Geomorphic History of the Ozarks of Missouri

by

J HARLEN BRETZ

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CONTENTS

	Page
Abstract	9
Introduction	11
Previous studies	15
Problems and conflicting interpretations	19
Themes of this study	21
St. Francois Mountains	22
Salem Plateau	30
Uplands of the Salem subprovince	31
The major divide	31
Monadnocks	35
Some divides of the northen slope	37
Eastern divides and escarpments	54
Tipton summit flat	70
Southeastern slope and Embayment "islands"	72
Southern slope	76
Some valleys of the Salem subprovince	88
Gasconade River valley	88
Bourbeuse and Meramec River valleys	92
Osage River valley	92
Springfield Plateau	95
Post-Ozark geomorphic records	106
Conclusions	131
Selected references	135
Index of geographic and geomorphic features	138

ILLUSTRATIONS

Plate — In Pocket

1. Index map of topographic sheets

Figure — Page

1. South end of Buford Mountain, St. Francois Mountains 22
2. Pilot Knob, St. Francois Mountains 23
3. Elephant Rocks, St. Francois Mountains 24
4. Map of complex drainage pattern, central St. Francois Mountains 25
5. Divides across valley bottoms, St. Francois Mountains 26
6. Shut-in narrows of Stouts Creek, St. Francois Mountains 27
7. Marlow-Black Mountain narrows, St. Francois River 28
8. Ozark peneplain remnants on summit of main divide, Boss Quadrangle 32
9. Ozark peneplain remnants on summit of main divide, Licking and Raymondville Quadrangles 34
10. Lead Hill, a monadnock on Ozark peneplain near Dunn 36
11. Rolla National Airport near Vichy 37
12. Lanes Prairie and environs 39
13. Gravel on Ozark peneplain remnant near Owensville 42
14. Sandstone boulder with stream worn surface 42
15. Windgap in Eureka Springs escarpment at head of James River .. 47
16. Ridge on slope of Osage River valley 50
17. Bethany escarpment overlooking Ozark peneplain 53
18. Marbut's map of physiographic belts and escarpments 55
19. Womack area in Castor River headwaters 57
20. Farmington or Jonca plain 59
21. Crystal escarpment and Gray Summit lowland 64
22. Crystal escarpment seen from near Gray Summit 65
23. Crystal escarpment sharpened by mining and road excavation near Pacific 65

Figure Page
24. Tipton summit flat 71
25. Tipton summit flat seen from the southwest 72
26. Embayment "islands" 73
27. Ozark peneplain, Grandin Quadrangle 75
28. Summersville upland flat and ridge 77
29. Skyline of part of Gainesville monadnock group 80
30. Ozark monadnock group, Gainesville Quadrangle 81
31. Asymmetrical ridge, Bradleyville Quadrangle 83
32. Interfluve whose flat top records White River strath, Ozark peneplain equivalent 85
33. Asymmetry of meander outlined peninsulas, Gasconade River 89
34. Gasconade Valley strath seen from Potts on U. S. Highway 50 .. 90
35. Osage outer valley floor, Toronto and Bagnell Quadrangles 93
36. Eureka Springs escarpment, Springfield peneplain and monadnock 96
37. Bassville monadnock 101
38. Fair Grove Mound 102
39. Unrejuvenated portion of Osage River valley 107
40. Abandoned part of Moreau River valley 111
41. Abandoned valley of Moreau River 112
42. "Lost hills" in cut-off entrenched meanders 113
43. Reconstruction of Osage age meanders along Missouri River 114
44. Trimmed and steepened bluff, Missouri River valley north of Jefferson City 115
45. Betrunked ravine system 118
46. The Saline County Big Bend 119
47. Teteseau Flats 122
48. Fountain Bluff and environs 127

LETTER OF TRANSMITTAL

Rolla, Missouri
January 21, 1965

Honorable WARREN E. HEARNES
Governor of Missouri
Jefferson City, Missouri

Dear Governor Hearnes:

I have the honor to transmit herewith a comprehensive report on the GEOMORPHIC HISTORY OF THE OZARKS OF MISSOURI prepared by Dr. J Harlen Bretz, Professor Emeritus of the University of Chicago, under the auspices of this Division.

A complete study of this nature has not been made of the Ozarks since C. F. Marbut's outstanding contribution was published in 1895 by the Geological Survey of Missouri under the directorship of Charles R. Keyes. Extensive advances in the technology of topographic mapping and in the science of geomorphology have long since outdated Marbut's excellent work, and it is because of these advances that the recently resigned Director of Division, Dr. Thomas R. Beveridge, realized the necessity of acquiring the services of one of the country's leading geomorphologists to update and supplement the information in Marbut's report for the benefit of the citizens of Missouri and the students of the earth sciences.

I am proud to have had the privilege of seeing this work to completion and of transmitting to you such an important contribution so foresightedly conceived by Dr. Beveridge and so ably executed by Dr. Bretz.

Respectfully submitted,

WILLIAM C. HAYES
State Geologist and Director

Geomorphic History of the Ozarks of Missouri

by
J HARLEN BRETZ

ABSTRACT

With but slight changes of outlines, Fenneman's classification of the Ozark province (also called the Ozark dome) into subprovinces is followed herein, although overlap of some of these beyond the borders of Missouri are treated where data significant in understanding Missouri's geomorphology are involved.

As a subordinate science under the larger purview of Geology, Geomorphology has two main aspects: the operation of processes now observable and the record of past operations in making our present land forms. The latter is the theme of this study. As herewith presented, that history consists of a conflict between diastrophic forces which have repeatedly elevated the Ozark province and gradational forces which, during long intervening periods of tectonic quiet, have repeatedly reduced most of the uplifted region to low relief.

Ozark uplands, from which many hundreds of feet of once overlying rocks have been eroded away and which now stand hundreds of feet above major river valley bottoms, have long been interpreted as remnants of uplifted peneplains. Although this view is challenged today by two newer concepts of land sculpture, the earlier view is herein defended as the correct one.

An almost complete coverage of the province by topographic maps has made possible extensive correlations among these upland residuals. Building on the work of earlier students, the interpretations of this study find what is considered to be convincing evidence that the newer concepts of cyclic pedimentation and of noncyclic dynamic equilibrium are in error when applied to the geomorphic development of the Ozark province.

The succession of events, diastrophic alternating with gradational, is found to consist of the following:

1. A probable early peneplanation suggested by summit altitudes of the Boston Mountains of closely adjacent northwestern Arkansas. However, the record of this event has been wholly destroyed throughout the province itself.

2. An uplift that rejuvenated the radial pattern of rivers flowing off the Ozark dome, launched a new erosion cycle which destroyed the presumed Boston Mountains peneplain over the whole province, and culminated in making a later and lower peneplain, the Springfield. But only a few remnants of the Springfield peneplain, constituting flat-topped monadnocks, are still in existence because of a yet larger uplift and consequently another rejuvenation of the streams.

3. The Ozark cycle of erosion was initiated by this uplift, and it continued to the peneplain stage, only in turn to suffer the fate of the

Springfield peneplain by reason of a third uplift. Remnants of its peneplain are the nearly baseleveled upland plains, only slightly warped by the domal uplift, which now constitute an outstanding feature of much of Ozark landscape: that of an apparently continuous, unaccented plain if one is unaware of the relatively narrow, deep and steeply sloped river valleys between him and the distant uplands at his level.

This dissected plain, the Ozark peneplain, is traceable off the slopes of the dome northward across Missouri River to drift-covered northern Missouri, eastward across the Mississippi River into Illinois, southward across White River into Arkansas and westward into Kansas. Yet many of its remnants possess low gradient creeks still operating under Ozark cycle conditions. Some of this surviving old-age drainage is actually radial for individual uplands only a few square miles in area, their creeks and wet-weather drainages abruptly descending from the upland margins into bordering deep valleys. This drainage pattern is in most places quite independent of bedrock control.

