented to Congress for consideration. The Corps plan provided for a series of dams and reservoirs on the Missouri River and its principal tributaries primarily for flood control and navigation purposes, but with multiple-purpose water storage for other needs. The Bureau plan provided for a large number of tributary dams and reservoirs primarily for irrigation and land reclamation, but with provision also for storage for other uses. In the interest of overall development of the basin's water resources, Congress requested that the two plans be combined into one program, utilizing the best features of both proposals. The coordinated program, popularly known as the Pick-Sloan plan, was authorized by the Flood Control Act of 1944.

It was one of the most comprehensive programs ever devised for a region as large as the Missouri River Basin. Missouri, as the lowermost State in the basin, would benefit substantially from the program even though comparatively few projects would be located within the

State. In Missouri, the program included 6 reservoirs and 2 local protection projects under the jurisdiction of the Corps of Engineers. A top coordinating body known as the Missouri Basin Interagency Committee, consisting of the Governors of the 10 States in the basin and representatives of seven Federal agencies, was established in 1945 in recognition of the need for continuing coordination of resource development in the basin. This was one of the first and most extensive coordinated undertakings in the field of water resources development involving the State of Missouri. Subsequently, other coordinating bodies have been formed for the purpose of achieving efficient development and utilization of the State's water resources.

Today, Federal and State agencies are working together in Missouri to achieve optimum water resource development. The Corps of Engineers has constructed improvements for the protection of the St. Louis and Kansas Citys metropolitan areas and other river cities; agricultural levees for the protection of rural flood-plain areas along several major rivers; multiple-purpose reservoirs for flood control, water supply, recreation, and allied purposes; and navigation improvements to permit commercial shipping on the Mississippi and Missouri Rivers. In addition to projects that have been completed, a number of other projects are under construction or are authorized and still others are being studied by the corps to help meet the water needs of the State. The Soil Conservation Service, under authority of the Watershed Protection and Flood Prevention Act, Public Law 566, 83d Congress, is developing improvements in the interest of soil and water conservation throughout the State. The U.S. Geological Survey, in addition to its mapping and mineral resource programs, collects basic water resource data, studies areas of potential or existing water problems, and conducts hydrologic research. The Weather Bureau has the responsibility for forecasting river stages and compiling rainfall, snow, and other climatological data. The Bureau of Mines considers the water needs of the mineral industry and investigates the mineral resources that may be affected by future reservoirs. The Federal Power Commission evaluates hydroelectric power needs, and the Federal Water Pollution Control Administration is responsible for investigating requirements for municipal and industrial water supply, waste treatment, and streamflow supplementation for water quality control. Other Federal agencies such as the Fish and Wildlife Service, the Forest Service, the National Park Service, and the recently created Bureau of Outdoor Recreation coordinate their activities with both Federal and State agencies to insure optimum recreation and fish and wildlife development. The primary responsibility for coordinating the water interests of the State has been assigned to the Missouri Water Resources Board. County and local governments are also involved in water resources planning and development, especially since recent policy changes often require local participation in reservoir projects.

The foregoing discussion offers some insight as to the number of agencies and interests involved and the vast amount of coordination that is required in the development of the State's water resources.

EXISTING AND POTENTIAL DEVELOPMENTS

The following paragraphs discuss the major water resources developments of (a) the upper Mississippi River (above St. Louis) and its right-bank tributaries; (b) the Missouri River and its tributary basins; (c) the lower Mississippi River and its right-bank tributaries; (d) the St. Francis River Basin; (e) the White River Basin; and (f) the Spring River Basin. Throughout the State there have been numerous water resources developments, some of which, even though small in size, have had an important impact on the local economy. Some, like the skeletal remains of the Meramec Iron Works made possible in 1826 by the available waterpower from Meramec Spring, have been of considerable significance in the history of the State. But in this report it is not practicable to discuss all the smaller hydroelectric plants, the water-powered grist mills, the therapeutic springs, and the smaller recreational lakes scattered throughout the State. These must of necessity defer to the developments of greater contemporary importance and economic significance. Fortunately, much has been written elsewhere about these other natural and manmade developments. Figure 81 graphically illustrates the progress of major water resources developments in Missouri, the existing and authorized projects of the Corps of Engineers in the State, and several of the larger private developments.

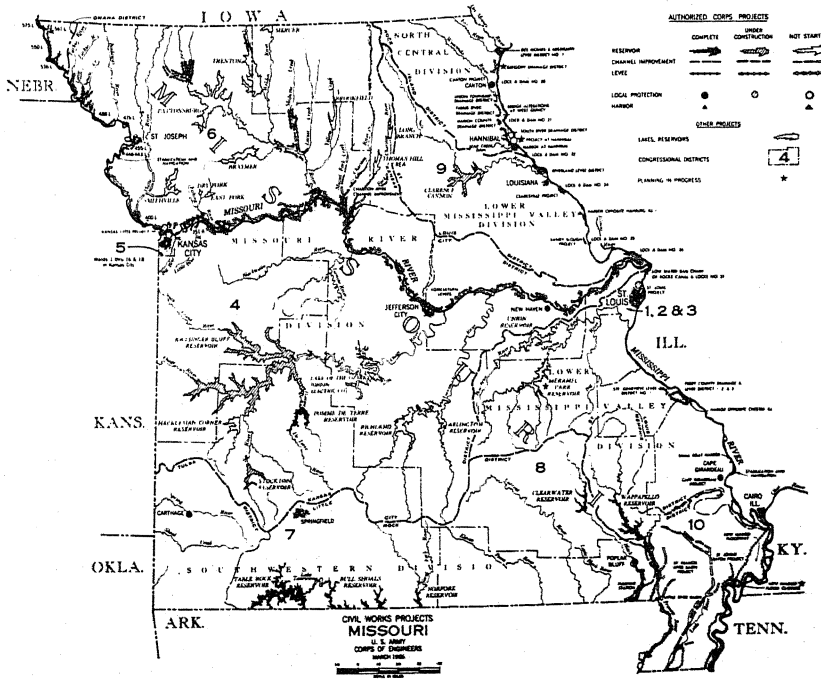


FIGURE 81.—Civil works projects of the U.S. Army, Corps of Engineers, and other water-resource developments in Missouri, March 1966.

UPPER MISSISSIPPI RIVER AND TRIBUTARIES

Upper Mississippi River

The upper Mississippi River, between the mouth of the Missouri River near St. Louis and Minneapolis, Minn., has been improved by the construction by the Corps of Engineers of a system of 28 locks and dams which permits slack-water navigation. As a result, the Mississippi serves as an important transportation link between downstream areas and cities such as Chicago, Minneapolis, St. Paul, and Milwaukee. Since the project was placed in operation in 1940, river traffic has increased rapidly. Six of the locks and dams comprising the project are in the Missouri-Illinois reach of the river above the mouth of the Missouri. A short distance below the mouth of the Missouri is the Chain of Rocks canal and locks No. 27 in Illinois which operates in conjunction with a low-water dam across the old channel on the Missouri side of the improvement. Other navigation improvements along the Mississippi River in Missouri include the Hannibal, Mo., small boat harbor, completed in 1958; and the construction of the new Chicago, Burlington, & Quincy RR. bridge at West Quincy, Mo., having adequate clearance and permitting better channel alinement. The bridge was completed in 1961 and the channel realinement in 1963. Recreational day-use areas with boat-access facilities are completed at lock and dam No. 26, under construction at lock and dam No. 25, and authorized at other river locations. A small-boat harbor project opposite Hamburg, Ill., also is authorized.

There have been several flood control projects along the upper Mississippi River in recent years. The Gregory Drainage District in Lewis and Clark Counties is protected by a riverfront levee which was improved by the Federal Government in 1939. A further improvement has been authorized and is tentatively scheduled in 1967. At Canton, Mo., a local protection project, consisting of a diversion of Canton Creek, construction of levees and floodwalls, and pumping plants, was completed in 1964. The Union Township Drainage District in Lewis County is protected by 9 miles of riverfront and tieback levees which were improved by a Federal project in 1946. The Fabius River Drainage District in Lewis and Marion Counties includes 14,264 acres of Mississippi River bottom land. A Federal project to strengthen and raise the protective levees and do some remedial work on railroads and roads was completed in 1963. The Marion County Drainage District is on the right bank of the Mississippi River several miles upstream from the city of Hannibal. Improvement of the agricultural levees was started in 1964 and is scheduled for completion in 1966. Improvement of levees of the South River Drainage District, also located upstream from Hannibal, was begun in 1963 and is also scheduled for completion in 1966.

A large portion of the city of Hannibal, including most of the city's business and industrial area, lies in the Mississippi River flood plain. A plan of protection consisting of levees and floodwalls along the waterfront was authorized in 1962. The project is in preconstruction planning status.

Des Moines River Basin

The Des Moines River forms the boundary between Iowa and Missouri along a 32-mile reach. Less than 1 percent of the drainage area

of this river lies in Missouri. The watershed in this State consists of a narrow strip of highly dissected glaciated terrain. Adjacent to the lower 10 miles of the Des Moines River is the Des Moines and Mississippi Levee District. The levees of this district are inadequate in section and construction, particularly along the Des Moines River. A Federal project to strengthen and raise the levees of this district is scheduled for initial construction in 1966.

Fox River Basin

Fox River rises in southeastern Iowa, flows southeasterly through northeastern Missouri, and enters the Mississippi River at mile 353.6 above the Ohio River. The basin has a length of about 75 miles and an average width of 7 miles. The drainage area is 502 square miles, approximately half of which is in Missouri. The area has an agricultural economy. The largest town in the Missouri portion of the watershed is Kahoka, with a population of 2,160.

The upper reaches of the Fox River and its chief tributary, the Little Fox River, have been straightened under a series of drainage districts organized between 1911 and 1922. Downstream from these straightened portions the streams are winding, running partly on hard rock, and the bottom lands are narrow. The Mississippi River flood plain through which the lowermost 12 miles of the stream meanders is referred to as the Mississippi and Fox River Drainage District, although the area has not been organized under State law as such.

Flooding occurs infrequently along the upstream straightened portions of the streams. These reaches have become enlarged and are efficient channels. The lands adjacent to the lower reaches of the straightened portions and immediately downstream therefrom, however, flood frequently since the channels have become clogged with sand and debris. These reaches have been abandoned and are considered beyond feasible reclamation. Between these abandoned reaches and the Mississippi River flood plain, the valley is quite narrow and floods frequently. The Mississippi and Fox River Drainage District is similarly subject to flooding not only from the Fox River, but from the main stem as well. The most severe flood of recent years was in 1963 when damage amounting to almost half a million dollars was sustained upstream from the Mississippi and Fox River Drainage District.

A survey of the Fox River in Iowa and Missouri for flood control and allied purposes was completed in 1965 by the Corps of Engineers under authority of a resolution by the Committee on Public Works of the U.S. House of Representatives, adopted 7 June 1961. Possible solutions to the flood problems studied included reservoirs, levees, and extension of channel straightening. No project for flood control or allied purposes was found to be feasible at that time except in the area of Mississippi River flood plain traversed by the Fox River. Local support for such project was lacking.

Wyaconda River Basin

The Wyaconda River consists of two branches, the North Wyaconda and the South Wyaconda Rivers. These rise in southeastern Iowa, flow southeasterly into northeastern Missouri, and join about 52 river miles upstream from the mouth. The river enters the Mississippi River near the town of LaGrange, 337 miles above the Ohio River.

The basin is about 70 miles long, 5 to 8 miles wide, and has a drainage area of 458 square miles.

The economy of the watershed and adjacent region is based on agriculture. The largest town in the basin has a population of 400, and the basin as a whole has a population density of 11 per square mile.

Portions of the upper reaches of the two branches of the Wyaconda River have been straightened. The lower 45-mile reach of the stream has not been straightened and is characterized by a narrow, gorge-like valley. Flooding occurs throughout the length of the river, but most frequently occurs in the vicinity of the termination of the straightened reach. The most severe flood of recent years, in 1960, caused damages amounting to almost $650,000. About 65 percent of that damage occurred in the reach between the unstraightened portion and the confluence of the branches.

A survey for flood control and allied purposes on the Wyaconda River, Mo. and Iowa, was conducted by the Corps of Engineers under authority of a resolution by the Committee on Public Works of the U.S. House of Representatives, adopted June 7, 1961. Studies were made of possible reservoirs, channel enlargement, channel cleanout, and construction of levees. The survey and report were completed in 1965. None of the aforementioned possible solutions to the flood problem was found to be feasible at that time. A Soil Conservation Service Watershed project on the North Wyaconda River, comprising an 82-square mile area, is authorized for planning.

Fabius River Basin

The Fabius River proper is a short stream flowing across the Mississippi River flood plain. It is formed by the confluence of three branches, the North, the Middle, and the South Fabius Rivers, which join within a short reach near the bluff line of the Mississippi River. The main stream enters the Mississippi River 323 miles upstream from the Ohio River. The drainage area is 1,570 square miles, and, except for about 100 square miles in southeastern Iowa, lies in northeastern Missouri. The basin is about 80 miles long and has a maximum width of about 25 miles.

The economy of the region in and about the Fabius River watershed is essentially agricultural. The largest town in the basin is Memphis, Mo., with a 1960 population of 2,106.

Projects for local flood protection have been completed by the Corps of Engineers in the Fabius River Drainage District and in the Marion County Drainage District, both adjacent to the lower reaches of the Fabius River. These projects, however, are considered mainly as protection against Mississippi River floods. Since prior to World War II, when studies for flood control were conducted on the North and Middle Fabius Rivers, there has been no survey of any of the Fabius Rivers. The earlier studies found that flood damage occurred but that possible solutions were economically infeasible. Application for a Soil Conservation Service watershed project on the Middle Fabius River, comprising an area of 193 square miles, has been approved by the Governor's Watershed Advisory Committee. A watershed project on Bear Creek, a tributary of the North Fabius River, is under construction. The watershed has an area of 52 square miles.

Bear Creek

Bear Creek rises in Marion County and flows easterly to its junction with the Mississippi River at a point 308.8 miles above the mouth of the Ohio River. The creek has a basin about 11 miles long and 5 miles wide.

The lower 4 miles of Bear Creek flow through a section of Hannibal, a city of some 20,000 population. About 500 dwellings, 200 commercial establishments, 7 manufacturing plants, including one of the Nation's largest shoe factories, and municipal water, power, and sewage-treatment plants are within the area affected by Bear Creek floods. Trackage, shops, and yards of two railroads are also located within the Bear Creek flood plain.

Flash floods in Bear Creek have occurred frequently at Hannibal, causing much damage to residential and industrial property in the city. These floods, resulting from intense rainfall over the watershed, usually occur during the summer months. The flood of June 1947 on Bear Creek was the most destructive of record, resulting in damage estimated at $703,600. In that flood, 900 persons had to be evacuated from the flood area.

A project for local protection at Hannibal from floods on Bear Creek was authorized by Congress in the Flood Control Act of 1954. The plan of improvement consisted of construction of a dam and reservoir on Bear Creek about 5.4 miles above its mouth, together with remedial and appurtenant works. The dam is of impervious rolled earthfill, approximately 1,250 feet in length at its crest elevation, and 65 feet in maximum height above the streambed. Concrete outlet works extend through the base of the dam at the toe of the right bluff. A saddle-type spillway was cut in the right bluff, some 4,000 feet southwest of the dam. Relocation of railroad tracks, of power and communication lines, and of access roads to farmsteads were required.

All Bear Creek floods having an average expectancy up to once in 100 years will be contained in the reservoir. The estimated average annual benefits to be realized from the project are $271,000. Damage that would be prevented by the improvement if the design flood occurred is estimated at $2, 870,800. The total damages prevented since the Federal project has been in operation (1962 to date) are estimated at $357,000. Construction was initiated in August 1960 and completed in January 1962.

Salt River Basin

Salt River Basin covers an area of approximately 2,900 square miles in northeast Missouri and embraces parts or all of 12 counties. Salt River rises in Schuyler County about 12 miles south of the Missouri-Iowa State line, and flows in a generally southeasterly direction approximately 192 miles, emptying into the Mississippi River about 2 miles above Louisiana, Mo. Its major tributaries are South Fork, Middle Fork, and North Fork. Land in the upper part of the basin is a gently undulating plain, becoming more rolly and hilly in the middle and lower reaches of the river. High rock bluffs border the stream at various points. Maximum topographic relief is about 650 feet. The valleys are characterized by fairly narrow, tortuous courses, interspersed by areas of widened bottom land. The population of the basin, numbering over 95,000, is engaged largely in farming, livestock

raising, coal mining, and brick and tile manufacturing. The density of population reflects a pattern of distribution equally divided between urban and rural residents. Commercially significant natural resources in the basin consist of fire clay, limestone, gravel, and coal. Average annual rainfall in the basin is 36.6 inches. Salt River is characterized by extreme range in flow and rapid fluctuations in stage. Rises of 15 feet and more in 24 hours have been recorded by most of the gages. Flows usually taper off from the flood peaks of early spring and summer, and on occasions, during extended drought, zero flow has been recorded. The maximum flood of record, July–August 1958, had a measured flow of 71,100 second-feet at Monroe City.

Clarence Cannon Dam and Reservoir

In 1938, construction of a dam and reservoir on Salt River about 63 miles above its mouth was authorized by Congress as part of a comprehensive plan for the upper Mississippi River basin. Planning funds only were appropriated for this project. A resurvey prepared in 1961 recommended that the dam and reservoir be authorized as a multiple-purpose project to be operated for flood control, hydroelectric power generation, water supply, recreation, and fish and wildlife conservation. This project was authorized by the Flood Control Act of 1962. The reservoir will have a total storage capacity of 1,428,000 acre-feet. It will provide protection to approximately 27,500 acres of land along the Salt River; effect important flood reductions in the upper, middle, and lower Mississippi River; provide 50,000 kilowatts of firm capacity through use of pump-storage operations; supply anticipated future water demands for 10 communities having a total population of about 25,000; provide for fish and wildlife conservation; attract a large number of visitors seeking recreation; and afford incidental benefits to navigation on the Mississippi River. Preconstruction planning has been initiated and completion of project is presently estimated for 1972. The name of the multiple-purpose project, formerly known as Joanna Dam and Reservoir, has been changed by congressional resolution to the Clarence Cannon Dam and Reservoir.

There are six drainage districts comprising approximately 19,200 acres located along the North Fork of Salt River which are quasi-public corporations organized under the drainage laws of Missouri.

MISSOURI RIVER AND TRIBUTARIES

Missouri River

The Missouri River is the largest tributary of the Mississippi River. The basin has an area of 529,000 square miles and consists of about one-sixth of the area of the contiguous 48 States. It extends from the Continental Divide, down the eastern slope of the forested Rocky Mountains through the semiarid Great Plains, to the humid areas of Missouri. All or part of Nebraska, Montana, North Dakota, South Dakota, Wyoming, Kansas, Missouri, Colorado, Iowa, and Minnesota are included in the basin. With this wide diversity of climate and physiographic features, water—or lack of it—is the root of many of the basin's economic difficulties. Well over half of the population of the basin is concentrated along its humid eastern border, where the farming conditions are most dependable and where principal manu-

facturing industries provide employment. The extensive but more rugged and dryer western part contains a relatively small portion of the basin's 1960 population of nearly 8 million. In the upper basin, droughts have turned extensive farm areas into dust bowls, sometimes for extended periods, and have forced the farmers to dispose of their livestock and, often, to abandon their land. Floods in the lower basin have long plagued development along the river. They have destroyed crops, drowned livestock, severely damaged cities and small communities, and taken many human lives. These troubles have stimulated a search for solutions.

More than half of Missouri's area lies within the Missouri River Basin and flooding and related problems pose major difficulties. Early attempts at solving these problems started with a drainage law passed by the State legislature in 1851. The law, which provided several methods for the formation of drainage districts, referred primarily to the drainage of swamp and overflow lands donated by the Federal Government in 1850. Principal drainage laws were also enacted in 1899, 1905, 1909, 1911, 1913, 1917, and 1919. In addition to the formal organization of districts under State laws, a plan of cooperation between local interests and the Federal Government was authorized by the River and Harbors Act of March 1915. The general principle of cooperative construction was based on the landowners paying 75 percent of the cost of such work, and the United States 25 percent.

The Flood Control Act of 1928 authorized studies for flood protection and control, hydroelectric power, irrigation, and navigation for the entire Missouri River Basin. Several upstream reservoirs were proposed for further study under the resulting plan. However, because most of the floodwaters often originate in the lower basin area, these reservoirs would provide incomplete flood protection below St. Joseph, Mo. The plan proposed for further study in Missouri provided for 15 levee units protecting about 158,000 acres of agricultural lands in the Missouri Valley between St. Joseph and Boonville, Mo., and for protection of the Kansas Citys.

The 1938 Flood Control Act authorized a comprehensive plan for the control of floods and development of water resources in the Missouri River Basin. Expansion of that plan was subsequently authorized by the Flood Control Act of 1944. The expanded plan, popularly referred to as the Pick-Sloan plan, was based upon separate proposals recommended by the Corps of Engineers and the Bureau of Reclamation. It was developed primarily for four major purposes: flood control, irrigation, hydroelectric power, and improvement of navigation on the lower Missouri River. Other benefits would accrue to the people of the basin and to the Nation as a whole in the form of improved water supply and sanitation, soil erosion control, fish and wildlife conservation, and public recreational opportunities. Missouri, as the lowermost State in the basin, would be a significant beneficiary of the plan.

The Pick-Sloan plan originally provided for the construction of some 103 reservoirs with a total multiple-purpose storage capacity of about 110,000,000 acre-feet; local levees and floodwalls to protect municipal, industrial, and agricultural areas; and agricultural levees on both sides of the Missouri River from Sioux City to the mouth. The plan included six reservoirs and two local protection projects

77-278 O—67——24

in Missouri. Some of the projects authorized prior to 1944 were closely associated with the Pick-Sloan plan, and additional projects have been, and are being, developed as the need arises and integrated with the overall basin plan. At present, there are 15 corps reservoirs and several local protection projects authorized in the Missouri part of the Missouri River basin. The latter includes the Kansas Citys and New Haven municipal protection projects, the Missouri River agriculture levees, and levee and channel improvement projects in the Chariton and Little Chariton, Grand, and Platte River Basins. Other water resource developments include watershed projects of the Soil Conservation Service. This program has undergone significant expansion in recent years. In the Missouri River Basin, there are presently one pilot watershed project and 18 Public Law 83–566 watershed projects in various stages in the State, of which two are completed and in operation.

The six large, multiple-purpose reservoirs on the upper Missouri River, although outside the State of Missouri, play a vital part in the development of Missouri's water resources. They not only provide flood control and navigation releases for the Missouri River but also affect the design and feasibility of certain developments within the State.

Missouri River stabilization and navigation project

The unimproved Missouri River was a wild unpredictable stream, many channeled and meandering, virtually useless for commercial navigation and a constant threat to any improvements along its banks. The stabilization and navigation project, as its name implies, is designed to stop bank erosion and meandering, and to provide for the low-cost transportation necessary to full economic development of the region served. The existing project, as modified by Congress in the River and Harbor Act of 1945, provides for a 9-foot channel, 300 feet wide, from the mouth of the river to Sioux City, Iowa, a distance of 735 miles, of which about 553 miles lie across the State of Missouri and along its northwestern boundary. Both distances reflect an adjustment of river mileages made in 1960.

The project is of the open river regulation type, with no dams or barriers to form slack-water pools. Instead, the tremendous energy of the flowing river is put to work to continually maintain its own channel in an alinement fixed by means of dikes and revetment. With the river banks permanently secured in the desired alinement, the scouring action of the flowing water, on the river bed rather than on the banks, will dig out and maintain the desired channel width and depth favorable for navigation.

By January 1966, the overall project was about 96 percent complete between Omaha and the mouth and about 94 percent complete between Omaha and Sioux City.

In 1953, two privately owned common carriers started regularly scheduled operations on the river as far upstream as Omaha, Nebr. These operations have been supplemented in recent years by several contract carriers. Commercial tonnages have increased from a mere 152,000 tons in 1953 to a high of approximately 2,613,000 tons in 1964. The main commodities being shipped are grain, steel products, petroleum, chemicals, minerals, molasses, building materials, machinery, and vegetable and animal products.

Although navigation on the Missouri River is still in its infancy as compared with other inland waterways, there is a substantial potential tonnage available. A survey of nearly 1,500 industrial plants, milling interests, grain companies, steel firms, and other manufacturers was made in 1950 and, on the basis of these contacts, it was estimated that potential commerce of approximately 5 million tons annually could be expected to develop for shipment on the Missouri River. Representatives of some of the firms now operating barges on the river have indicated that they believe the potential tonnage now greatly exceeds that figure.

Interest in the growth of traffic is indicated by the rate at which new docks and terminal facilities are being built at points all along the project from Sioux City to the mouth, by the expansion of existing facilities, and by the steady increase in the numbers of operators, towboats, and barges each navigation season.

The stabilization works perform additional important functions as part of the comprehensive program for the Missouri River Basin. The completed works will prevent the annual destruction by erosion of more than 9,000 acres of farmland and will open up an additional 188,000 acres of new land to agriculture. Permanently secured river banks are definitely required before the authorized agricultural levees along the Missouri River below Sioux City can be safely constructed.

The levees are a vital part of the flood control program for the main river.

Missouri River agricultural levees

The Missouri River agricultural levee program, as authorized by the Flood Control Act of 1944, called for the construction of about 1,500 miles of levees along both banks of the Missouri River from Sioux City, Iowa, to the mouth. These levees were designed to operate in conjunction with reservoirs on the upper Missouri River and on tributaries in the lower part of the Missouri River Basin. Many of these reservoirs are now completed or in construction status.

Of the 150 units originally contemplated in the entire agricultural levee program, seven have been completed in Missouri. With a combined length of 84 miles, these units protect approximately 56,500 acres of agricultural lands, and have prevented flood damages estimated at more than $6 million through 1965.

Levees that have been built under the Missouri River agricultural levee program are generally of semicompacted earthfill with a top width of 10 feet. Drainage structures through the levees are provided to avoid the ponding of water behind them. The levee program was initiated in the reach between Kansas City and Omaha in 1948, and, by 1965, about 220,000 of the 400,000 acres susceptible to flooding in the reach had been protected.

Kansas Citys local protection project

Located at the confluence of the Missouri and Kansas Rivers, the Kansas Citys of Missouri and Kansas include about 32 square miles of flood plains of the two rivers. This area, containing major industrial, transportation, and municipal facilities, and some residential development, with a total value of approximately $3.4 billion, is included in the Kansas Citys flood control project.

The local project was authorized by the Flood Control Act of 1936 and construction was started in 1940. An amended plan, on which the present project is based, was authorized by the Flood Control Act of 1944.

In order to facilitate construction, management, and operation, the overall project was set up in separate units for the several geographical areas and other major elements. Seven geographical units have been designated: the Fairfax-Jersey Creek unit on the Missouri River in Kansas; the Argentine and Armourdale units on the Kansas River in Kansas; the central industrial district unit which lies in both States and is bounded on the west by the Kansas River and on the north by the Missouri; and three other units—the North Kansas City, East Bottoms, and Birmingham units, all in Missouri. The design and construction of each of these units were coordinated with the others, yet each became effective as it was completed and each is operationally independent. Complete effectiveness of the overall project is contingent upon adequate reservoir control in the upper Missouri and Kansas River Basins. Levees, floodwalls, and pumping plants comprise the main protective structures, and other major elements include channel and floodway improvements in both rivers, bridge and approach alterations, and the Liberty Bend cutoff in the Missouri River immediately downstream from Kansas City.

The project was only partially completed when the unprecedented 1951 flood, out of the then uncontrolled Kansas River, struck the area. Works along the Kansas River afforded protection up to and beyond their design discharge for several days prior to the final crest, but all were finally overtopped. Ironically, in the heavily industrialized Fairfax-Jersey Creek district along the Missouri River, the levee protection would have been adequate, but flooding resulted from rupture of the covering over Jersey Creek where a pressure-conduit had been scheduled for construction, starting a few days later. The pressurized conduit has since been completed. The remaining local protection works along the Missouri River, supplemented by intensive flood-fighting activities, prevented flood damages which would have reached an estimated $264,640,000. This saving, together with losses prevented during floods in 1943, 1944, 1945, 1947, 1950, 1952, 1958, 1960, 1964, and 1965, amounts to about $775 million. This is almost 16 times the total cost of the local protective works.

The few reservoirs then in operation on the upper Missouri River teamed with the Kansas Citys levees to prevent damage during the major Missouri River flood of 1952. Since that time, these upper Missouri reservoir impoundments have been supplemented by the completion of additional reservoirs. The Kansas River still lacks adequate control, but substantial headway is being made in that direction. The Corps of Engineers Kanopolis Reservoir on the Smoky Hill River, Tuttle Creek Reservoir on the Big Blue River, and Wilson Reservoir on the Saline River, all in Kansas, have been completed. In addition, three Bureau of Reclamation reservoirs with flood control effects have been completed. These are the Kirwin, Webster, and Lovewell Reservoirs in Kansas. Flood control operations in both Bureau and Corps reservoirs are under a coordinated system operation directed by the Kansas City district of the Corps.