Another persistent feature of the upland remnants of the Ozark peneplain is the red clay soil, highly charged with chert fragments, that survives from the Ozark peneplain. Another is the existence of monadnocks which stand alone or in compound groups on interfluves and whose summits in a few cases carry the profile, even the soil or the stream gravel, that records the Springfield peneplain.

The many air-filled caves of the Ozarks prevailingly record an origin under phreatic conditions, under the vanished water table of pre-peneplain stages of the Ozark cycle. They also prevailingly contain records of a former complete or nearly complete fill of unctuous red clay that filtered into them when peneplanation was essentially complete and groundwater circulation therefore had come to a standstill.

This Ozark peneplain was not wholly a product of enormously widened river valleys. What remnants survive are the very gently sloped divide summits which existed at the close of that cycle. A few places give evidence of a relief of 50 to 100 feet and even more between divide summits and valley bottoms of that old land surface.

4. This third domal uplift, which initiated the dissection of the Ozark peneplain, caught the Mississippi, the Missouri, and the White rivers on its flanks. Their resulting trenchlike valleys demanded comparable deep, steep-sided valleys of all the tributary rivers flowing radially off the dome. Thus, the Ozark's characteristic topography was initiated.

5. The major river valleys which were developed in post-Ozark time possess dissected strath terraces independent of stratigraphic control. Two sets of these benches may be seen in the largest valleys and in their existence are records of two minor uplifts that came late in the valley making. In them also is a record of departure from a theoretical symmetrical uplift for they are lacking in a group of valleys on both the southeast and northwest flanks of the dome. Indeed, valley bottoms in a large area to the northwest have very probably been alluviated, rather than deepened, during these strath-making episodes. This came about from a minor upwarping athwart their course farther downstream, but marked enough that the streams could no more than keep pace with the uplift. Bottoms of these valleys are essentially at base level today.

Radially directed dip of the sedimentary formations involved in the dome structure is prevailingly steeper than the radial gradient of the peneplain-beveled interfluve uplands. One consequence of this disparity has been the development of in-facing cuestas. The greatest of Ozark cuestas, the Eureka Springs escarpment, separates the centrally located and largest subdivision of the province, the Salem (or Ozark) subprovince on the east from the next largest, the Springfield subprovince on the west. Much of the summit of this escarpment is beveled by the Springfield peneplain. Other cuestas carry definite Ozark peneplain beveling. Yet the drainage patterns of some rivers show that along considerable stretches, these cuestas were interfluves throughout the entire decipherable history, a part of the relief ascribed to the Ozark peneplain.

The Springfield peneplain is correlated with the Dodgeville peneplain of southern Wisconsin, northern and extreme southern Illinois and eastern Iowa. The Ozark peneplain is considered to be correlative with the Lancaster (Calhoun) peneplain of the same states. The earlier and higher strath terraces in valleys on the north slope of the dome (Osage strath) are considered to be of the same age as the Central Illinois partial peneplain and the lower set (post-Osage) to be equivalent to the Havana strath of Illinois. But in the extreme southwestern part of the province where are the most extensive Springfield peneplain remnants, it is believed that the Ozark peneplain on the southern slope is traceable westward into the White River drainage as the higher strath of that valley, and thus to become an Ozark strath. A lower one there represents the Osage strath stage.

Dating of these diastrophic and erosional events is tentative. The Springfield peneplain may be recorded in well data in the low Embayment area of the Missouri "boot". The Ozark peneplain appears to be recorded there in hill lands of some of the "island" tracts of Paleozoic rock now isolated in the Embayment alluviation. If so, it truncates the Wilcox formation and therefore is at least post Early Eocene.

Pleistocene events have a scant record in the extreme northern part of the province. Glacial ice of Nebraskan or Kansan age, which had crossed the Missouri River valley for short distances, briefly interfered with drainage but the resulting changes cannot yet be definitely tied to certain drainage changes that came probably after the post-Osage strath stage.

INTRODUCTION

The Ozark Plateaus physiographic province, as defined by Fenneman (1938), includes the relatively high country that lies south of the Missouri River, east of the Prairie Plains of Kansas and Oklahoma, north of the Arkansas Valley, and west of the Mississippi Valley and Embayment. The province also has an eastward linear extension across the Mississippi River into southern Illinois. Recognized subdivisions based on topographic, altitudinal, and lithologic differences are: 1) the Salem Platform or Plateau of south-central Missouri and north-central Arkansas; 2) the St. Francois Mountains, an island of crystalline rocks entirely surrounded by the Salem Plateau; 3) the Shawneetown Ridge in

southern Illinois; 4) the Springfield Platform or Plateau of southwestern Missouri and northwestern Arkansas; and 5) the Boston Mountains Plateau in northern Arkansas and eastern Oklahoma.

The Missouri Geological Survey restricts the term "Ozark Plateau" to Fenneman's Salem subdivision. However, the "Ozark province" includes all the subprovinces named and for an elucidation of the geomorphic history of this part of the continent their relations in space and their sequences in tectonic and gradational events must be considered together.

During the accumulation of its thousands of feet of Paleozoic sediments, the province repeatedly became a positive area. It has been a land area continuously since Pennsylvanian time. It is commonly called the Ozark dome because of its general topographic contour and prevailing outward dip of Paleozoic formations. As a topographic dome, it is elongated east-west with major structural elongation toward the northwest. Minor folds and faults diversify the structure. Mesozoic and Cenozoic denudation has scalped much of the central part of the dome down to Ordovician formations. In places, this erosion has exposed Cambrian rocks. Younger systems lie at lower altitudes around its slopes in irregular and locally interrupted belts. Dips are generally steeper than the radial topographic slopes, hence there is consistent beveling of the formations and an infacing of cuestas.

The highest area of the sedimentary rocks is on Mississippian formations near the western end of the elongated dome. But the highest country is found in the St. Francois Mountains subprovince of Precambrian crystalline rocks at the eastern end of the dome's axis, and here also are the highest altitudes of such Paleozoic formations as are present.

As is to be expected of a repeatedly uplifted dome, major drainage with few exceptions is radial. The very crooked courses of the larger streams have been the subject of studies since 1893. Most authorities now consider that inheritance from meandering regimens demanded by earlier baselevels is a large factor. The number of peneplanations since the province last became land and the amount and character of subsequent modifications have varied with the investigator, but entrenchments from former peneplain courses is acceptable to almost all.

Rocks of the dome are prevailingly calcareous, and solutional reduction has occurred on a considerable scale. Missouri alone has more than 1,450 catalogued caves. Yet karst topography is limited as compared with the same formations in Kentucky and Tennessee. The caves have been interpreted as largely the product of subwater-table circulations under a mature topography that vanished with peneplanation.

The St. Francois Mountains constitute the most striking departure from the preceding generalizations. They are a limited tract (about 70 square miles) of closely assembled mountains or peaks of granite and felsite that rise islandlike above a sea of Paleozoic marine sediments which once largely buried them. The

Cambrian and Ordovician transgressions found no peneplaned Precambrian region here, nor have these eminences suffered peneplanation during removal of covering sedimentaries, although such surrounding formations carry traces of a peneplain right up to the flanks of the crystalline hills. In neighboring Kansas, a late Precambrian peneplain on igneous and metamorphic rocks is reported from well log data, although its quartzite monadnocks are still completely buried beneath Paleozoic sedimentary rocks.

The dominant form of a St. Francois Mountain is rudely conical. Dissection to exhume the mountains has produced many narrows or "shut-ins" in the igneous rocks, upstream from which are broad re-excavated Precambrian valleys still floored with early Paleozoic sediments.

Another departure from the fairly consistent domal structure is found in the Shawneetown spur that lies in southern Illinois, east of the Mississippi River trench. Here is a regional monocline chiefly of upper Mississippian and lower Pennsylvanian rocks that carries a south-facing cuesta whose north-dipping beds disappear under the central Illinois coal basin. It is uncrossed by any stream. Faulting is more common in the St. Francois subprovince than anywhere else in the entire province, with consequent effects on the stream-dissected topography.

The Boston Mountains of Arkansas comprise another marginal subprovince of the Ozark province. Structurally, these mountains constitute a flat, asymmetrical anticline containing subordinate folds. They possess a strongly marked cuesta cliff facing the dome, and their gentle southward regional dip carries their formations into and under the Arkansas River valley. Lithologically, the Bostons consist largely of Pennsylvanian shale and intercalated sandstone. Topographically, the east-west elongated mountain group is greatly dissected, and if it ever carried a summit peneplain, that feature is no longer recognizable. Curiously, the summits of this weak Pennsylvanian rock which flanks the dome to the north are higher than any place on the summit of that structure, even with its dense dolomites, limestones, sandstones, and crystallines.

Without question, the northern scarp of the Bostons—greatest of all the Ozark province escarpments—is the retreating cuesta of a probably once-complete, Pennsylvanian cover of the entire dome, except for the St. Francois Mountains.

The Salem Platform (or Ozark Plateau) is the largest of the subdivisions of the province and constitutes most of the summit area of the topographic dome. Most of this subdivision is held up by calcareous Ordovician rocks, but near the higher Springfield Plateau or Platform to the west there are many scattered monadnocks of Mississippian rocks. Although much dissected in the present erosion cycle, radial interfluves and tangential cuestas of the Salem (or Ozark) subprovince carry unequivocal evidence of a former erosional base leveling that had reduced the subprovince to low relief.

The contact of this Springfield subdivision and the Salem is

marked by a cuesta escarpment, longer and more irregular but lower than that on the north face of the Bostons. This, the Eureka Springs escarpment (called the Burlington in early literature), is stratigraphically the edge of the retreating Mississippian formations that, like later Pennsylvanian, once completely covered the province. The Springfield's flattish upland surface slopes westward and, thus, much of it is no higher than the central part of the Salem. Its southern portion extends into Arkansas, and there it has been read as a stripped plain on cherty Mississippian limestone. Prevailing opinion is that it is an erosional plain that transects local structures. But opinion is again divided on the question of its relation to the adjacent Salem. Is it of older development, or is the Eureka Springs escarpment simply a surviving and refreshed cuesta of one and the same erosional surface?

The precision of contour maps and photographs is relied on in illustrating this report instead of profile drawings which almost invariably require gross vertical exaggeration. Limitations of page space, however, have required omission in some cases of environing features that are genetically related to the subject depicted. Accompanying features not involved and which would detract from the purpose of the illustration have also been omitted in some cases. The reader who wishes a complete picture should examine the quadrangle maps specified.

Quantification has been limited in this study to simple arithmetical measurements and comparisons of altitudes, gradients, areas, and proportions. It might have been possible to develop formulae, even equations, for the space and time relations statements in mathematical language that would be impressive perhaps but quite unnecessary in establishing the history we seek to unravel. We believe that the English language provides all the precision our problems can involve.

Acknowledgements.—The field work on which this study is based has been the cumulative result of three separate studies in Missouri by the writer. The Geological Society of America financed a study of filled sink structures, the Missouri Geological Survey under Edward L. Clark's direction authorized a study of Missouri caves, and the same Survey under Thomas R. Beveridge's administration requested the present study. Many thousands of miles of traverses of the Ozark country have resulted from these field studies. The present report could not have been written without the almost complete coverage by the Missouri Geological Survey and the United States Geological Survey of topographic maps. Nor could it have resulted from office study of the maps alone.

Many geologists have been consulted on various items of the interpretation herewith presented. The chief "bone of contention", the failure of the theory of dynamic equilibrium to explain Ozark geomorphology, has been discussed particularly with Thomas Beveridge, Charles Brown, Lewis Cline, Chauncey Holmes, Leland Horberg, W. D. Keller, John Koenig, Morris Leighton, Paul MacClintock, Hoover Mackin, Robert Sharp, and Arthur Trow-

bridge, some of them in the field. The interpretations herein are believed to be acceptable to all.

Previous Studies

Geomorphology of various parts of the Ozark province has had published descriptions and interpretations for the past three quarters of a century. Interpretations have varied with their authors and some ideas, once acceptable, have been abandoned by later students because of increased knowledge of the field and better understanding of processes involved. But differing concepts of the region's geomorphic history exist today. Outstanding among rival schemes for delineating Ozark history are the Davisian cycle of stream erosion, the Penckian cycle of pedimentation, and the noncyclic concept of dynamic equilibrium. Pros and cons involved will be repeatedly stressed in this study.

In addition to these fundamental thories are many local problems encountered during this present study, for the solution of which there are at present insufficient data. Alternative explanations for these are outlined with preferential leanings of the author.

The history of the unravelling, to date, of Ozark geomorphic events began in the mid-nineties when two men, O. H. Hershey and C. F. Marbut, almost simultaneously announced the first genetic interpretations of the Ozark dome's geomorphology. Hershey (1895) saw "duplex valleys" along the larger streams, specifically the White and Missouri Rivers (Springfield and Salem subprovinces), whose valley-in-valley character recorded epeirogenic uplift after graded conditions had been attained. He also saw the broad Ozark province interfluve uplands as remnants of a former peneplain which transgressed all Paleozoic systems present and was diversified locally by monadnocks. He rejected structural and stratigraphic control for the flat uplands and for the floors of the outer valleys.

Marbut and Hershey probably crossed each other's routes without being aware that another's investigation was in progress, and Marbut probably did not see Hershey's paper before his own contribution (1896)) was sent to the printer. In comparing Ozark physiography—the word "geomorphology" had just been invented —with that of the Appalachians, Marbut (1896, p. 26) noted that "In Missouri, there is no evidence of more than one cycle." He wrote many pages on valleys and stream courses of the province without mentioning the double valley character which Hershey had designated as "duplex". His voluminous report covering the entire state was intended originally to be a Ph.D. thesis under W. M. Davis, but for some reason the degree was never conferred.

Though the concept of a peneplain had been some decades in developing, the word was only six or seven years old when Hershey and Marbut first used it, and the province belongs to those regions where peneplanation was early recognized. These students worked with nothing more than a few scattered 50-foot contour maps,

aneroids, some railroad profiles, and their own "seeing eyes". All credit to pioneers who saw so well.

In 1901, Hershey again discussed Ozark geomorphic history, this time reporting remnants of two peneplains in the uplands and reaffirming the verity of broad outer valleys cut into the second peneplain and in turn trenched by deep valleys of the present rivers.

The first doubter of the verity of Ozark peneplanation was A. H. Purdue (1901) who denied Hershey's arguments and attributed the even crests of the Boston Mountains to "massive beds of sandstone" and their altitude to late Tertiary or post-Tertiary uplift of this physiographic unit.

Hershey (1902) promptly replied to this paper, amplifying former arguments but withdrawing his earlier ideas: 1) that comparison with the Ouachitas was valid and 2) that Quaternary uplift had occurred in the Bostons. He could see no "escape from the conclusion that the Boston Mountains was a residual on [standing above] the baselevel represented by the plain to the north—the Ozark plateau" (Hershey, 1902, p. 163). Survival of the mountain mass was attributal largely to the fact that it occupied the broad divide between the Arkansas River and the White River and, thus, had suffered only headwater erosion. The longer valleys of the southern slope do actually record a succession of rejuvenations, the erosional benches "coalescing so as to be apparently the product of a single cycle of erosion" (Hershey, 1902, p. 163). The great northern scarp is not a fault or faultline scarp, as it must be if there had been late uplift of the mountain block.