Two other major Corps reservoirs, Milford and Perry, and a Bureau reservoir, Glen Elder, all of which will have important flood control effects at the Kansas Citys, are under construction in Kansas. Milford Reservoir will be operable in late 1966. In addition, three smaller reservoirs on streams tributary to the lower Kansas River were authorized by the Flood Control Act of 1962. This same act also authorizes modification of the portion of the Kansas Citys project along the Kansas River, consisting primarily of raising the levees and floodwalls in the Argentine, Armourdale, and central industrial districts. Except for these modifications, the Kansas Citys project is practically completed.

New Haven local protection project

Located on the right bank of the Missouri River in Franklin County, New Haven includes an area of about seven city blocks of business and residential property in which the flood problem was twofold. During moderate floods, water from the Missouri River backed through sewers into basements, and during more severe floods the entire area was subject to inundation from the river.

The project consists mainly of a levee averaging about 7 feet high and about a half mile in length, with provision for pumping of interior drainage. Construction was initiated in the fall of 1954 and completed in April 1955 when the project was turned over to local interests. The project has prevented about $51,000 in damage since its completion.

Gasconade River Basin

The Gasconade River rises in Wright County in south-central Missouri and flows generally in a northeast direction for about 270 miles to its juncture with the Missouri River at mile 104.4, about one-half mile downstream from the town of Gasconade, Mo. The basin is approximately 130 miles long with widths ranging from a maximum of 50 miles near the headwaters to about 8 miles near the mouth. The drainage area of 3,600 square miles is mostly Ozark Mountain region and includes parts of 10 Missouri counties. Newburg, in Phelps County, Mo., is located on the right bank of Little Piney Creek about 4 miles above its confluence with the Gasconade River. The town is traversed by Newburg Branch, which is also known as Yadkin Creek. Fort Leonard Wood, an important U.S. Army installation, is located near the town of Waynesville, Mo., virtually in the center of the basin. This post has a military population of about 30,000. The 1960 basin population was approximately 100,000, most of whom resided in rural areas and in towns having populations of 1,000 or less.

In 1880, the Corps of Engineers initiated a continuing project in the interest of navigation on the Gasconade River. This project provided for annual maintenance by the removal of snags and other obstructions and for open-channel improvements to increase shoal depths on the lower 62 miles of the river. In 1926, the Chief of Engineers recommended curtailment of the project by eliminating the portion above Cooper Hill (mile 36.0) and limiting work below that point to that necessary to provide a 2-foot depth during low water flows. Prior to 1900, traffic volume was at times as great as 50,000 tons per year, of which 75 percent or more was timber rafting. As the timber resources

in the basin diminished, navigation traffic decreased rapidly. The advent of a highway system and the trucking industry further affected river transportation and, since 1929, no commercial river traffic has been reported and maintenance of navigable improvements has been discontinued.

The Flood Control Act of 1938 authorized two reservoirs in the Gasconade River Basin, both on the main stem, as part of a system of flood control works to provide protection especially along the lower Mississippi River. The Arlington damsite is about 107 miles above the mouth and about 10 miles west of Rolla, Mo. The reservoir would extend into Pulaski County. Since the project was authorized, considerable railroad and other development has taken place in the reservoir area, changing the economic and physical aspects of the project materially. The Richland site is in Pulaski County about 170 miles upstream from the mouth and about 5 miles east of the town of Richland. The reservoir would extend into Laclede County. Following the completion of a partial definite project report by the Corps of Engineers in 1945, these projects were placed in an inactive status due to significant changes which had occurred in the basin since the 1938 authorization. Previous studies had indicated that a flood control project on the Gasconade River would develop substantial benefits by reducing flood damages on the lower Missouri River and on the Mississippi River. However, as other existing and authorized projects will substantially reduce the flood problems in these areas, the effect of Gasconade River reservoirs would be limited to reduction of relatively moderate residual annual damages. Although the Gasconade River flood plains are generally narrow and in most places are not intensely developed, they are subject to frequent and severe flooding which could be significantly reduced by reservoirs or other flood control works in the basin.

A flood control study was authorized by a resolution of the Committee on Public Works of the U.S. House of Representatives, adopted June 13, 1956, to determine if any additional improvements for flood control and allied purposes are justified in the Gasconade River Basin. An earlier resolution of the House Committee on Public Works, adopted July 5, 1946, authorized an investigation of the need for flood protection on Newburg Branch of Little Piney Creek at Newburg. The basinwide investigation was initiated with a public hearing at Rolla, Mo., on April 3, 1963. It includes a review of the physical and economic feasibility of the authorized Arlington and Richland Reservoir projects. The flood problem at Newburg is also being included in the basinwide investigation. Types of improvements under consideration include multiple-purpose reservoirs, levees, channel improvements, and appurtenant works. Studies will also determine the feasibility of hydroelectric power development in the basin. A report on the investigation is scheduled for completion in 1967.

Osage River Basin

The Osage River is formed by the confluence of the Marais des Cygnes and Little Osage Rivers in west-central Missouri. It flows eastward and northeastward to join the Missouri River near Jefferson City. Floods and related water resource problems have plagued the Osage River Basin for many years. As the largest tributary of the

Missouri River in Missouri, Osage River discharges have also made substantial contributions to flood crests on the Missouri and Mississippi Rivers. Floods in the basin since 1941 have caused aggregate damages estimated at more than $73 million Two storms in May 1943 caused the highest stages of record on the Osage River from Osceola to the mouth, while the disastrous flood of July 1951 established record flood heights in the upper basin areas. Flood damages in the basin during 1951 totaled more than $33 million, of which over $14 million occurred in Missouri. The July 1958 flood caused damages of more than $7 million in the Missouri portion of the basin.

An act of Congress in 1904 declared the Osage River navigable from the mouth to near Warsaw, Mo. A navigation study provided for the construction of a lock and dam, and for open-channel works consisting of wing dams and training walls, removal of obstructions, and dredging between the mouth and Warsaw to obtain a uniform 3-foot channel depth. The Bagnell Dam, a hydroelectric project constructed by the Union Electric Co. at river mile 81.7, was placed in operation in 1931, and the navigable portion of the Osage River now consists of two reaches: the river from the mouth to Bagnell Dam and the Lake of the Ozarks, which extends from Bagnell Dam to the vicinity of Warsaw. Prior to 1900, commercial tonnage on the Osage River reached a yearly maximum of over 100,000 tons; however, as road and rail transportation routes were developed in the basin, the interest in navigation declined. By 1943, tonnage had dropped to about 8,000 tons and there is little interest in commercial navigation on the Osage River at the present time.

Prior to the 1930's, several engineering reports which considered flood control, navigation, and related water resource development were prepared by Federal agencies and by drainage district organizations. In 1933, the Corps of Engineers submitted a report on the Missouri River which included a plan for the Osage River Basin as part of a system for flood control on the Mississippi River. This plan led to the authorization, in 1938, of the Osceola Reservoir on the Osage River, the South Grand Reservoir on the South Grand River, and the Pomme de Terre Reservoir on the Pomme de Terre River. The Pomme de Terre Reservoir has since been constructed, but the Osceola and South Grand Reservoirs were deauthorized in view of a more satisfactory plan authorized by the Flood Control Act of 1954.

A plan for development of the Osage River Basin was developed by the Corps of Engineers in 1948 in a comprehensive study which involved Federal and State cooperation under the guidance of a coordinating committee named by the Governor of Missouri. Submitted to Congress in 1950, the plan, consisting of four reservoirs in the Missouri portion of the basin and five reservoirs and two local protection projects in the Kansas portion, was designed to protect against a flood resulting from a storm and runoff pattern based on the most severe flood events then of record in the area. The plan was authorized by the Flood Control Act of 1954, and a modification of the Kaysinger Bluff Reservoir was authorized by the Flood Control Act of 1962.

There are a total of 15,300 square miles in the Osage River Basin, of which 11,000 square miles are in Missouri. The reservoirs in the authorized plan will control a total drainage area of 11,500 square miles, of which nearly 8,000 square miles are in Missouri. In addition

to flood control and water conservation, recreational development has been included in the plans for each of the reservoir projects. Power production has been authorized for the Pomme de Terre, Stockton, and Kaysinger Bluff Reservoirs, but the power feature for Pomme de Terre Reservoir has been deferred. Benefits from stabilized flows will be reflected on the Osage, Missouri, and Mississippi Rivers.

The first of the Federal projects in the Osage River Basin to be started, Pomme de Terre Reservoir, was placed in operation in 1961. Construction of Stockton Reservoir was started in the fall of 1963, and construction of the Kaysinger Bluff Reservoir was initiated in the fall of 1964. Hackleman Corner Reservoir, the fourth of the reservoirs in the Missouri portion of the basin, was deferred for a restudy which is underway.

A further investigation of the Osage River Basin was authorized in 1961 by resolutions of the Committees on Public Works, U.S. Senate and House of Representatives. Its purpose is to determine if additional works in the interest of water supply, flood control, water quality control, power, and related purposes in the Osage River tributary areas are advisable at this time. A public hearing to ascertain the view of local interests was held at Clinton, Mo., on January 21, 1963. The investigation is generally limited to tributaries upstream from Bagnell Dam since the problems in the lower basin are the subject of a separately authorized investigation. Consideration is being given to multiple-purpose reservoirs and local protection measures as means of alleviating water supply problems, localized flood conditions, and other water resource problems in the upper basin. Additional reservoirs, if found to be needed and economically feasible, would supplement the benefits of the authorized program and provide much needed water supply for a number of communities in the basin. A report on the investigation is scheduled for completion during 1966.

In addition to the major reservoir projects in the basin, which are discussed under separate subheadings, the Soil Conservation Service is conducting an investigation of the land and water resources in the Osage River Basin. The principal objectives of the study are to determine the type and extent of watershed problems in the basin, the need for watershed projects, and the specific watersheds suitable for development. Also, application has been made to the Soil Conservation Service for investigation of the Little Drywood Creek and the Cedar-Horse-Alder Creek watersheds in the Osage Basin. The Little Drywood Creek watershed, a tributary of the Marmaton River, comprises an area of more than 111,000 acres in Barton and Vernon Counties, Mo. The Cedar-Horse-Alder Creek watershed consists of approximately 243,000 acres in Barton, Cedar, Dade, and Vernon Counties.

At the request of the State, the University of Missouri made an investigation of the Big Creek Watershed. This watershed encompasses an area of 420 square miles in Henry, Johnson, Cass, and Jackson Counties. It drains into the South Grand River about 8 miles west of Clinton. Completed in 1963, the purpose of the study was to investigate the economic feasibility and possible locations of impoundments in the Big Creek Watershed area for the purposes of flood control, water supply, fish and wildlife conservation, and recreation. Of the sites investigated, seven floodwater-retarding structures

appeared to be economically justified, with one additional site considered essential to provide the desired degree of protection. A report on the investigation was completed in 1963. However, no application for development of the watershed has been filed.

Pomme de Terre Dam and Reservoir

The Pomme de Terre River, a tributary of the Osage, rises in western Webster County, Mo., and flows generally north to empty into the Osage River near Fairfield, Mo. The Pomme de Terre River has been a frequent contributor to floods on the lower Osage River which, in turn, contributes substantially to floods on the lower Missouri River and on the Mississippi River below the mouth of the Missouri.

The Corps of Engineers Pomme de Terre Dam is located 3 miles south of Hermitage in Hickory County, Mo., about 45 miles upstream from the confluence of the Pomme de Terre and Osage Rivers. The dam is about 7,500 feet long, including a dike section, and has a maximum height of about 155 feet above the streambed. The main embankment is about 950 feet wide at the base and 36 feet wide at the crown. The reservoir has a gross capacity of 650,000 acre-feet and controls a drainage area of 611 square miles. On the rare occasions of temporary, full flood control pool impoundment to elevation 874 feet, mean sea level, the water would cover an area of about 16,100 acres. Normal level of the conservation pool, elevation 839 feet, mean sea level, forms a lake of about 7,800 acres. About 13,000 acre-feet of storage space are reserved for accumulation of sediment.

Closure of the dam was made in June 1960 and the project was placed in flood control operation in October 1961. All major construction items of the project were completed by April 1963. Flood protection is provided to more than 7,000 acres along the Pomme de Terre River and, operating in conjunction with other units of the Osage River Basin system, the project contributes to the protection of about 30,000 acres on the lower Osage River, including 2,400 acres bordering the Lake of the Ozarks. As part of the overall Missouri River Basin program, Pomme de Terre Reservoir contributes to the reduction of flood damages on 160,000 acres of highly productive land along the Missouri River and on additional acres along the lower Mississippi. The project has already demonstrated its effectiveness in controlling floods by preventing flood damages of more than a quarter-million dollars. Important benefits in periods of drought will also be realized through releases to improve and stabilize downstream flow.

Located in an area of natural scenic beauty and clear-water streams, the Pomme de Terre Reservoir offers significant recreational opportunities. Sanitary facilities; camp areas; access roads; parking areas; boating, fishing, and swimming aids; and other basic improvements are provided at nine public use areas. The Missouri Park Board has developed one of the areas, and further recreational development is expected from local and governmental sources. The reservoir's popularity as a recreational area has been demonstrated by more than 1 million visitors during each of the past 2 years.

Although power was authorized at Pomme de Terre, production at the present time has been determined economically unfeasible by the Federal Power Commission. Provision has been made for installation

of power facilities at some future date, if needed. If power is developed at Pomme de Terre, the operation will be coordinated with power operation at the Kaysinger Bluff and Stockton Reservoirs for maximum overall efficiency.

Bagnell Dam-Lake of the Ozarks

Located on the Osage River at mile 81.7, Bagnell Dam forms the Lake of the Ozarks. The project was constructed by the Union Electric Co. of Missouri for the generation of hydroelectric power and was placed in operation in 1931. The dam is a gravity-type concrete structure about 2,500 feet long and 148 feet high. The power installation consists of eight units with a total installed capacity of 176,200 kilowatts.

The lake extends for about 90 miles along the Osage River and, with its many arms at tributary inlets, forms a shoreline of more than 1,300 miles. It has a surface area of approximately 60,000 acres. At full pool, the reservoir has a total storage capacity of over 2 million acre-feet. The project is operated under Federal Power Commission License No. 459. It generates peaking power for the company's extensive network in eastern Missouri.