By 1904, Marbut (p. 527) had recognized "the existence of a peneplain lying at a lower level than that of the so-called Cretaceous peneplain of the same region. It is probably the same feature as the one described locally in Barry and Stone counties by Hershey in 1895." Instead of 1895 it should have read 1901 for Hershey never called his outer valley bottoms even partial peneplains. Furthermore, a report by Marbut in 1907 on Morgan County, Missouri, (Salem subprovince) indicates that his lower "peneplain" is probably Hershey's "benchland" of the "duplex valleys" and not an extensive beveling recorded in interfluve summits.

In 1907, W. S. T. Smith and C. E. Siebenthal identified the uplands of the Joplin district on the western slope of the dome as a Cretaceous-Tertiary peneplain truncating structures and carrying monadnocks. "When the land was near base-level", widespread upland chert gravels "must have covered much of the surface with a heavy mantle" (Smith and Siebenthal, 1907, p. 8).

N. M. Fenneman reported (1909) on the land forms of the St. Louis region (Salem subprovince). His interpretation was that but one peneplain was identifiable in the uplands. "In the nearly perfect condition of the peneplain, the streams which made it wandered over its surface somewhat aimlessly" (Fenneman, 1909, p. 53). He believed that it had once been largely covered by La-

fayette gravel from which cover the present meandering stream courses had been superimposed after uplift. No references to earlier publications were made. The possibility of two peneplains was considered but rejected.

Approximately coinciding in date with Fenneman's study was a report by E. R. Buckley on the lead deposits in St. Francois and Washington Counties of southeastern Missouri (Salem and St. Francois subprovinces) in which two peneplains were recognized. Old stream gravels were found only on the lower and younger surface.

In 1913, two erosion cycles were again reported in the Ozarks. Wallace Lee found their record high on the northern slope of the uplift in the Rolla Quadrangle of Phelps County (Salem subprovince). The later one had run to "late maturity or old age" before interruption.

In 1916, A. H. Purdue and H. D. Miser found no evidence for a Boston Mountains summit peneplain and were inclined to follow Purdue's earlier view (1901) that the "rather even summits" are determined by the resistant sandstone of the Winslow formation (Purdue and Miser, 1916, p. 19). Similarly, they favored the idea that the Springfield Platform is a structural plain determined by the cherty "Boone" formation and that the Salem Platform, at least in northwestern Arkansas, is also structural. Nevertheless, they recognized that successive erosion cycles, each the consequence of an immediately preceding uplift, were on record. During the Salem cycle, most of the Springfield Platform was destroyed, but many monadnocks record its former presence.

W. A. Tarr (1924) found that the Osage River (Salem subprovince), which almost tangentially skirts the low northern flank of the Ozark uplift, had been caught on the rising bulge in such a way that its valley bluff summits today become higher in altitude for many miles downstream. The river thus is flowing diagonally against the regional slope. Taken with the remarkable entrenched meanders, this meant that the river originally traversed a peneplain and that later up-warping had occurred slowly enough for the stream to retain its antecedent course.

C. L. Dake (1930) believed that "a lower and younger partial peneplain" (p. 19) was identifiable far up Big River drainage off the northeastern slope of the dome. Not noted by Dake is the fact that this erosional surface, traced farther southward on the Ironton Quadrangle, constitutes a valley bottom divide between north-flowing Big River and south-flowing St. Francis River.

Josiah Bridge (1930, pp. 31-32) saw a "high, much dissected terrace" as a "remnant of a wide valley" margining the present narrow valleys of Jacks Fork and Current Rivers (Salem subprovince) on the south slope of the Ozark uplift.

In 1935, Dake (p. 705) found limited but widely distributed remnants of a peneplain lying below the general upland level along the Bourbeuse, Gasconade, and Meramec Rivers (Salem subprovince). Distinction between such an erosion surface and the outer

member of Hershey's "duplex valleys" is difficult where briefly stated geomorphic interpretations are incidental to the major theme. But Dake (1930) had clearly stated that one headwater area—unquestionably at Summit (Bonne Terre Quadrangle)—was beveled by his younger surface and was still untrenched by modern valleys.

Fenneman's monumental digest of literature dealing with the physiography of the United States appeared in two volumes dated 1931 and 1938. The later volume contains an excellent presentation (pp. 631-662) on the "Ozark Plateaus". The Boston Mountains in adjacent Arkansas which overtop the highest parts of the Ozark dome are treated as a much dissected plateau belonging to the Ozark physiographic province. Hershey's concept of 1902 is accepted, i.e. the Boston Mountains' record includes two erosion cycles while "Only one general peneplain seems to have been developed on the top of the Ozark dome in Missouri" (Fenneman, 1938, p. 658). Thus, the Springfield upland or plateau surface on Mississippian rocks is considered to be of the same age as the Ozark peneplain on Ordovician rocks in the central part of the dome. A subdued cuesta held up by the "Boone" chert interrupted the old land surface and separated the two portions of the peneplain. "Freshened" by subsequent erosion, this is the Eureka Springs escarpment, the outstanding escarpment of the Ozark dome.

Fenneman (1938, p. 661) saw the outer valley of White River as a "strath or incipient peneplain", correlated it with similar features in other Ozark river valleys, and apparently accepted the idea that they were of "Lafayette" age.

R. F. Flint (1941) interpreted the course of the Mississippi River between St. Louis and Cape Girardeau (Salem and Shawneetown subprovinces) as antecedent to the warping which elevated the peneplaned dome and caused its dissection. He found no valley records in eastern Missouri of two stages in this uplift.

J H. Bretz (1942, 1953, 1956) interpreted a widely distributed unctuous red clay in Ozark caves as derived from the residual soil of a peneplain; such caves, therefore, being older than the peneplain. No commitment was made that more than one peneplain is recorded in the Ozark land surfaces.

After more than 60 years of tacit acceptance, by nearly a dozen students, of the broad interfluves of the dome as peneplain remnants, this concept has recently been challenged. Two students deny that peneplanation is recorded in any Ozark flat-topped interfluves. J. H. Quinn (1956) has argued that all these upland flats are pediments or pediplanes, left behind by scarp retreat during arid interglacial episodes of the Pleistocene. The river valleys were eroded during the glacial episodes which produced only pluvial climates south of the limits reached by the continental ice sheets. Quinn (personal communication) believes that the pediplanes developed during the three interglacials are the Boston Mountains (Aftonian), the Springfield upland (Yarmouth) and the Ozark or Salem upland (Sangamon).

J. T. Hack (1960) has denied the validity of the Davis scheme of sequential stages in a cycle of erosion and the possibility of peneplanation. His discussion includes the Ozarks. His substitute procedure of erosional reduction of a topography is "dynamic equilibrium", and its end product is essentially the mature stage of Davis' erosion cycle.

J H. Bretz (1962) briefly reviewed the field evidences bearing on Ozark geomorphic history and denied that the "dynamic equilibrium" concept can be substituted in the Ozarks for the cycle of erosion concept.

Problems and Conflicting Interpretations

The concept of peneplanation as the eventual result of uninterrupted downwearing by running water, developed by W. M. Davis, has had worldwide acceptance by students of the genesis of land forms. But in recent years, this concept has been losing adherents. Some geomorphologists have developed and adopted modified forms of Walther Penck's (1953) concept of pedimentation (backwearing) to account for an erosionally made, broad area of low relief. Particularly, Davis' picture of the process of denudational attack in arid regions has undergone attack. Many peneplains of a generation ago are now interpreted as pediplanes, even where the supposedly required aridity has vanished.

Some students (e.g. King, Ruhe, Hack) deny the formation of Davisian peneplains under any conditions of rock or climate. Others (e.g. Baulig, Holmes) would divide the field, allowing peneplanation to occur under consistently humid climates.

Quinn's brief challenge is in line with this tendency to read presumably established peneplains as the product of pedimentation processes and sets up one problem of Ozark topographic genesis. The problem must be approached and kept within the bounds of field evidence, drawn from both land forms and the time element available.

Hack denies that diastrophic uplift of a region undergoing stream attack has alternated with long periods of quiescence and erosional reduction toward base level. No "cycles of erosion" have occurred in making the "maturely dissected peneplains" so widely recognized by the Davis school. The "stages" of the Davis concept are purely theoretical. In Hack's concept of "dynamic equilibrium" in erosional forms, "all elements of the topography are mutually adjusted so that they are downwasting at the same rate" (Hack, 1960, p. 85), that rate determined by rate of uplift (if uplift is occurring), by character of substratum rock, and by slope attained. The "rather uniform height of the hills" in a "ridge and ravine" topography (a maturely dissected peneplain by the Davis school) is the result of "regularity of the drainage pattern that has developed over long periods, by the erosion of rocks of uniform texture and structure" (Hack, 1960, p. 91). This mature topography is the end product, although as relief is lowered, the rate of down-

wasting is slowed, and the waste removed is altered to even finer textures.

There can be no resolution of the conflicts among these contrasted schemes of geomorphic evolution without careful search in existing erosional topographies for disharmonies, both internal and external. The Missouri Ozarks contain evidence of some significant disharmonies which will be pointed out on later pages.

Field evidence must also be used in dealing with an older division of opinion on the origin of the Ozarkian summit flats. Were Purdue, Miser, and others correct in their understanding of the Boston Mountains summit and of the Springfield and Salem plateaus as stripped, structural plains? Admitting the erosion, they refused to accept reduction to grade by it.

Successive epochs of active denudation with intervening times of little alteration of the land surfaces are part of almost every interpretation found in the Ozark literature. But every student except Marbut has dealt with only a limited portion of the province, and Marbut's work was done early under handicaps that later students have not encountered. He obviously never saw the Arkansas Bostons, and he admitted that some Missouri areas were not traversed. He found but one upland peneplain. Others have found two, even three. Where multiple base leveling is on record in separate limited tracts (Hershey, Buckley, Dake), the problem of correlation is faced. Fenneman attempted it, using his fixed idea that Salem and Springfield plateaus are of the same age. This problem must be re-examined and other reported baseleveled tracts correlated.

Dating of erosional surfaces in the Ozark province has been attempted by proposed correlations with Appalachian surfaces, by presumed truncation of Mississippi Embayment formations, by assumptions as to the age of overlying stream gravel, and by reference to the Pleistocene glaciations.

The date of the oldest erosion surface, the Boston Mountains, has ranged from Jura-Cretaceous (Hershey) to Aftonian Pleistocene (Quinn). The *making* of the most widespread existing surface, the Salem Plateau (named the Ozark peneplain by Fenneman). has been assigned to the Boston Mountain cycle by Hershey, but its *dating* has been, by both Hershey and Fenneman, a full erosion cycle later. By Hershey's theory, the Boston Mountains' second uplift failed to affect the Ozark dome and, thus, left the Missouri part of the peneplain of Boston Mountain age lying safely at base level while the mountains entered a second cycle. The mountains themselves do not possess Hershey's second or Tertiary peneplain; it only flanks them.

The Bostons' present rough topography is, therefore, the cumulative result of all erosion on their shales and relatively thin sandstones since uplift of the oldest peneplain. The only alternative offered (Purdue, 1901) has been that the Bostons were uplifted, and their dissection was begun in late Tertiary or in post-Tertiary time.

The curious existence of this mountainous group of shaly rock in the highest of the subprovinces thus has had two explanations, each involving a sequence and a dating completely at variance with the other. Because there appears to be no third choice, one of these explanations must be correct. Which one?

Equally curious is the survival of Precambrian mountains in the St. Francois subprovince. Not alone were they mountains of respectable magnitude when the Paleozoic seas first invaded the region, but they have remained without any notable modification through the vicissitudes of all subsequent erosion.

Stream gravels on high terraces and even on major interfluve summits have been reported and generally dismissed as "Lafayette". Times and conditions of high-level gravel deposition have very probably been different in different places.

The northern margins of the Salem and Springfield subprovinces carry records of a continental ice sheet or ice sheets invading from the north.The extreme limit reached is not definitely known. The effect of such an invasion on the trans-state portion of the Missouri River and its tributaries from the south and the terrace records left after ice withdrawal began await more attention.

Themes of This Study

In this report, the following propositions will be defended:

1) None of the erosional flats on interfluve summits of the Missouri Ozarks has been made by pedimentation. None is a structural plain *per se.* None records a noncyclic "dynamic equilibrium" during its development. All are remnants of former peneplains.

2) Three successive peneplains (Boston Mountains, Springfield, and Ozark) are recorded in the Missouri and Arkansas Ozarks. All have been much dissected, and the oldest, though possessing rude accordance of summit level in the Boston Mountains, Arkansas, has lost all summit flats. Only a very few remnants of it exist outside the Boston Mountains subprovince.

3) The eastern margin of the Springfield Plateau is part of an erosion surface (Springfield peneplain) older than the Salem Plateau (Ozark peneplain).

4) Uplifts which inaugurated successive erosion cycles warped the uplifted peneplains. Evidence of the warping is found in the interfluve longitudinal profiles and valley cross sectional profiles, not in changes of drainage courses.

5) Uplift of the Ozark dome after its third (Ozark) peneplanation has been interrupted by two pauses which are recorded by strath terraces.

6) Stream gravel on upland surfaces is of different ages in different places, and its existence alone cannot be used in correlating surfaces.

7) The Eureka Springs escarpment, where distant from major streams, has retreated but little since the end of the Ozark cycle.

8) Much base leveling of Ozark age occurred in the Springfield Plateau west of the scarp. Only summit portions of the cuesta still carry Springfield peneplain flats.

9) The Springfield peneplain is to be correlated with the Dodgeville peneplain of Wisconsin and Illinois. The Ozark peneplain is the equivalent of the Lancaster peneplain of Wisconsin and Illinois.

ST. FRANCOIS MOUNTAINS

Two subdivisions of the Ozark province lack the characteristic summit plane of a plateau. Views across the Boston Mountains can, with a knowledge of the structure, convince one that the tract once had a summit plane since lost to the rapacity of its streams. The St. Francois Mountains subprovince, however, apparently never possessed such a feature. Its topography is unlike a dissected plateau for the individual eminences vary greatly in altitude and lack flattish summits (Fig. 1). Nor is their ground plan that of the expectable dendritic drainage pattern. Furthermore, there is no system in the cross sectional profiles of the hills. Although drainage goes to north-flowing Big River and south-flowing St. Francis and Black Rivers, the subprovince's divides do not consistently remain on hilltops, nor where so located, do they consistently follow hilltop elongations. In more than a dozen places in this relatively small tract, major and minor water partings cross valley lowlands at high angles to the trend of the valleys.

These aberrant drainage features are readily understood when one realizes that most of the subprovince's uplands are exhumed, steep-sided, Precambrian mountains (or mountain sum-

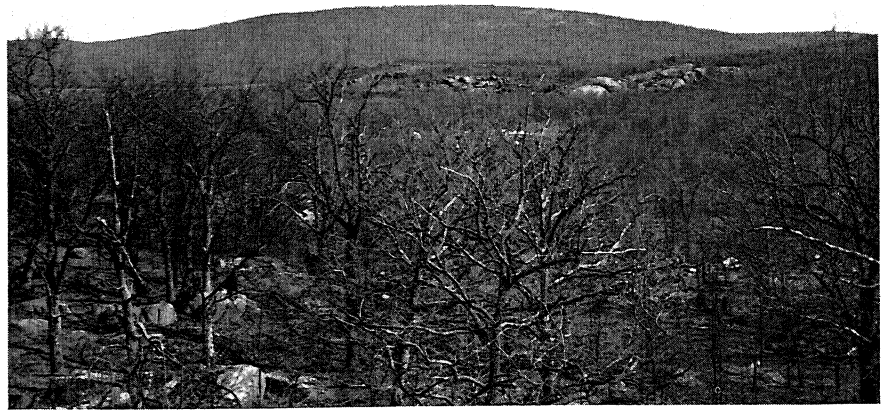

Fig. 1. South end of Buford Mountain seen from Elephant Rocks, St. Francois Mountains; Ironton Quadrangle. R. Zangerl, photo.