The Lake of the Ozarks has become a recreational mecca of national significance, and the tourism which it has engendered has enhanced the economy of this part of the Missouri Ozarks. Reservoir area developments include many commercial resorts having modern hotel and cabin facilities, permanent residences and summer homes, access roads, boat docks, swimming beaches, and other recreational facilities. The Lake of the Ozarks State Park, located near Osage Beach, is the largest in the Missouri State Park system, containing 16,335 acres. It has 89 miles of shoreline and about 4,000 acres of water.

Kaysinger Bluff Dam and Reservoir

Construction of the Kaysinger Bluff Dam and Reservoir project by the Corps of Engineers was started in October 1964. With the dam on the Osage River about 1 mile upstream from Warsaw, at the headwaters of the Lake of the Ozarks, the reservoir will control flows of both the Osage and South Grand Rivers. As originally authorized by the Flood Control Act of 1954, purposes other than flood control were considered as incidental. However, subsequent studies led to authorization by the Flood Control Act of 1962 of a project modification which provides for a substantial conservation pool and hydroelectric power generating facilities.

Current plans provide for a 100-year sediment reserve and a conservation and power pool of 1,040,000 acre-feet. This will create a lake of 55,600 acres, second in Missouri only to the 60,000-acre Lake of the Ozarks. Above this pool level, there will be storage space for temporary impoundment of 3,918,000 acre-feet of floodwater, or enough when operating in conjunction with other existing and authorized reservoirs to control the 1951 flood runoff. The dam will be a compacted earthfill structure rising 100 feet above the normal level of the Lake of the Ozarks and extending about 5,000 feet across the valley. It will include a concrete spillway and powerhouse section in the right abutment. In addition, there will be a substantial dike section across Sterret Creek Valley, about 2 miles northeast of the damsite.

As now planned, the power installation will consist of reversible pump turbines with an installed generator capacity in excess of 150,000 kilowatts and will be operated as a pumped storage hydropower plant utilizing the Lake of the Ozarks as an afterbay. Power operation of Kaysinger Bluff and Stockton Reservoirs will be coordinated to insure maximum overall efficiency.

The Kaysinger Bluff project will provide flood protection to the resort and recreational areas along the shores of the Lake of the Ozarks. Operating in conjunction with the authorized upstream reservoirs in the basin, it will protect about 28,000 acres along the Osage River below the lake. It will also contribute to the protection of areas along the Missouri River downstream from the mouth of the Osage, in the Greater St. Louis area, and in other areas along the Mississippi River.

A notable feature of the Kaysinger Bluff project has been the coordination of planning and construction between the Federal Government and the Missouri State Highway Commission in the reconstruction of State Highway No. 13 south from Clinton. To avoid subsequent relocation of the new road as a part of the reservoir construction, the Federal Government contributed to the road construction as coordinated with the reservoir plan. This cooperative action, authorized by Public Law 86-645, permits the Federal Government to participate in urgently needed road relocations prior to actual reservoir construction.

The expanding population, increased length of vacation periods, anticipated shorter workweek, and longer life expectancy with more persons in a retired status all produce increased demands for outdoor recreation. These facts, coupled with a highly mobile public, can be expected to result in an exceptionally large annual recreation usage of the Kaysinger Bluff Reservoir. Situated generally within the Ozark region, the reservoir will provide a variety of recreation opportunities attractive to much of the public. The project is tentatively scheduled for completion in 1972.

Stockton Dam and Reservoir

The Stockton Dam is located on the Sac River, a tributary of the Osage River, in Cedar County some 2 miles east of Stockton. Construction of this multiple-purpose project was started in October 1963 and overall completion is scheduled for late 1970. The primary purposes of the reservoir are flood control, hydroelectric power, augmentation of low flows, and recreation.

The dam complex will include a rockfill, clay core embankment 5,100 feet long and 153 feet high above the streambed; a concrete gravity-type spillway; and a powerhouse in the left (west) abutment. An administration building, operators quarters, overlook, and other facilities will be located near the dam.

The gross capacity of the reservoir will be 1,674,000 acre-feet, of which 774,000 are allocated to flood control, 875,000 to power and recreation, and 25,000 to sedimentation. The conservation pool will have a surface area of 24,900 acres and a shoreline of 298 miles. At full pool elevation, the impoundment would temporarily cover 38,300 acres.

Stockton Reservoir will provide flood protection to about 19,300 acres along the Sac River above the Kaysinger Bluff Reservoir area. It will contribute to the protection of about 28,000 acres along the

Osage River below Kaysinger Bluff, 160,000 acres along the Missouri River, and additional areas along the middle and lower Mississippi River.

The Stockton powerplant will consist of one turbine generator unit with an installed capacity of 45,200 kilowatts and the power pool operation will be coordinated with the Kaysinger Bluff Reservoir operation for maximum overall efficiency.

It is anticipated that after a short development period, annual recreation usage of Stockton Reservoir will reach about 1½ million visitor-days. In order to accommodate this large annual attendance, 10 public-use areas are planned for initial development. In addition sites have been designated for camp development and use by nonprofit, quasi-public groups such as Boy Scouts, Girl Scouts, and church councils. The Missouri State Park Board plans to enter into the recreation program at Stockton by developing one of the 10 public-use areas as a State park.

Hackleman Corner Dam and Reservoir

The Hackleman Corner Reservoir was authorized as a unit of the Osage River Basin program in 1954. The Hackleman Corner damsite is located on Cedar Creek in Cedar County, Mo., about 10 miles northwest of Stockton, where the project would control the runoff from an area of 415 square miles. Preliminary plans envision an earthfill dam about 5,000 feet in length and rising about 75 feet above the streambed.

Hackleman Corner Reservoir would provide flood protection to about 1,500 acres along Cedar Creek and, together with Stockton Reservoir on the Sac River, would protect about 10,000 acres downstream on the Sac. It would contribute proportionately to the protection of about 28,000 acres on the lower Osage River, including shore areas of the Lake of the Ozarks, and additional areas along the Missouri River below Jefferson City and along the middle and lower Mississippi River. Its public use facilities would accommodate an estimated 1 million visitors annually on and around its 9,200-acre lake. The economic feasibility of the reservoir is presently under study in connection with the survey investigation of the upper Osage River tributaries.

Bennett Spring State Park

Water resources developments in Missouri include the utilization of many of the State's big springs. Bennett Spring in the Osage River Basin has an average daily flow of 71 million gallons of clear, cool water. Developments at this location include a State-operated fish hatchery and the Bennett Spring State Park.

Lamine-Blackwater River Basin

The Lamine-Blackwater River Basin is a triangular-shaped area of 2,640 square miles of gently rolling prairie and foothills just south of the Missouri River, in west-central Missouri. The Lamine River, formed by the junction of Flat and Richland Creeks in the southeastern portion of the basin, meanders 64 miles north and east before entering the Missouri River at mile 202.2 near Boonville. The Blackwater River and its tributaries drain 1,550 square miles in the northern and western portions of the basin and discharge into the Lamine River about 10 miles above the mouth. The Lamine-Blackwater basin is

primarily an agricultural area, although it contains several important communities including Sedalia, Mo.

Floods on the Lamine and Blackwater Rivers are usually the result of spring and summer storms. However, the maximum flow of record on the Blackwater River at the Blue Lick gage, 54,000 cubic feet per second, occurred in November 1928 within 6 days after the minimum flow of only 0.5 cubic feet per second. A flow of 66,500 cubic feet per second was recorded at the Valley City gage on the Blackwater River in April 1960. On the Lamine River, the maximum recorded discharge of 65,500 cubic feet per second occurred in the flood of June–July 1951. About 100,000 acres in the two basins are subject to flooding and the June–July 1951 flood resulted in damages estimated at more than $5 million. In addition to the flood problem, the inadequacy of local water supplies has posed a serious threat during drought periods. The cities of Sedalia and Concordia, Mo., have both expressed an interest in water supply storage in any nearby reservoirs that might be built. Some channel deterioration has occurred, especially in the lower reaches of channels which were straightened about 50 years ago.

The Corps of Engineers, in response to a resolution of the Committee on Flood Control of the House of Representatives, adopted September 18, 1944, made an investigation in 1960 of the need for improvements for flood control and allied purposes on the Lamine and Blackwater Rivers. Various types of improvements were considered, but it was found that the most suitable solution to the basin's water resource problems consisted of a system of flood control reservoirs. Under the then current criteria, however, such a plan was found to be not economically justified and it was concluded that no practicable and economical Federal flood control project could be developed at the time. An investigation of the flood and related water resource problems on Flat Creek, a tributary of the Lamine River, was authorized by resolution of the Committee on Public Works, U.S. Senate, adopted October 21, 1965. Funds for this investigation have not yet been made available.

The Soil Conservation Service has completed a pilot watershed project on a 20-square-mile area along East Branch of South Fork of the Blackwater in Johnson County, Mo. This project includes 28 small retarding structures with detention capacities ranging from 0.60 inch to 3.72 inches of runoff, controlling a total of 6.93 square miles. The Soil Conservation Service also has under construction a Public Law 83–566 watershed project on the South Fork of the Blackwater, also in Johnson County. The watershed comprises an area of about 102 square miles and plans call for the construction of eight floodwater retarding structures, two of which will be multiple-purpose projects; 14 grade stabilization structures; 7.5 miles of channel improvement; and land treatment measures. The floodwater retarding structures will temporarily detain runoff from about 41 percent of the total watershed area. The two multiple-purpose structures will include municipal water supply storage for the towns of Holden and Kingsville, Mo., in addition to providing floodwater storage. The project is scheduled for completion in 1969. In addition to Federal measures, local interests have spent substantial amounts on drainage projects and channel improvements on the Blackwater River and its tributaries, Salt Fork and Davis Creek. These projects have generally provided protection against the smaller floods, except in the downstream portions

where streamflow deceleration has caused channel sedimentation and loss of capacity.

Chariton and Little Chariton River Basins

The Chariton and Little Chariton Rivers are left-bank tributaries of the Missouri River which together drain an area of 3,080 square miles in southern Iowa and north-central Missouri. Originally one drainage system, the two rivers are now separated by a cutoff of the Chariton River through which it discharges into the Missouri River about 12 miles upstream from the mouth of the Little Chariton River. The Chariton River rises in Clark County, Iowa, and flows southeasterly for about 70 miles to the State line, thence southerly through Missouri for 95 miles to the Missouri River. The Little Chariton River is formed by the confluence of Middle Fork and East Fork. Its basin is about 60 miles long, lying to the east of the Chariton River Basin, and is entirely in Missouri. The Chariton-Little Chariton River Basin is largely an agricultural area. The 1960 population of the basin was approximately 95,000. The cities in the basin are generally located on high ground above the flood plains and serve as marketing and distribution centers for the surrounding areas.

There is a continuing history of frequent flooding in the Chariton-Little Chariton River Basin and the area is also subject to droughts. During the 51-year period 1915 through 1965, the lower part of the basin has experienced at least 57 floods of such severity as to warrant newspaper mention. Floods in 1947 caused damages totaling well over $9 million in the basin. The May–June 1960 flood caused damages estimated at about $1 million. In addition to flood problems, there are also problems of pollution and inadequate low flows. In the Little Chariton River Basin, acid leachings from strip coal mine wastelands have contaminated low flows and created an acute stream pollution situation, including extensive fish kill.

Early investigations and local efforts were principally concerned with flooding along the main stem of the Chariton River. More than a dozen drainage districts, located along the main stem and on adjacent tributary reaches, have been organized since 1904 and have spent substantial amounts on local channel improvement projects. In addition, individual landowners have constructed numerous cutoffs and have made minor improvements. The original Chariton River flood control project, authorized by the Flood Control Act of 1944, included tieback levees at the mouth of the river and three sections of channel improvement: Chariton County Unit, Macon-Adair Counties Unit, and Reinhart Ranch Unit. Construction was started on the channel improvement sections in 1948 and the project was substantially completed, except for the levees at the mouth of the river, in 1952. The improvement has recently been expanded to include the previously designated Missouri River Agricultural Levee Unit L–234 (main stem levee along the Missouri River between the Chariton and Little Chariton Rivers and tieback levees along the Chariton and Little Chariton Rivers).

The Chariton River project furnishes substantial flood protection to about 59,000 acres in Chariton, Macon, Adair, and Schuyler Counties in Missouri. This area will be afforded a higher degree of protection when the Rathbun Reservoir, authorized in 1954 and now under construction on the Chariton River about 5 miles north of

Centerville, Iowa, is in operation. The reservoir will also furnish a fairly high degree of protection to about 72,000 additional acres in Missouri along the Chariton River, will afford additional benefits to downstream areas along the Missouri and Mississippi Rivers, and will provide a minimum streamflow in the Chariton River.

The Chariton River Federal project, as built thus far, consists mainly of channel cutoffs and enlargement and clearing of existing drainage ditches. Local interests have constructed four new bridges and modified several others as part of this improvement program. The Corps of Engineers project coordinated, as far as possible, the improvements previously constructed by local interests. The completed portion of the project has prevented flood damages estimated at more than $2.8 million through 1965.

In 1955, a congressional resolution was adopted which requested a review of prior reports on the Chariton River to determine if there was need for additional improvements for flood control and allied purposes in the basin. Subsequent studies of the Corps of Engineers were reported in House Document No. 238, 89th Congress, 1st session, which recommended a plan of improvement for flood control and other purposes. The plan, as originally developed, consisted of (a) 84 miles of channel improvement along Mussel Fork; along Little Chariton River, Middle Fork, and East Fork, including the lower part of Silver Creek; and along lower Shoal Creek; (b) 3½ miles of levee along the Little Chariton River in the Missouri River flood plain; and (c) construction of the Thomas Hill Reservoir on Middle Fork and the Long Branch Reservoir on East Fork of the Little Chariton. These reservoirs, in addition to providing flood control storage, would conserve water for downstream water quality control, fish and wildlife conservation, and recreation. The Thomas Hill Reservoir was to have included industrial water supply for cooling water for a steam powerplant. However, because of power commitments, the power cooperative proceeded with the construction of a reservoir at the Thomas Hill site and this project was excluded from the plan of improvement authorized by the Flood Control Act of 1965. Construction of the project is substantially completed. A study was authorized by resolution of the Senate Public Works Committee in 1965 to determine the Federal interest in the Thomas Hill Reservoir, as privately constructed by the Central Cooperative Power Co., of Missouri.

Thomas Hill Reservoir

The Thomas Hill Dam is located on Middle Fork in northwestern Randolph County. As constructed, the dam is an earthfill embankment about 3,000 feet long. The reservoir has a total storage capacity of 85,500 acre-feet, of which 60,200 acre-feet are allocated to conservation uses and 10,600 acre-feet could serve as flood control storage. The remaining 14,700 acre-feet are reserved for sedimentation. The conservation pool has a surface area of 4,800 acres, while the full pool would temporarily occupy 5,400 acres.