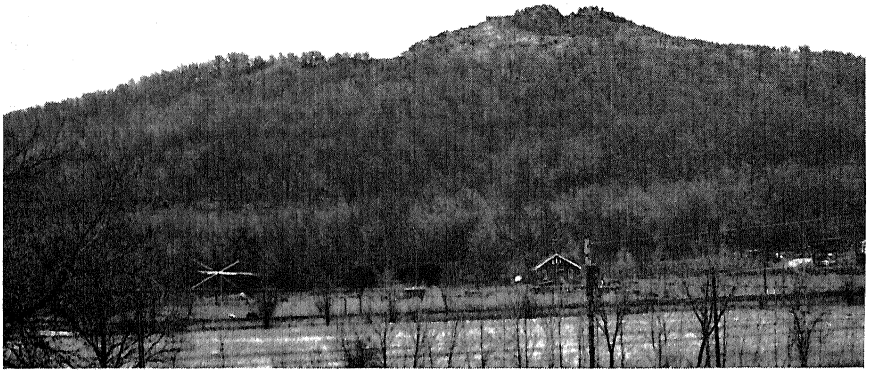

Fig. 2. Pilot Knob, St. Francois Mountains; Ironton Quadrangle. The notch in the summit and the steepened left (north) slope record early mining of hematite. R. Zangerl, photo.

mits) of crystalline rocks, highly resistant to erosion as compared with the once-overlying Paleozoic formations. The summits reflect something of the pre-Paleozoic drainage, but superposition of streams during the exhumation has produced many narrows in the emerging crystalline hills and presumably has failed to find and re-excavate many of the older waterway connections.

As noted, there is no record of a Precambrian peneplain in these summits. Profound erosion certainly has occurred, for the intrusion of magmatic, ore-bearing solutions (Fig. 2) and of coarse-grained granite (Fig. 3) predicates deep burial at some very early time. If the pristine topography was ever evenly truncated by erosion, the region underwent a later uplift followed by rejuvenation that left convincing evidence that it then stood far from any major continental river.

The ancient landscape now emerging has a relief of more than a thousand feet insofar as exposed today, and its hills were as steeply sloped and as crowded together as they remain today. Except for the later stream-cut narrows (with even steeper slopes) and talus and beach accumulations of Paleozoic age, the St. Francois Mountains today present almost no evidence of alteration from their Precambrian forms. Yet their slopes were subaerially exposed for a good portion of the Paleozoic era and much of all subsequent time, and their higher summits still rise above the highest surviving hills of Paleozoic rock.* One wonders how long a stillstand is recorded by the Precambrian peneplain of the Canadian Shield.

Most of the drainage of the subprovince belongs to the St. Francis River system. Figure 4 shows how that river's headwaters

*Taum Sauk Mountain, 1,772 feet A. T., is the highest place in the entire plateau, and is exceeded only by some summits in the Boston Mountains.

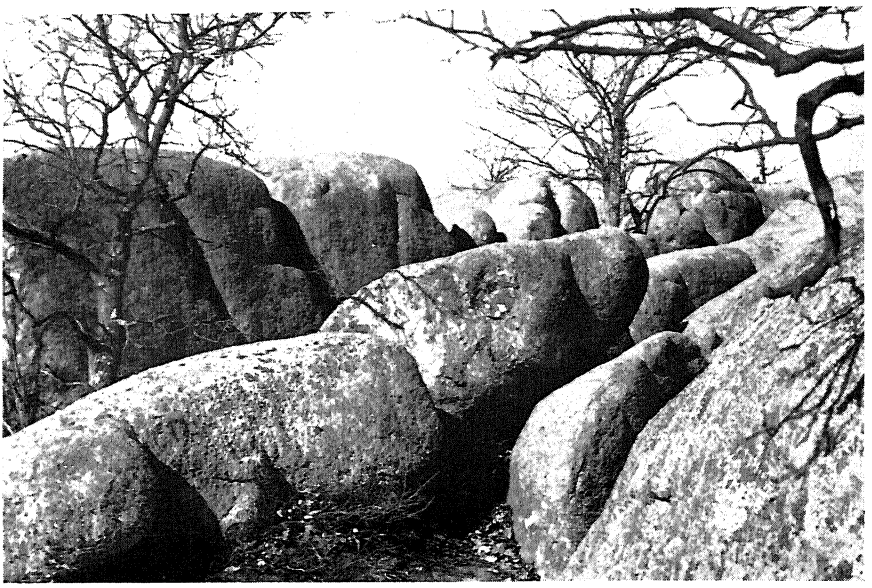

Fig. 3. Elephant Rocks, St. Francois Mountains; Ironton Quadrangle. Weathered outcrops of coarse-grained granite. R. Zangerl, photo.

describe a rude semicircle through the maze of crystalline hills which were largely or completely buried at the close of Paleozoic sedimentation. Tributary courses are even more erratic. Such a drainage system never descended directly from an original dendritic pattern on plateau rocks. Some of the abandoned (or unused) watergaps may be records of piracies now difficult or impossible to reconstruct. Lateral displacement as the deepening stream valleys encountered sloping crystalline surfaces may also have been a factor in producing the St. Francis River pattern. It fits no textbook classification. Simply stated, it is "complex".

Many through valleys have never had a through-flowing stream in post-Paleozoic time. They have been cleaned out entirely by headward erosion of opposite-flowing streams. Narrows farther down such streams, initially incised at altitudes higher than their headwaters' present valley-bottom divide, must neverthless be strictly contemporaneous with the headwater erosion.

Every divide separating the four headwater streams of the St. Francis drainage (see Fig. 4) descends from Precambrian summits in two or more places to *cross* Precambrian valleys on whose floors less than a mile may separate opposite-flowing stream heads. Graded slopes prevail on each valleyway and continue across the low divides. The Precambrian valleys thus intersected were once continuous. Then, when the region was an archipelago of mountain-top islands, they became completely obliterated by Paleozoic sediments. Why in the re-excavation, should the present valley floors

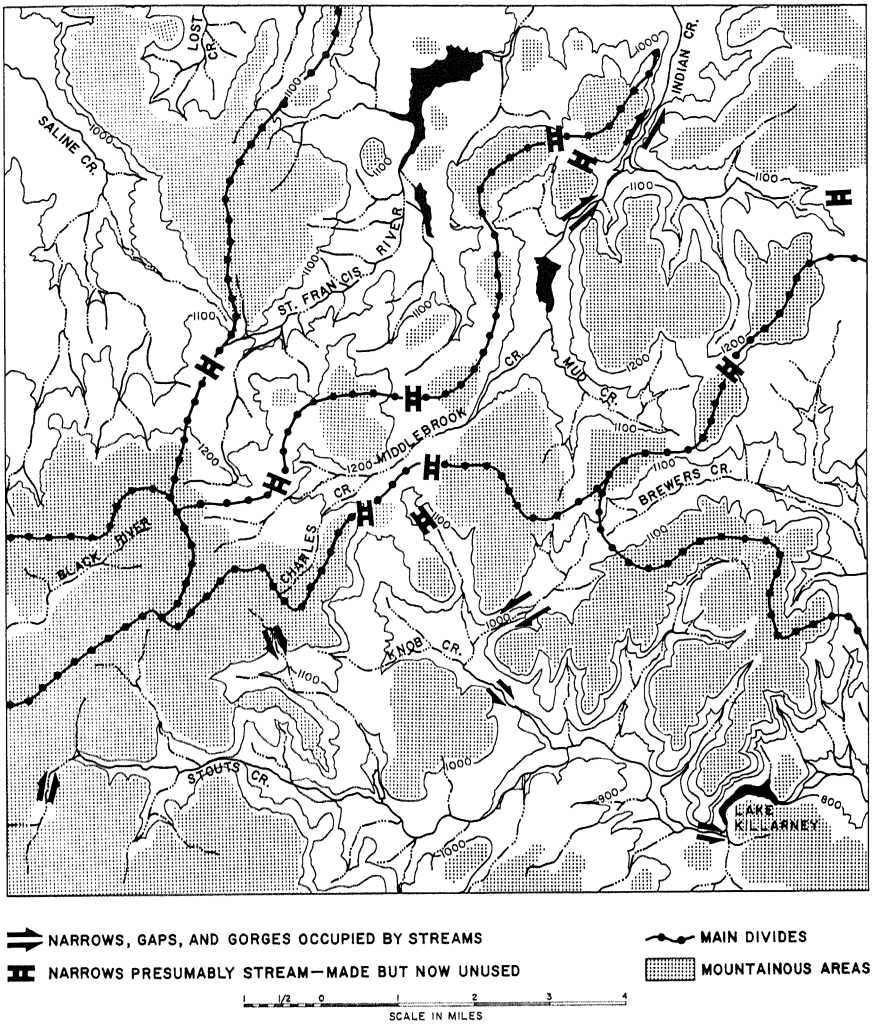

Fig. 4. Map of complex drainage pattern in central St. Francois Mountains showing: 1) narrows, gaps, and gorges occupied by streams, 2) narrows presumably made by streams but now unused, 3) main divides, and 4) mountainous areas.

at heads of opposed streams carry a valley bottom divide across with scarcely a break in slope?

The answer seems afforded by the Big River-St. Francis River valley bottom divide. Dake's younger base level in Big River headwaters, a "partial peneplain", is traceable southward as the unusually wide lowland (of northwestern Ironton and northeastern Edgehill Quadrangles) which is drained by north-flowing Saline Creek, a Big River tributary. Neglecting later stream entrenchment, this lowland across diverse Paleozoic formations (Dake) rises south-

ward upstream, 250 feet in six miles along the Saline and there, at 1,100 feet A. T. crosses (or is crossed by) the valley bottom divide to continue southward, as a narrower flat, for another two miles, there rising to 1,220 feet A. T. at Graniteville. But this two-mile length belongs to St. Francis River, not Big River! (Fig. 5).

At Graniteville, another valley bottom divide is crossed, beyond which the still more narrowed valley is drained eastward by Middlebrook Creek whose floor descends smoothly to 1,100 feet A. T. in two and a half miles farther.

The third divide across the attenuated valley separates Middlebrook drainage from the head of Knob Creek, south-flowing to Stouts Creek. Here are minor interruptions made by low irregular hills of Precambrian rock across which is a descent of about 50

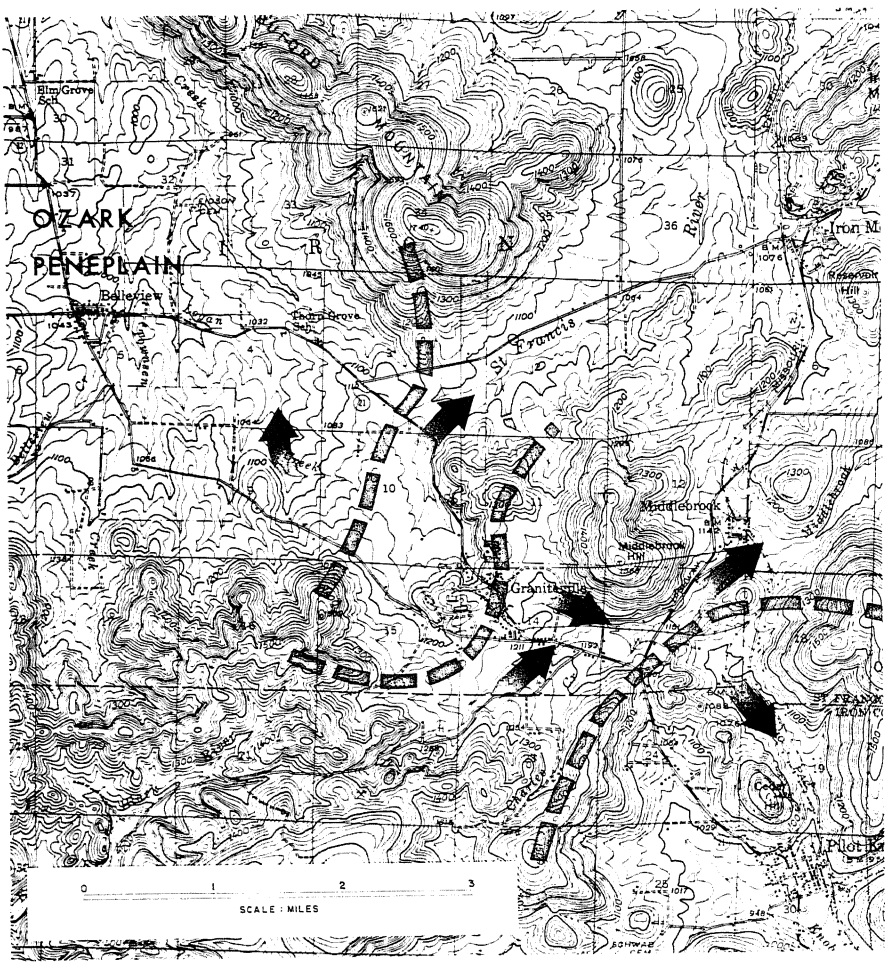

Fig. 5. Map showing divides across valley bottoms. St. Francois Mountains; Ironton Quadrangle. Arrows indicate direction of present drainage.

feet in a half mile. Other than this, the entire floor is unbroken across the heads of four separate streams, and it all was, before minor stream entrenchment, a graded extension back upstream from Dake's "partial peneplain".

This is only one valley bottom profile across the group of mountains. The map (Fig. 4) shows that several others exist: baseleveled flats on Paleozoics that still floor the Precambrian valleys; fingerlike ramifications attesting to a former peneplaned condition of the surrounding Salem subprovince.

The numerous narrows with cascades and low falls over crystalline rock on all streams of the St. Francois subprovince are a warning against too much confidence in this interpretation. To what extent may these valley floors be local peneplains? Perhaps some are. But may not a narrows in crystalline rock be cut down to grade, even if it is not widened, the while that weaker Paleozoic rocks are widely lowered to a long-standing base level? All present-day cascades and steep, rock-bottomed channels belong to the modern cycle of erosion; not one is a holdover from an earlier cycle.

As an example supporting this idea, consider the valley floors of Stouts Creek drainage upstream from the shut-in narrows above Lake Killarney (Fig. 6). There are two floors, the lower and central

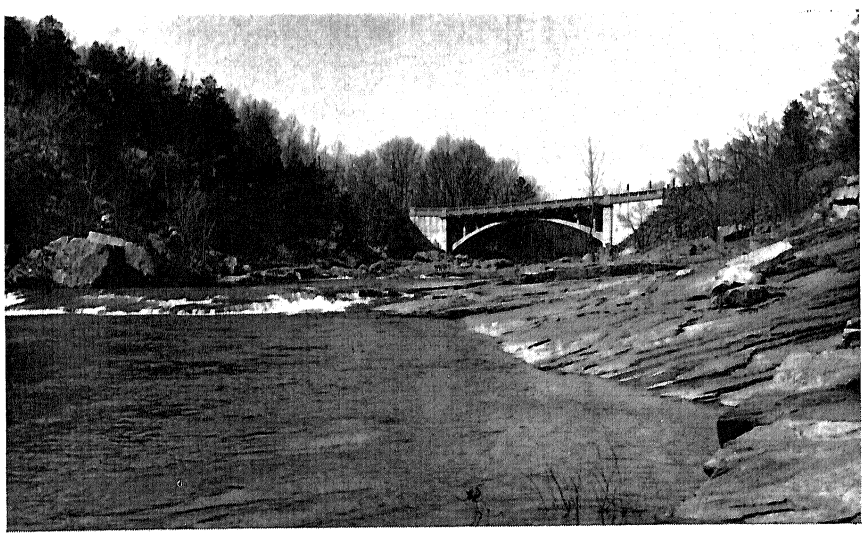

Fig. 6. Shut-in narrows of Stouts Creek, St. Francois Mountains; Ironton Quadrangle. Bridge for Missouri Hwy. 72. R. Zangerl, photo.

one adjusted to the tributary creeks which, united, are in turn controlled by the cascades at the shut-in. This floor may be called an incipient local peneplain. Its long slope is that of its streams. There is also a higher, dissected marginal floor, 100-150 feet above the shut-in's sill. In the valley west of Shepherd Mountain, untraversed by a through stream, this floor is intact at 1,020 feet A. T.,

175 feet higher than the altitude of the sill. No Lake Killarney sill determined this upper floor level. The Precambrian sill rock was still completely buried under Paleozoics when the Shepherd Mountain valley floor was made.