Long Branch Reservoir

The Long Branch Dam will be located on East Fork in south-central Macon County. It will control runoff from a drainage area of 110 square miles. The dam will be a compacted earth embankment 3,550 feet long, rising 74 feet above the streambed. The reservoir will

have a total storage capacity of 67,900 acre-feet, of which 29,300 acre-feet will be allocated to flood control, and 30,900 acre-feet to conservation uses, including downstream water quality control, fish and wildlife conservation, recreation, and possible future water supply. The remaining 7,700 acre-feet are allocated for the 100-year sediment reserve. The normal pool will have a surface area of about 2,500 acres, while the full flood control pool would temporarily occupy 3,650 acres.

The Soil Conservation Service has two watershed projects in the Iowa portion of the Chariton River Basin, but no organized watershed development has yet been undertaken in the Missouri portion. The only other federally financed water resource projects in the basin are small water-conservation ponds constructed by the Work Projects Administration.

The 700-acre Forest Lake, built as a water supply for Kirksville, Mo., is a feature of the 3,152-acre Thousand Hills State Park which attracts over 300,000 visitor-days annually. Smaller impoundments supply water for the cities of Marceline, Macon, Moberly, and Unionville in the Chariton River Basin.

Grand River Basin

The Grand River rises in southwestern Iowa and flows through northwestern Missouri to join the Missouri River near Brunswick, Mo., at river mile 250. The basin is about 150 miles long and 90 miles wide, with the major axis running north-northwest from the mouth. The drainage area of the basin is 7,900 square miles, of which almost 80 percent is in Missouri. The main stem of the Grand River is formed by the confluence of the West Fork, also known as the Grand River, with the Middle and East Forks near Albany, Mo. The principal tributary is the Thompson River which joins the main stem near Chillicothe, Mo. The Grand River Basin is primarily an agricultural area with an average population density of about 20 persons per square mile. The towns in the basin are marketing and distribution points for the immediate areas, with the metropolitan needs served by the nearby cities of St. Joseph and Kansas City, Mo.

The area is subject to intense and prolonged rainfall with consequent flooding of wide, fertile valleys within the basin and downstream along the Missouri River. The Grand River Basin has been plagued with many floods, inflicting millions of dollars of flood damage to the area, and with drought periods which have created critical municipal water shortages. Damage within the basin from the June 1947 flood alone, the maximum flood of record in the basin, was estimated in excess of $22 million.

The need for flood protection on the Grand River was recognized as early as 1888 in an annual report of the Chief of Engineers. Subsequently, numerous reports have covered the flood problems within and related to the basin. There are, however, no federally constructed flood improvements in existence in the Grand River Basin. The Chillicothe Dam and Reservoir, recently deauthorized, had been authorized by the Flood Control Act of 1938. The Missouri River Agricultural Levee project, authorized by the Flood Control Act of 1944, includes units at the mouth of the Grand River. Following the floods in 1915, many local drainage districts were organized for the construction of flood control works. Some 50 districts and 10 privately

financed organizations spent over $10 million for channel straightening, drainage ditches, and levees. Local levees which have been damaged in subsequent floods frequently have been repaired at Federal expense under the emergency repair program.

The flood control and water resources problems of the Grand River Basin have been the subject of investigation for many years and by many Federal and State agencies. The study culminated in a report submitted by the Corps of Engineers which recommended seven multiple-purpose reservoirs and extensive channel improvements and levees. The Flood Control Act of 1965 authorized construction of five of these reservoirs and most of the channel and levee projects. A further study was authorized of the economic feasibility of the proposed Linneus Reservoir on Locust Creek, the proposed St. Catherine Reservoir on East Yellow Creek, the proposed hydroelectric power installation at Pattonsburg Dam, and the proposed improvement of Honey and No Creeks. The projects which were authorized are discussed below.

Pattonsburg Dam and Reservoir

The Pattonsburg Dam, as planned, will be located on the Grand River, about 5 miles upstream from Gallatin, Mo. It will control runoff from a drainage area of 2,323 square miles. The embankment will be a compacted earthfill with a total length of 6,500 feet and a height of about 103 feet above the valley floor. The outlet works section of the dam may include a hydroelectric powerplant of 35,000-kilowatt capacity, providing the financial feasibility is demonstrated in a subsequent study. The reservoir will have a total storage capacity of 2.72 million acre-feet, of which 1.43 million acre-feet will be allocated to flood control, and 956,400 acre-feet to conservation uses, including possible power, water quality control, and recreation. The remaining 333,600 acre-feet are allocated for the 100-year sediment reserve. The conservation pool will have a surface area of about 42,000 acres, while the full flood control pool would temporarily occupy an area of about 77,000 acres.

Mercer Dam and Reservoir

The Mercer Dam on the Weldon River will be located about 6 miles north of Princeton, Mo., and 3 miles southwest of Mercer, Mo. It will control the runoff from an area of 427 square miles. The earthfill embankment will be about 6,700 feet long and 91 feet high above the valley floor. The reservoir will have a total storage capacity of 625,700 acre-feet, of which 326,000 acre-feet are allocated to flood control, and 235,800 acre-feet to conservation uses, including water quality, fish and wildlife, and recreation. The remaining 63,900 acre-feet are allocated for the 100-year sediment reserve. The conservation pool would have a surface area of 12,600 acres, while the full flood control surface would temporarily occupy 19,800 acres. Part of the pool area will extend into Iowa.

Braymer Dam and Reservoir

The Braymer Dam will be located on Shoal Creek, 6 miles north and 1 mile east of Braymer, Mo., close to the Livingston-Caldwell County line. It will control runoff from an area of 390 miles. The earthfill embankment will be about 7,920 feet long and 85 feet high above the valley floor. The reservoir will have a total storage capacity of 573,500 acre-feet, of which 299,500 acre-feet are allocated for flood control,

77-278 O—67——25

and 215,800 acre-feet for conservation uses, including water quality, fish and wildlife, and recreation. The remaining 58,200 acre-feet are allocated for the 100-year sediment reserve. The conservation pool will have a surface area of 11,500 acres, while the full flood control pool would temporarily occupy 19,500 acres.

Brookfield Dam and Reservoir

The Brookfield Dam will be located on West Yellow Creek about 5 miles northeast of Brookfield, Mo. It will control runoff from an area of 140 square miles. The dam will be an earthfill embankment about 4,800 feet long and about 88 feet high above the valley floor. The reservoir will have a total storage capacity of 215,600 acre feet, of which 117,200 are allocated to flood control, and 77,500 acre-feet for conservation uses, including water quality, fish and wildlife, and recreation. The remaining 20,900 acre-feet are allocated for the 100-year sediment reserve. The conservation pool will have a surface area of 4,600 acres, while the full flood control pool would temporarily occupy 7,100 acres.

Trenton Dam and Reservoir

The Trenton Dam will be located on the Thompson River about 5 miles northwest of Trenton, Mo., and about 2½ miles upstream from the mouth of the Weldon River. It will control runoff from a drainage area of 1,079 square miles. The embankment will be compacted earthfill with a total length of 2,640 feet and a height of 97 feet above the valley floor. The reservoir will have a total storage capacity of 1,675,000 acre-feet, of which 748,100 acre-feet are allocated to flood control, and 765,800 acre-feet to conservation uses, including water quality, fish and wildlife, and recreation. The remaining 161,100 acre-feet are allocated for the 100-year sediment reserve. The conservation pool will have a surface area of 32,000 acres, while the full flood control pool would temporarily occupy 46,500 acres.

Other water resources developments

Besides the Corps of Engineers improvement program, the Soil Conservation Service has in various stages seven Public Law 83–566 watershed projects, encompassing nearly 1,000 square miles, in the Grand River Basin. One of the projects, the Grindstone-Lost-Muddy Creek watershed project, will provide for municipal water supply for the city of Maysville, Mo. The following table shows the various watershed projects in the Missouri portion of the Grand River Basin and their status:

Department of Agriculture, Soil Conservation Service, watershed projects in the Grand River Basin

Watershed	County	Area (square miles)	Status
East Fork of Big Creek	Harrison	81.3	Under construction.
Panther Creek	do	34.4	Do.
Big Creek (Daviess)	Daviess	17.0	Do.
Big Creek Tributaries	Harrison	209.4	Application received.
Indian Creek	Livingston	38.3	Do.
Grindstone-Lost-Muddy Creek	Gentry, DeKalb, and Daviess	326.7	Work plan approved.
West Fork Grand	Gentry, Nodaway, and Worth.	286.5	Application received.

The U.S. Fish and Wildlife Service maintains its 10,679-acre Swan Lake National Wildlife Refuge near Sumner, Mo. The 2,150-acre State-owned Fountain Grove Wildlife area is a few miles upstream on the Grand River near Fountain Grove, Mo. The Swan Lake and Fountain Grove areas have become valuable waterfowl refuges and both offer public shooting opportunities. While these facilities have enhanced the recreation and fish and wildlife resources of the basin, there is a need for further development such as can be achieved by the authorized reservoirs. Fishing and municipal water supply lakes include Lake Paho, a State-owned fishing lake in Mercer County.

Fishing River Basin

Fishing River is a left-bank tributary of the Missouri River, draining an area of 282 square miles in Clay, Ray, and Clinton Counties, Mo. At the lower end of the basin, in Ray County, Fishing River and the Missouri River share a common flood plain, which will ultimately be protected against both Missouri River and Fishing River floods by the authorized Missouri River Agricultural Levee system. The basin is roughly triangular in shape, about 27 miles long and 20 miles wide. The larger tributary streams are Clear Creek and East Fork Fishing River. The basin is largely a rural area with an economy based on crop and livestock production. However, the urban area of Kansas City, Mo., extends into the western headwaters, and Excelsior Springs, a spa and health resort since the discovery of mineral water springs in 1880, is located in the eastern part of the basin. In 1960, the population of Excelsior Springs was approximately 6,500 but this population is often exceeded by the number of transients in the city.

The Fishing River Basin is subject to both intense, flood-producing storms and periods of drought. The most severe flood of record occurred in 1947, when damage in the basin amounted to $1.8 million. Of this total, approximately $1.1 million occurred in Excelsior Springs, along East Fork and Dry Fork which have their confluence in the heart of the city. Damaging floods also occurred in the basin in 1941, 1943, 1951, and 1965, the latest causing an estimated $1.6 million damage. Other water resource problems are concerned with the need for municipal water supply for Excelsior Springs, streamflow supplementation for water quality control, and facilities suitable for water-based recreation in the area.

In response to congressional resolutions adopted in 1961 and 1962, the Corps of Engineers made an investigation of the water resource problems in the Fishing River Basin, which was reported in House Document No. 281, 89th Congress, 1st session. The plan of improvement, as recommended by the Corps of Engineers and authorized by the Flood Control Act of 1965, consists of two multiple-purpose reservoirs, one of which will be located on Dry Fork and the other on East Fork Fishing River, upstream from Excelsior Springs. Together, they will prevent an estimated 97 percent of the average annual flood damage at Excelsior Springs. Both reservoirs will provide storage for water quality control and recreation, and East Fork Reservoir would additionally provide storage for municipal water supply.

East Fork and Dry Fork Reservoirs

The East Fork dam, as planned, will be a compacted earthfill structure across the East Fork about 0.5 mile northeast of Excelsior

Springs. It will control runoff from a drainage area of 19.4 square miles. The embankment will be 1,900 feet long and about 135 feet high above the valley floor. The reservoir will have a total storage capacity of 27,000 acre-feet, of which 11,360 acre-feet are allocated to flood control, 13,700 acre-feet to conservation uses, and 1,940 acre-feet for the 100-year sediment reserve. The conservation storage includes 5,000 acre-feet for Excelsior Springs municipal water supply, 2,500 acre-feet for water quality control, and 6,200 acre-feet for recreation. The full conservation pool will have a surface area of 480 acres, while the full flood control pool will temporarily occupy an area of 700 acres.

The Dry Fork Dam will be located on Dry Fork less than 0.5 miles north of Excelsior Springs. It will control runoff from a drainage area of 3.2 square miles. The compacted earth embankment will be 940 feet long and about 95 feet high above the valley floor. This reservoir will have a total storage capacity of 3,620 acre-feet, of which 1,620 acre-feet are allocated to flood control, 1,730 acre-feet to conservation uses, and 320 acre-feet for the 100-year sediment reserve. The conservation pool will form a lake of 75 acres and, when full, the reservoir will temporarily occupy 120 acres. Application has been made for a Soil Conservation Service investigation of the Williams Creek watershed, which comprises an area of 16,000 acres in Clay County, and of the Kinney-Rollins Creek watershed, which has an area of about 25,000 acres in Ray County. Applications for these watershed projects have been approved by the Governor's Watershed Advisory Committee.

Little Blue River Basin

The Little Blue River is a right-bank tributary of the Missouri River located in Jackson and Cass Counties, just east of Kansas City, Mo. The basin has an area of approximately 225 square miles and is 38 miles long and about 13 miles wide. Although the basin lands are still largely agricultural, there is substantial industrial and transportation development, and suburban residential development is accelerating. Cities and communities occupying portions of the basin include Grandview, Lee's Summit, Unity Village, Knobtown, Kansas City, Raytown, Independence, and several others. Other developments in the basin include parts of the Richards-Gebaur Air Force Base, the Lake City Army Ammunition Plant, and the municipal airport and powerplant of Independence, Mo.

The downstream portions of the Little Blue River were subjected to 15 floods during the period 1948 to 1965, with the most severe of record occurring in September 1961. Damages totaled nearly $900,000. In addition to the flood problem, the Raytown and Lee's Summit sewage treatment plants, and several small plants constructed in connection with real estate developments, discharge their effluent into the Little Blue River, thus creating a water quality problem. With the rapidly expanding suburban development, this problem is expected to become more acute. The population increase in the basin is also creating water supply problems.

The only Federal flood control improvements in the Little Blue River Basin are the downstream tieback levee and attendant channel rectification works of Missouri River Agricultural Levee Unit 351–R,

which extend about 9 miles up the Little Blue River. Construction of the unit is scheduled to be essentially complete by the end of 1966. The Prairie Lee Lake was constructed under the Works Projects Administration as a recreation lake in the 1930's and is operated and maintained by Jackson County, Mo. Lake Jacomo was developed and is operated by the county as a public recreational area. A third reservoir in the basin, Lake Tapawingo, is a private real estate development. Resolutions of the Senate and House Committee on Public Works, adopted in 1962, authorized the Corps of Engineers to make an investigation of the need for improvements for flood control and allied purposes. The investigation was initiated with a public hearing at Independence in March 1964, and is scheduled for completion in 1966. Types of improvements under consideration are multiple-purpose reservoirs, levees, and channel improvements.

Blue River Basin

The Blue River is a right-bank tributary of the Missouri River, draining an area of 272 square miles in Jackson and Cass Counties, Mo., and Johnson County, Kans. It is formed by the confluence of Wolf Creek and Coffee Creek between the towns of Stanley and Stillwell, Kans., and flows in a generally northeasterly direction to the Missouri River. The upper portion of the basin, in Kansas, is largely suburban and rural, while the lower portion, much of which is within the city limits of Kansas City, Mo., is heavily industrialized and contains a highly developed transportation system.

The Blue River basin has suffered numerous damaging floods. The most severe flood of record in the basin occurred in September 1961, causing damages estimated at about $8 million. Severe floods were also recorded in 1928, 1935, 1951, and 1958. The flood problem along the Blue River has been aggravated by economic growth, with its increased flood damage potential; by industrial, commercial, and transportation encroachments on the floodway; and by the increased runoff rate from pavements and other developments in the area.

The flood threat has long been of concern to city officials, businesses, and residents in the basin. The channel of Brush Creek, a major tributary, has been improved and stabilized, and this work has been quite effective in reducing floods along that stream. During the 1930's, some minor channel improvements were made under the Work Projects Administration program to increase the channel capacity of the Blue River, but they have not been maintained. The report on the Missouri River and tributaries at Kansas Citys, Mo. and Kans., prepared in 1943, included one unit in the Blue River Basin, designated the Blue Valley industrial unit, in the plan of improvement. This unit, however, was never constructed. After the record flood of 1961, interest in flood control was renewed by the city of Kansas City, Mo., and other local interests. Resolutions of the Senate and House Committees on Public Works, adopted in 1961 and 1962, respectively, authorized the Corps of Engineers to investigate the flood and related water resource problems in the Blue River Basin. A public hearing on the matter was held at Kansas City in December 1962 to obtain the views of local interests and a report on the investigation is scheduled for completion in 1966. Types of improvements under consideration include multiple-purpose reservoirs in the upper basin and channel

improvements, levees, and floodwalls in the more extensively developed areas. A report is also being prepared by the Corps of Engineers to present information on floods and flood hazards along the Blue River within the limits of Kansas City, Mo., in response to an application by the city in 1962. This report is also scheduled for completion in 1966.

Platte River Basin

The Platte River rises in southwestern Iowa and flows southward through northwestern Missouri to its confluence with the Missouri River at mile 391.1, a few miles above Kansas City. It drains an area of 2,440 square miles, of which nearly 70 percent is in Missouri. The basin is 135 miles long and has a maximum width of 28 miles. Major tributaries of the Platte River are the One Hundred and Two River and the Little Platte River. The economy of the basin is primarily agricultural, except in the vicinity of the two major urban areas of Kansas City and St. Joseph, Mo.

The Platte River Basin area is subject to the extremes of intense flood-producing storms, usually occurring during the period March through July, and extended drought periods. Excessive rainfall and resulting floods may, however, occur during any month. In the middle and upper part of the basin, local interests have made extensive channel improvements which have been effective in reducing the damage from flood flows through these reaches but severe flood problems remain in the lower part of the basin. Near the mouth, one tieback levee of the Missouri River Agricultural Levee program has been constructed and another is authorized. Flooding has occurred at Agency, Mo., and in the lower part of the basin during 31 of the past 42 years. The most severe flood of record in the basin occurred in 1947 when damage was estimated at $7.7 million. In July 1965, a storm in northwest Missouri, with rainfall amounts ranging up to 20 inches, produced the maximum flood of record in the lower Platte River Basin. The total flood damage from this flood was estimated at $6.7 million, of which about $2.8 million was damage to the town of Smithville, Mo., on the Little Platte River. In addition to the flood problems, there are existing and foreseeable needs for water conservation throughout the basin.

A flood control and water resources investigation by the Corps of Engineers led to authorization, by the Flood Control Act of 1965, of the Smithville Reservoir on the Little Platte River near the town of Smithville, and of channel improvements on the Platte and Little Platte Rivers. The Smithville Reservoir will provide flood protection for the city of Smithville, and will contribute to flood protection along the little Platte and lower Platte Rivers. It will also furnish municipal water supplies for Kansas City and Smithville, will assure water quality control and a desirable flow for fish and wildlife below the dam, and will afford opportunities for outdoor recreation. The Platte River improvement will include 38 miles of channel realinement and enlargement from the mouth upstream to the vicinity of Agency. The Little Platte River improvement will involve 2.4 miles of channel rectification in the vicinity of Smithville. In addition to the Smithville Reservoir, the Corps of Engineers included in its study an investigation of five other reservoirs in the basin for possible future development. These, however, failed to meet all the necessary economic criteria under current conditions.

Smithville Dam and Reservoir

The Smithville Reservoir, as planned, will be located on the Little Platte River about 1 mile northeast of Smithville and 5 miles from the north city limits of Kansas City, Mo. It will control runoff from an area of 219 square miles. The dam will be a compacted earthfill structure, 4,200 feet long and 95 feet high, with a 2,000-foot dike over a saddle in the left abutment, about one-half mile southeast of the damsite. The reservoir will have a total storage capacity of 299,000 acre-feet, with 105,000 acre-feet for flood control, 105,000 acre-feet for conservation uses, and 89,000 acre-feet for the 100-year sediment reserve. The conservation storage includes 90,000 acre-feet for Kansas City water supply, 8,000 acre-feet for Smithville water supply, and 7,000 acre-feet for streamflow regulation in the interest of fish and wildlife conservation and water quality control. The conservation pool will have a surface area of 7,800 acres, while the full flood control pool will temporarily occupy an area of 12,500 acres.

Other developments in the Missouri portion of the basin include two watershed projects of the Soil Conservation Service which will provide floodwater detention structures, grade stabilization structures, channel modifications, and land treatment measures. One of these, the Platte River and tributaries watershed project in Worth County, is completed. The other project is the One Hundred and Two River tributaries watershed in Nodaway County, which is under construction. The latter watershed project also provides for construction of a multiple-purpose reservoir about 5 miles north of Maryville, Mo. In addition to providing flood detention storage capacity, the reservoir will have a permanent lake of 72.5 acres, primarily for fishing and other recreational use. This lake will help to satisfy the increasing demand for water-based recreation in northwestern Missouri. The Missouri Conservation Commission is one of the sponsors of the project and will take over operation and maintenance of the reservoir upon its completion.

The only other Federal improvements in the Platte River Basin were constructed many years ago as part of the Work Projects Administration program. These consist mainly of small water conservation projects on individual farms.

Nodaway River Basin

The Nodaway River rises in southwestern Iowa and flows in a generally southerly direction through a predominantly rural agricultural area to its junction with the Missouri River a few miles upstream from St. Joseph, Mo. The river drains an area of about 1,800 square miles and occupies a basin approximately 115 miles long and varying in width from 10 to 35 miles.

The Nodaway River Basin area is subject to both floods and periods of drought. The most severe flood of record in the basin occurred in June 1947, causing damages estimated at more than $4 million. Floods during May–July 1951 and June–July 1965 each caused more than $1 million damage. Severe floods were also experienced in 1885 and 1903. As means of alleviating flood damage from frequent overflows, channel improvements and local levees have been constructed over the years by organized levee and drainage districts and by individual landowners. These measures have been partially successful

and have reduced the flood damages, but the improvements have not been coordinated and they have not solved the basin's flood problems. A resolution of the Committee on Flood Control of the House of Representatives, adopted in 1946, requested the Corps of Engineers to investigate the need for improvements for flood control and allied purposes in the Nodaway River basin. However, no funds were provided, and the study has not been initiated.

The Soil Conservation Service has under construction a watershed protection and flood prevention project for the Hoover-Frankum Watershed in west-central Nodaway County, Mo. This watershed has an area of 28.6 square miles and includes a group of right bank tributaries of the Nodaway River. The project consists of grade stabilization structures, channel improvement, and land treatment measures.

LOWER MISSISSIPPI RIVER AND TRIBUTARIES

Lower Mississippi River

Lower Mississippi River channel improvement

Below the Chain of Rocks Canal and Locks No. 27, below the mouth of the Missouri River, the Mississippi is an open river. A low-water navigation channel 9 feet deep and 300 feet wide is provided by the stabilization of the channel by means of revetment and dikes and by selective dredging. Protection of the banks from erosion and caving is accomplished by revetment, composed of articulated concrete mattress under water and a riprap or asphalt pavement above the waterline. In 1944, an increase in the low-water depth to 12 feet was authorized for the Mississippi River channel below the mouth of the Ohio River, and this work, too, is being accomplished by the Corps of Engineers. The Mississippi River, which served initially as the route of the earliest explorers to reach Missouri, now carries over 30 million tons of traffic past St. Louis, annually.

St. Louis and vicinity local protection project

Protection for St. Louis, Mo., against Mississippi River floods is provided by a levee and floodwall system along the riverfront, now under construction by the Corps of Engineers. When completed, the project will include 10.6 miles of levees and floodwalls, closure structures, 26 pumping plants, and alteration to 44 sewer systems which will provide protection to about 3,200 acres of heavily urbanized area.

Perry County Drainage District

Extensive levee improvements and construction are nearly completed in the Perry County Drainage and Levee Districts, where 26,000 acres of agricultural land are being protected from major floods on the Mississippi River.

Cape Girardeau local protection project

At Cape Girardeau, 1,900 feet of levee and 6,100 feet of floodwalls, pumping stations, and apurtenant works provide protection against Mississippi River floods to the main business district of the city.

Mississippi River levees

Main line Mississippi River levees within the lower Mississippi River Valley are considered as one project. There are about 1,657

miles of these levees, starting on the west bank just south of Cape Girardeau and, except for gaps where tributaries join the Mississippi, extending unbroken almost to the Gulf of Mexico.

The Mississippi River levee system in the State of Missouri is 142 miles in length, of which 141 miles have been completed to the authorized grade and includes the lower 20 miles of the Little River Headwater Diversion system. The levees in the Little River Headwater Diversion system are part of the project adopted by the act of May 15, 1928, for flood control of the lower Mississippi River Valley. They protect urban and rural areas of more than 992,000 acres from the maximum probable Mississippi River floods.

The Birds Point-New Madrid Floodway, a part of the authorized project in Missouri, extends from opposite Cairo, Ill., to New Madrid, Mo., on the right bank of the Mississippi River. This floodway, consisting of 130,000 acres, insures when necessary a wider passage for the floodwaters during periods of excessive streamflow in the Mississippi and Ohio Rivers. Its primary purpose is to aid in fully protecting Cairo by reducing the stages of extreme flood crests.

The St. Johns Bayou project, adjacent to the lower end of the Birds Point-New Madrid Floodway, and consisting of a controlled outlet culvert, is complete. It will prevent flow of Mississippi River backwater behind the Mississippi River levee on the Missouri side of the river in the St. Johns drainage area. This work is part of the lower Mississippi River Valley levee system.

New Madrid Floodway

Modification of the existing flood control project was authorized by the 1954 Flood Control Act, to provide improvements needed in the New Madrid Floodway area. The modification provides for the closure of the existing levee gap at the lower end of the floodway and the construction of a floodgate to prevent the overflow of lands in the floodway by backwater from the Mississippi River. The project will benefit about 48,000 acres, and will have no appreciable effect on the floodway operation of the existing project. Planning for the improvement is in progress, but construction has not been initiated.

Meramec River Basin

The Meramec River Basin covers an area of approximately 4,000 square miles in the east-central portion of Missouri and embraces parts or all of 15 counties. The drainage system consists of the Meramec River and its two principal tributaries—the Big River and the Bourbeuse River. The basin resembles a somewhat irregular rectangle with a median length of about 65 miles and a median width of about 55 miles. The basin may be described as a highly dissected plateau with land surface sloping gently to the north and becoming increasingly more rugged to the south. Local relief averages between 200 and 400 feet. The population of the basin is approximately 212,000, of which almost half is in the St. Louis metropolitan statistical area. Approximately 62 percent of the land in the basin is in timber, 35 percent in crop land and pasture land, and the remaining 3 percent in other uses. Excluding St. Louis County, about 25 percent of the basin labor force is engaged in agricultural pursuits. Crop production is principally for a livestock economy. Commercially significant natural resources

in the basin consist primarily of iron and lead with some limestone and gravel production.

Average annual rainfall in the basin is about 39 inches. Streams in the basin are characterized by extreme range in flows and rapid fluctuation in stages. Frequent large floods occur during the period of March through June with occasional lesser floods during the remainder of the year. Relatively slow infiltration results in the high rate of runoff, and the steep topography allows runoff to reach the streams quickly. The greatest flood of record (August 1915) had a measured flow of 175,000 second-feet at Eureka, Mo. The lowest flow of record, 196 second-feet, occurred in 1936.

The U.S. Forest Service owns and manages approximately 192,000 acres of the Clark National Forest located within the boundaries of the basin. In addition to timber management and development, that agency has established recreational and camping facilities. The Missouri State Park Board operates two parks within the basin, Meramec State Park and Washington State Park. Meramec State Park, located on the Meramec River near Sullivan, Mo., contains approximately 1,100 acres of land. Each of these two parks provides water-oriented and land-based recreational facilities. A park at Meramec Spring has been developed at the site of a historic iron ore smelter and is maintained by the James Foundation. Stock trout fishing is maintained by the Missouri Conservation Commission in the Spring Branch. Indian Trails State Forest and Refuge, containing some 13,300 acres, is located near Salem, Mo. This area is maintained primarily for timber management and development and as a wildlife refuge.

The Corps of Engineers has recently completed a comprehensive basin study and has recommended for construction five reservoirs and establishment of 19 angler-use sites to meet the immediate and near future needs of the basin for flood control, general recreation, water supply, water quality control, and fish and wildlife conservation. Of the five reservoirs, two, Union and Bourbeuse River, are located on the Bourbeuse River; two, Pine Ford and Irondale, are located on the Big River; and Meramec Park is located on the Meramec River. The reservoirs will substantially reduce flood damages in the Meramec Basin and effect important reduction of flood crests on the Mississippi River; provide approximately 27,800 water surface acres for recreation with a total shoreline length of about 400 miles; with full development of recreational facilities, the reservoirs will support approximately 12 million visitor-days annually; with conversion of joint use storage at selected points of time, will provide all water supply requirements in the lower basin area to the year 2070, as well as provide acceptable levels of water quality control through stream flow augmentation in both the upper and lower basin area; and by the operation of the reservoirs for low flow augmentation will provide incidental benefits to navigation during low flow periods on the Mississippi River. The 19 angler-use sites in conjunction with the reservoirs will enhance hunter and fisherman opportunities in the basin. Of these five reservoirs, Meramec Park and Union have been previously authorized by the Flood Control Act of June 28, 1938. Under that authorization, preconstruction planning for the Meramec

Park Reservoir has been initiated. Certain headwater reservoirs found economically justified may be constructed under the provisions of Public Law 80–858, as amended, or Public Law 83–566.

The Department of Agriculture has recently completed a study which provides a framework of future needs as to headwater reservoirs and installation of land treatment practices. Approximately 60 reservoirs are proposed for watershed protection and recreation. Some storage will be available for municipal water supply, irrigation, and fish and wildlife uses. Some 48 reservoirs will provide about 11,000 surface acres for much-needed water-based recreation. Five local protection projects, located in the lower reaches of the Meramec and found economically feasible, have been deferred until after construction of the major reservoirs (Meramec Park, Union, and Pine Ford) and the need for additional flood protection has been established.

ST. FRANCIS RIVER BASIN

St. Francis River

The St. Francis River rises in the rugged hill section of southeastern Missouri and flows in a generally southerly direction 475 miles through Missouri and Arkansas to enter the Mississippi River near Helena, Ark. It drains an area of 8,400 square miles, of which approximately 30 percent is in the alluvial valley of the Mississippi River. The basin is about 215 miles long and has a maximum width of 53 miles. The major tributary of the St. Francis is Little River. The St. Francis River Basin covers portions of seven counties in Missouri. Principal urban centers are Sikeston, Kennett, Caruthersville, Dexter, Malden, Hayti, New Madrid, and Portageville. Agriculture is the predominant economic activity within the basin.

High river stages may usually be expected during January to May, and serious floods occur at intervals of about 3 years. Even when overflow is not experienced, sustained high stages, resulting in ineffective draining, frequently prevent cultivation of large areas or reduce the yields therefrom.

A St. Francis River Basin flood control project, a feature of the Mississippi River and Tributaries project, was adopted by the Flood Control Act of May 15, 1928, as later modified by the acts of June 15, 1936, June 28, 1938, August 18, 1941, July 24, 1946, May 17, 1950, and October 27, 1965. Approximately 465,000 acres in Missouri will be protected from floods when the Missouri portion of the comprehensive St. Francis River Basin project for flood control and drainage is completed.

Wappapello Dam and Reservoir

The Wappapello Reservoir, located on the St. Francis River in Wayne County, Mo., is a principal feature of the comprehensive plan for the control of floods in the St. Francis River Basin project, Missouri and Arkansas. The project was authorized by the Flood Control Act of 1936 and was placed in operation in June 1941. Its overall designed effectiveness is dependent upon downstream levees and other flood control works in the alluvial valley, some of which are not yet under construction.

The Wappapello Dam is a compacted earthfill structure extending across the St. Francis River for a distance of 2,700 feet and rising to

a height of 109 feet above the streambed. The reservoir controls a drainage area of 1,310 square miles. It has a total storage capacity of 625,000 acre-feet, of which 586,000 acre-feet are allocated to flood control and 39,000 acre-feet to conservation. The flood control pool, when filled, has an area of 23,000 acres. The conservation pool has an area of 5,200 acres. Release of water is regulated by means of three gates in the control structure, electrically operated with power supplied by a small hydro plant. Public-use attendance at Wappapello Reservoir for the period 1950 through 1965 averaged about 683,000 annually. Visitor-day attendance at the project totaled approximately 1.1 million during 1965.

Other water resource developments

Other Missouri features of the project in the valley include channel improvements of the main stream between Wappapello Reservoir and Crowleys Ridge, and some tributaries; a levee on the west bank of the St. Francis above Crowleys Ridge; a leveed floodway below that reach; levees protecting the Elk Chute drainage district near Hornersville, Mo.; and a small portion of the west bank levee of Little River between Hornersville and Big Lake. Total length of these levees is 122 miles. By June 30, 1965, the partly completed project had prevented damages in Missouri amounting to more than $8 million.

The St. Francis River Basin project in Missouri also includes improvements in the Little River Basin. Features include enlargement and extension of the upper 14.5 miles of the Little River headwater diversion levee and improvement of Elk Chute Ditch and several ditches in the Little River Drainage District of Missouri. Improvements within Little River Basin will provide protection for about 200,000 acres in the southeastern part of Missouri.

In 1951 and 1952, the U.S. Fish and Wildlife Service established the Mingo National Wildlife Refuge northwest of Puxico, Mo., in an area which was formerly subject to flooding by the St. Francis River. The refuge consists of about 21,600 acres in Stoddard and Wayne Counties, Missouri, and provides a feeding and resting area for migratory waterfowl. Runoff from about 104 square miles is impounded in the area by means of a dike constructed along the approximate southern boundary of the refuge, which is above the latitude of Wappapello Dam. Outflow from the refuge to the St. Francis River, through Mingo ditch, is controlled by a radial gate and a spillway.

The Little River Drainage District of Missouri, which embraces parts of seven southeastern Missouri counties, has constructed a network of ditches which carries the runoff from 750 square miles within the district and from about 960 square miles of adjacent lands in the Little River Basin into the head of Big Lake at the Missouri-Arkansas State line. The Little River Drainage District also constructed the headwater diversion system which prevents runoff from about 1,200 square miles of Ozark foothills from entering the lowlands of the Little River and St. Francis River valleys.

Other local drainage districts in Missouri have constructed many hundreds of miles of drainage ditches tributary to the Little River and St. Francis River systems. They include ditches in New Madrid, Pemiscot, Dunklin, Stoddard, and Scott Counties.

WHITE RIVER BASIN

White River

The White River rises in the rugged terrain of the Boston Mountains of northwestern Arkansas at an elevation approximately 2,100 feet above mean sea level. It flows in a general northerly direction for about 128 miles where it crosses the Missouri-Arkansas State line and then flows easterly through southern Missouri for about 115 miles where it intersects the State line once again. It meanders on either side of the Missouri-Arkansas boundary for 30 miles where it begins a southeasterly flow through Arkansas for about 190 miles to the vicinity of Newport, Ark. Downstream from Newport, it flows southerly for about 258 miles to its confluence with the Mississippi River at mile 599 above Head of Passes, La. The total length of the White River is about 720 miles. The elevation at its mouth is approximately 107 feet above mean sea level, or approximately 2,000 feet lower than its source.

The White River Basin comprises 27,765 square miles, with 10,622 in southern Missouri and 17,143 in northern and eastern Arkansas. The basin is fan shaped, 250 miles in length in a north-south direction, and varies in width from 210 miles near the Missouri-Arkansas border to approximately 50 miles near its mouth in southeastern Arkansas. The Ozark Plateaus province, commonly known as the Ozark Mountains, comprise the northwestern three-fourths of the basin area, and the remaining one-fourth of the basin is composed of the alluvial valley section of the Gulf Coastal Plain province. The escarpment of the Ozark Mountains extends southwesterly across the basin from the vicinity of Poplar Bluff, Mo., to the western basin divide near Cabot, Ark. Nearly all of the basin in southern Missouri is in the Ozark Mountains region. Only a small portion, southeast of Poplar Bluff, lies in the Gulf Coastal Plain province.

The river flows through the Ozark Mountains of southern Missouri in a relatively narrow channel and past numerous vertical bluffs formed through centuries of erosive action. The streambed in this area is composed primarily of rocks, boulders, and gravel. The entire reach of the White River in southern Missouri is now a series of reservoirs, beginning with the Bull Shoals Reservoir at the State line and, proceeding upstream, includes Lake Taneycomo and Table Rock Reservoir. The Bull Shoals and Table Rock Reservoirs are Corps of Engineers multiple-purpose projects.

Bull Shoals Dam and Reservoir

The Bull Shoals Reservoir extends for a distance of 87 miles along the White River from the Bull Shoals Dam, 10 miles west of Mountain Home, Ark., to the Ozark Beach Dam near Forsyth, Mo. The project was authorized by the Flood Control Act of 1941 for flood control, generation of power, and other beneficial water uses.

The Bull Shoals Dam, one of the larger concrete dams in the Nation, extends for a distance of 2,256 feet across the White River Valley, rises to a height of 258 feet above the riverbed, and contains 2,100,000 cubic yards of concrete. Eight 18-foot diameter penstocks deliver water to the powerhouse. Four 40,000- and four 45,000-kilowatt generating units are in operation.

The Bull Shoals Reservoir has a storage capacity of 5,408,000 acre-feet, of which 2,360,000 is for flood control and 2,084,000 is for power drawdown, with 964,000 in dead storage for power head. The flood control storage is equivalent to a depth of 7.3 inches of water over the area of 6,036 square miles that drains into the reservoir, and the total storage is equivalent to a depth of almost 17 inches over the area. When full, the reservoir has a surface area of 71,240 acres and a shoreline of 1,050 miles. The full power pool covers an area of 45,400 acres and has a shoreline 740 miles long.

The project affords flood protection for the White and lower Mississippi River Valleys, hydroelectric power, and recreational opportunities. Since July 1951, when filling of the power pool began, 47 floods have occurred in the White River which were regulated by the combined operation of the Bull Shoals and Norfork Reservoirs, with Table Rock Reservoir effecting regulation since 1957 and Beaver Reservoir since 1964. Crest stages of these floods were reduced an average of 9 feet at Calico Rock, 59 miles downstream from the Bull Shoals Dam. Flooding was prevented on an average of 22,640 acres of improved land for each flood.

Power generation was begun in September 1952 and through June 1965 the project has produced 5,938,046,000 kilowatt-hours of electric energy which has been marketed by the Southwestern Power Administration, Department of the Interior. Through June 1965, the accumulated flood losses prevented that have resulted from the operation of the reservoir amounted to about $9.5 million.

A comprehensive master plan for recreational purposes and land management for the Bull Shoals Reservoir was prepared in cooperation with the National Park Service, U.S. Fish and Wildlife Service, Missouri Conservation Commission, Arkansas Game and Fish Commission, U.S. Public Health Service, Missouri State Health Department, and Arkansas State Health Department in order that the best possible use could be made of the reservoir area.

The Corps of Engineers has established 14 public use areas around the reservoir, 12 of which include leases for commercial boat dock concessions. Seven of these public use areas are located in the State of Missouri, including five boat docks, and all others are in Arkansas. One additional public use area with a boat dock, developed by the Corps of Engineers, is under license to the city of Forsyth, Mo. All boat docks provide rental boats and motors, boat storage, fish bait, soft drinks, and other allied services. All public use areas have been provided with free public use facilities including picnicking and camping facilities, water supply, launching ramps, and sanitary facilities. These facilities are being expanded each year to meet the increasing demands. In addition, areas have been allocated for campsites for Boy Scout troops, church groups, and other nonprofit organizations. The Arkansas State Publicity and Parks Commission has been granted a license to an area lying on both abutments of the damsite, extending above and below the dam, comprising 994 acres. Free public use facilities for picnicking and camping have been provided and concession developments, including floating docks, are located on both banks of the river below the dam to provide services for float fishermen attracted to the area by the outstanding trout fishery in the river. A license has been granted to the Missouri Conservation

Commission for use of 12,135 acres of land and water areas for conservation and management of fish and wildlife. The Arkansas Game and Fish Commission has been granted licenses for the Jones Point Wildlife Management Area consisting of 1,527 acres of reservoir lands, and to 33 acres in the vicinity of Lead Hill boat dock for development of a fish nursery pond. During 1965, visitor-day attendance at the project was estimated at 2,137,800.

Table Rock Dam and Reservoir

The Table Rock Dam is located on the White River in southwestern Missouri about 8 miles southwest of Branson, Mo. The Table Rock Reservoir extends about 79 miles upstream along the White River and inundates areas in both Missouri and Arkansas. The project was authorized by the Flood Control Act of 1941 for flood control, generation of hydroelectric power, and other beneficial water uses.

The Table Rock Dam is 6,423 feet long and consists of a concrete section 1,602 feet long and 252 feet in height above the riverbed, and two earth embankment sections with a total length of 4,821 feet. The structure contains 1,230,000 cubic yards of concrete and 3,320,000 cubic yards of embankment. Four 18-foot diameter penstocks convey water to four 50,000-kilowatt generating units in the powerhouse.

The Table Rock Reservoir provides a storage capacity of 3,462,000 acre-feet, of which 760,000 is for flood control and 1,932,000 is for power drawdown, with 770,000 in dead storage for power head. The flood control storage is equivalent to a depth of 3.5 inches of water over the area of 4,020 square miles which drains into the reservoir. When full, the reservoir has a surface area of 52,300 acres and a shoreline 857 miles long. The full power pool covers an area of 43,100 acres and has a shoreline 745 miles long.

The Table Rock Reservoir is being operated during flood periods in conjunction with other reservoirs in the basin to prevent flood damages along the White and lower Mississippi Rivers. Since May 1957, flood reduction in the White River has resulted from the combined effect of the Table Rock, Bull Shoals, and Norfork Reservoirs, with Beaver Reservoir effecting regulation since 1964. Twenty-six floods have occurred through June 1965, which were reduced in crest stages averaging 9 feet at Calico Rock. The reservoirs have prevented flooding on an average of about 21,110 acres of improved land for each flood.

The accumulated flood losses prevented that have resulted from operation of the project amount to nearly $2.9 million. The first two units were ready for generation of power in June 1959, and installation of units 3 and 4 was completed in August 1961. Through June 1965, the projects produced 1,571,093,000 kilowatt-hours of electric energy which was marketed by the Southwestern Power Administration, Department of the Interior.

A comprehensive master plan for recreational purposes and land management for Table Rock Reservoir was prepared in cooperation with the National Park Service, U.S. Fish and Wildlife Service, Arkansas Game and Fish Commission, Missouri Conservation Commission, U.S. Public Health Service, Arkansas State Health Department, and the Missouri State Health Department in order that the best possible use could be made of the reservoir area.

The Corps of Engineers has designated 19 areas for public use development initially, 11 of which include commercial boat dock concessions. Seventeen of the public use areas, including 10 boat docks, are located in the State of Missouri and the remaining two, one of which includes a boat dock, are located in Arkansas. Four docks are located in areas under license to other governmental agencies, comprising three municipalities in Missouri and the development by the State of Missouri of Table Rock State Park adjacent to the damsite. Each of the boat docks provides rental boats and motors, boat storage, fish bait, soft drinks, and other allied services. All public use areas have been provided with public use facilities including picnicking and camping, water supply, launching ramps, and sanitary facilities, and have been free of charge except in Table Rock State Park where a nominal charge is made for overnight camping. These facilities are being expanded each year to meet the increasing demands. The Missouri Conservation Commission has been granted a license to 51,300 acres of land and water for conservation and management of fish and wildlife purposes, and to about 300 acres immediately below the dam where a trout hatchery has been placed in operation and launching facilities to the river have been provided. During 1965, visitor-day attendance at the project was estimated at 3,331,600.

Lake Taneycomo

Lake Taneycomo was the first major impoundment of water in Missouri for power production. The lake is formed by the Empire District Electric Company's Powersite Dam on the White River near Forsyth, Mo., completed in 1912, and lies between the Bull Shoals and Table Rock Reservoirs. It is about 15 miles long, covers 2,080 acres, and has been a major attraction for those interested in water-based recreational activities since it became operational. Along the lake's miles of shoreline are the vacation communities of Forsyth, Rockaway Beach, Branson, and Hollister, Mo. The shores are also dotted by vacation resorts and retirement homes.

Black River

The principal tributary of the White River in Missouri is the Black River. It rises northwest of Poplar Bluff, Mo., in the Ozark Plateaus and enters the alluvial valley region near Poplar Bluff. It flows along the edge of the Ozark escarpment to near Newport, Ark., where it enters the White River. The drainage area of the Black River comprises 8,520 square miles in Missouri and Arkansas. The Clearwater Reservoir is a Corps of Engineers flood control reservoir on the Black River.

Clearwater Dam and Reservoir

The Clearwater Reservoir is one of the original six reservoirs included in the comprehensive plan for flood control and other purposes in the White River Basin which was approved by the Flood Control Act of 1938. It is located on the Black River in the Ozark highlands of southeastern Missouri, about 32 miles northwest of Poplar Bluff, Mo.

The Clearwater Dam is an earthen structure extending across the Black River valley for a distance of 4,225 feet and rising to a height of 154 feet above the riverbed. Construction of the dam required placing 5,500,000 cubic yards of embankment, and construction of the spillway on the right abutment required excavation of 2,135,000 cubic yards

of material. The reservoir has a total storage capacity of 413,000 acre-feet, which is equivalent to a depth of almost 9 inches of water over the area of 898 square miles which drains into the reservoir. Of this total capacity, 391,000 acre-feet are for flood control. The lower part of the reservoir contains the remaining 22,000 acre-feet of water in a permanent pool for sedimentation reserve and covers an area of 1,650 acres and has a shoreline 27 miles long. When full, the reservoir has a surface area of 10,350 acres and a shoreline 172 miles long. Water is released from the reservoir through a tunnel about 1,100 feet long with a diameter of 23 feet.

Seventy-one floods in the Black River have been regulated by the reservoir between the start of operation in 1948 and June 30, 1965. On the average, flood crests at Poplar Bluff, 46 miles downstream, were reduced 3.4 feet and flooding was prevented on 7,140 acres of improved land for each flood. Flood losses prevented accruing to the project through June 1965 amount to about $5.6 million.

A master plan for recreational purposes and land management for the Clearwater Reservoir was prepared in cooperation with the National Park Service, U.S. Fish and Wildlife Service, Missouri Conservation Commission, U.S. Public Health Service, and the Missouri State Health Department in order that the best possible use could be made of the reservoir area.

The Corps of Engineers has established five public use areas around the reservoir, three of which include commercial boat-dock concessions. The boat docks provide rental boats and motors, boat storage, fish bait, soft drinks, and other allied services. All public use areas have been provided with free public use facilities, including picnicking and camping facilities, water supply, launching ramps, and sanitary facilities. These facilities are being expanded each year to meet the increasing demands. In addition, areas have been allocated for campsites for scout troops, church groups, and other nonprofit organizations. During 1965, visitor-day attendance at Clearwater Lake was estimated at 549,700.

Local protection projects on the Black River in Missouri are described in the following two paragraphs:

Black River levee project

The Poplar Bluff, Mo., to Knobel, Ark., project which was authorized by the Flood Control Act of 1936 provides for enlargement and reconstruction of private levees along both banks of the Black River between Poplar Bluff, Mo., and Knobel, Ark., and other appurtenant facilities. The Arkansas portion of the project, consisting of 37.5 miles of levees along both banks of the Black River, was constructed and transferred to local interests for operation and maintenance in June 1941. The Missouri portion of the levees was not constructed because local interests did not meet requirements of local cooperation. However, a pumping station with a capacity of 35,000 gallons per minute was constructed in the extreme southern part of the Inter-River Drainage District of Butler County and was transferred to local interests for maintenance and operation in December 1952. The average annual benefits from the pumping station are estimated to be $7,800. Flood losses prevented accruing to the entire project through June 1965 amounted to approximately $1.5 million.

Poplar Bluff local protection project

The Poplar Bluff and East Poplar Bluff, Mo., local protection project is on the left bank of Black River in and adjacent to the city of Poplar Bluff, Mo., and was authorized by the Flood Control Act of 1936. Completed in June 1957, the project included construction of 3.9 miles of standard levee, raising of 0.5 mile of street to serve as levee. construction of 14 drainage structures, and excavation of 0.7 mile of ditch.

The project, in conjunction with Clearwater Reservoir, provides protection to 410 acres in the city of Poplar Bluff and 310 acres of adjacent agricultural land. Through June 1965 the project has prevented losses estimated at $86,000.

Black River navigation project

Improvement of the Black River for navigation was first authorized in 1871, but no work was done until adoption of the existing project in 1880. This project provides for improvement of the Black River below Poplar Bluff, Mo., a distance of 211 miles, of which 40 are in Missouri, by snagging operations and construction of wing dams and other contraction works. The principal traffic on the river consisted of materials and products of saw and stave mills. Traffic declined from 107,000 tons in 1926 to none in 1948. The project is not now being maintained owing to the lack of navigation.

The larger tributaries of the Black River are the Current River with a drainage area of 2,613 square miles, the Eleven Point River with a drainage area of 1,196 square miles, the Spring River with a drainage area of 1,215 square miles, and the Strawberry River with a drainage area of 811 square miles. These streams originate in the Ozark Mountains area and enter the Black River on the right bank.

Navigation projects for improvement of the Current River were authorized in 1872 and 1881 and were superseded by the existing project in 1894. This project provides for improvement of the Current River below Van Buren, Mo., a distance of 90 miles, of which 37 are in Arkansas, by snagging operations and construction of contraction works. The principal traffic consisted of logging and barge movement of sand and gravel. Traffic amounted to 18,000 tons in 1926 but no traffic has been reported since 1934. The recent increase in small pleasure-craft navigation on this stream has pointed up the need for snagging at certain locations between Van Buren, Mo., and the mouth. Snagging work at six locations was completed in fiscal year 1964.

Although there are currently no Corps of Engineers reservoir projects on the Black River tributaries, the Water Valley Dam on the Eleven Point River was authorized as one of the six reservoirs included in the White River Basin plan as authorized in the Flood Control Act of 1938. The project was approved for flood control and the possible installation of penstocks for future power development. The damsite is located about 6 miles west of Pocahontas, Ark., and the reservoir would extend upstream into Oregon County, Mo.

Other tributaries of the White River in Missouri include the North Fork River with a drainage area of 1,825 square miles, the Kings River with a drainage area of 594 square miles, and the James River with a drainage area of 1,456 square miles.

Norfork Dam and Reservoir

The Norfork Dam and Reservoir is a multiple-purpose Corps of Engineers project located on the North Fork River a few miles east of Mountain Home, Ark., and extends into southern Missouri. It was authorized by the Flood Control Act of 1938 as one of the original six reservoirs in the comprehensive plan for flood control and other purposes in the White River Basin. The authorization was modified by the Flood Control Act of 1941 to include power generation.

The Norfork Dam is a concrete structure extending for a distance of about 2,624 feet across the North Fork River valley. It rises to a height of 220 feet above the riverbed and contains 1,500,000 cubic yards of concrete. Two 35,000-kilowatt generators are in operation in the powerhouse and facilities have been provided in the dam for installation of two additional units. When full, the reservoir contains 1,983,000 acre-feet of water, and has a surface area of 30,700 acres and a shoreline 510 miles long. The upper part of the reservoir is reserved for storage of 732,000 acre-feet of floodwater, which is equivalent to a depth of almost 8 inches over the area of 1,806 square miles which drains into the reservoir. Of the remaining storage, 707,000 acre-feet are reserved for power drawdown, and 544,000 acre-feet are in dead storage for power head. When full, the power pool covers an area of 22,000 acres and has a shoreline of 380 miles long. Operations of the reservoir for generation of power will lower the surface of the power pool a maximum of 42 feet in very dry periods.

Prior to July 1951, 26 floods occurred in the White River which were modified by operation of the Norfork Reservoir. The average crest stage reduction of these floods at Calico Rock, 17 miles downstream from the mouth of the North Fork River, was 3.9 feet. Since July 1951, flood reductions on the White River have resulted from the combined effect of the Bull Shoals and Norfork Reservoirs, with Table Rock Reservoir effecting regulation since 1957 and Beaver Reservoir since 1964. Forty-seven floods have occurred through June 1965, which were reduced in crest stages at Calico Rock an average of 9 feet. Flooding was prevented on an average of about 22,640 acres of improved land for each flood.

The first power unit was placed in operation in June 1944 and the second in the spring of 1950. Through June 1965 the project has produced 3,515,590,000 kilowatt-hours of electric energy which was marketed by the Southwestern Power Administration, Department of the Interior. In addition to the power, through June 1965, the accumulated flood losses prevented that have resulted from the operation of the project have amounted to more than $5.1 million.

A comprehensive master plan for recreational purposes and land management for the Norfork Reservoir was prepared in cooperation with the National Park Service, U.S. Fish and Wildlife Service, Arkansas Game and Fish Commission, Missouri Conservation Commission, U.S. Public Health Service, Missouri State Health Department, and the Arkansas State Health Department in order that the best possible use could be made of the reservoir area.

The Corps of Engineers has established 17 public use areas around the reservoir, 11 of which include leases for commercial boat dock concessions. Two public use areas with boat docks are located in the

State of Missouri and all others in Arkansas. The boat docks provide rental boat and motors, boat storage, fish bait, soft drinks, and other allied services. All public use areas have been provided with free public-use facilities, including picnicking and camping, water supply, launching ramps, and sanitary facilities. These facilities are being expanded each year to meet the increasing demands. In addition, areas have been allocated for campsites for scout troops, church groups, and other nonprofit organizations.

The U.S. Fish and Wildlife Service has been granted a permit for use of 44 acres of land downstream from the dam on the right bank and has constructed a trout hatchery which was completed and placed in operation in 1957. During the calendar year 1964, facilities at the trout hatchery were doubled. The Arkansas Game and Fish Commission has been granted a license on 2,120 acres of reservoir land for use as a game management area. During 1965, visitor-day attendance at Norfork Lake was estimated at 1,504,200.

Flood control and drainage are closely related and constitute major water problems in the White River Basin. Although existing flood control projects have materially reduced flood damages in the basin, serious flood problems remain. Large flood damages are experienced and large areas of potentially productive agricultural lands are dormant because of the flood hazard and the wet condition of the soil.

Floods in the White River Basin originate in the mountainous headwater areas and travel rapidly downstream to overflow large areas of agricultural lands. Flood crests on the lower White River move slowly through the flat terrain of the alluvial valley. The principal area in Missouri sustaining flood damages is the area in the vicinity, and south, of Poplar Bluff in Butler County, Missouri, along the Black River. Additional flood control storage is needed on the Little Black, Spring, Eleven Point, James, and Kings Rivers to alleviate flooding in the basin.

SPRING RIVER BASIN

Spring River, a major tributary of the Grand (Neosho) River, has a 2,581-square-mile drainage area. Nearly 85 percent of this area is in Missouri. The river rises in the foothills of the Ozark Mountains near Aurora, Lawrence County, Mo. It flows westerly through Jasper County to the Missouri-Kansas State line, then southwesterly through Kansas into Pensacola Reservoir, Okla. Spring River's largest tributary is Shoal Creek, which drains approximately 470 square miles.

The basin's watershed area is subjected to intensive rainfalls. The resulting excessive runoff is very damaging to the flood plains. Minor floods occur once a year, with major floods occurring at a frequency of about once in 5 years. Most flood-producing storms have occurred in the months of April, May, and June; however, flood-producing storms have occurred in nearly every month of the year. The Missouri cities of Joplin, Sarcoxie, Neosho, Pierce City, and the Monett have serious flood problems. In this watershed, the Corps of Engineers has only the Carthage levee project in operation. This levee has prevented an estimated $286,000 in flood damage since its completion in 1956.

In the report on Grand (Neosho) River and tributaries, prepared in January 1945 and published as House Document 442, 80th Congress, 2d session, in 1948, possible solutions were considered for all flood and other water resources problems known at that time. Along with other reservoirs considered in Kansas, this report considered the merits of a reservoir on the Elk River at the Noel site and on Spring River at the Waco site. The Noel site is located on the Oklahoma side of the Oklahoma-Missouri State line, about 14 miles downstream from Noel, Mo. The studies found that the Noel Reservoir would completely control the flows from the Elk River, but not at a cost commensurate with anticipated benefits. The Waco Reservoir site on Spring River is generally north and a little west of Joplin, Mo. The report recommended that the Waco Reservoir be constructed on Spring River north of Joplin, Mo.; however, the House and Senate of the 63rd General Assembly of Missouri objected to project construction. Therefore, the recommendation was withdrawn.

By the Flood Control Act of May 17, 1950, Congress directed that a coordinated comprehensive plan of improvement be developed for the basins of the Arkansas, White, and Red Rivers. A report was completed in 1955 and published as Senate Document No. 13, 85th Congress, 1st session. This AWR report presented a long range plan of water resource development and included findings and possible solutions in the Spring River area. In connection with that report, the Corps of Engineers reconsidered the Waco and Noel projects and made preliminary studies of reservoirs for flood control and conservation on Shoal Creek (Galena site) in Kansas and Center Creek (Prosperity site) in Missouri. The preliminary studies made for these reservoirs were not encouraging on the basis of project analysis at that time; therefore, the projects were not included in the long-range plan of development.

Congress has directed that a single investigation of Spring River and tributaries be made for flood control, water supply, and allied purposes. This study was started in the fall of 1965 and is scheduled to be completed in 1967.

The Soil Conservation Service has made a study on the potentials for Public Law 566 program development and potentials in the Missouri portion of the Spring River basin. It is expected that six Public Law 566 watershed projects covering approximately 448,000 acres will develop. These projects will control about 21 percent of the watershed area.

○