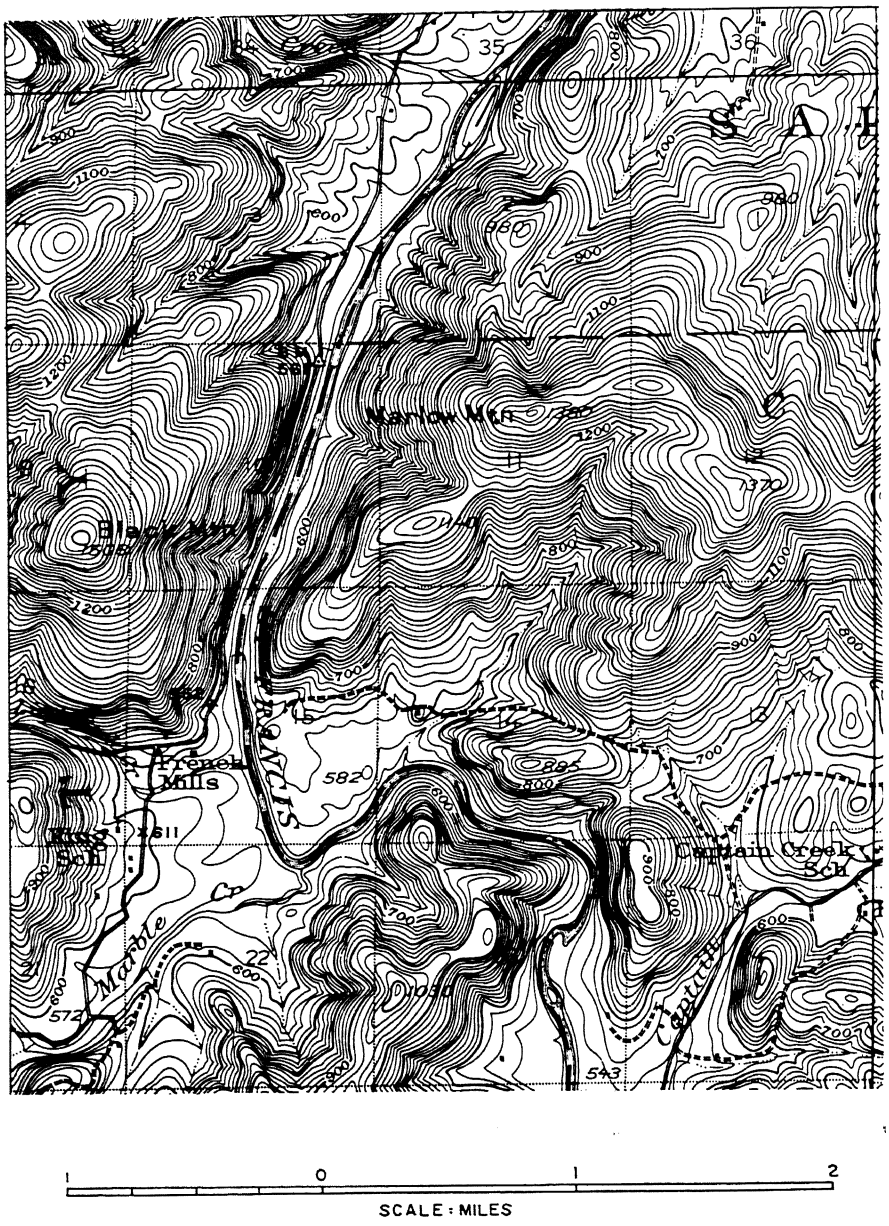

Fig. 7. Map of Marlow-Black Mountain narrows, St. Francis River, St. Francois Mountains; Coldwater Quadrangle.

Other narrows lie farther downstream along Stouts Creek and St. Francis River before drainage escapes the Precambrian confines, but only one (between Marlow and Black Mountains, Coldwater Quadrangle) has summit altitudes adequate to account for the dissected higher terrace floor. This effective narrows (Fig. 7) is 17 miles distant by river routes from the Lake Killarney sill, and the original summit of Precambrian rock encountered by the downcutting St. Francis was approximately 1,000 feet A. T. The higher floor along Stouts Creek—the towns of Arcadia, Ironton, and Pilot Knob stand on it—is lower than this and, therefore, must have developed after the Marlow-Black narrows was initiated.

The walls of this narrows, approximately 500 feet high, have no intermediate bench to record any long pause during its deepening. The river's gradient through the one and a half mile long gorge, read from the Coldwater topographic map, is about 25 feet per mile while the river's gradient upstream for the next 12 miles (to junction of Stouts Creek) is about half of that. Most of that 12 miles is on Precambrian rock.

There is nothing in the steep sides of this gorge to support the idea that a pause in deepening the Black-Marlow gorge or narrows ever occurred. But a former baseleveled condition is recorded at 800 feet plus on the country underlain by Paleozoic rocks south of this gorge (on interfluves in midlength of Coldwater and Marquand Quadrangles), and Paleozoics in the Stouts Creek valley about Arcadia, Ironton, and Pilot Knob could share in that experience without the highly resistant Precambrian rock slopes of the gorge recording it. A general southeastward decrease in altitude of such remnants of an upland plain of erosional origin is recognizable on the Des Arc, Coldwater, and Marquand topographic maps, where the plane of the flat-topped, accordant ridge summits transects more steeply dipping formations ranging from Cambrian Bonne Terre to Ordovician Jefferson City formations. This dissected surface is interpreted as the warped Ozark peneplain descending the southeast slope of the dome.

Assumption of a Marlow-Black narrows 100 feet deep *on the Ozark peneplain* allows a gradient thence upstream to the Arcadia-Ironton terrace of three feet per mile, an adequate slope for our interpretation. Upstream from Arcadia to the empty valley west of Shepherd Mountain, the terrace gradient steepens to 10 feet or so per mile, an expectable increase in approaching the up-valley limit of Paleozoic floor rock. The old valley floor thus appears to be of Ozark cycle age.

If these interpretations are sound, there should be identifiable remnants of the Ozark peneplain along St. Francis River upstream from the Stouts Creek junction. Such remnants are found: 1) on the "Jonca" Plain of the Farmington Quadrangle, north of the Fredericktown Quadrangle, 2) about Womack on the Higdon Quadrangle east of the Fredericktown Quadrangle, and 3) along Big River drainage north of the St. Francois Mountains (Bonne

Terre Quadrangle). These areas lie out in the surrounding Salem subprovince and will be discussed later.

The abrupt drop of about 50 feet from Middlebrook flat to that at the head of Knob Creek may at first glance seem difficult to explain by the preferred interpretation of graded, even base-leveled, valley flats of the St. Francis drainage anastomosis. The anomalous steepness should probably be attributed to the broken row of small Precambrian hills at this valley-bottom divide. The difference in altitude, however, is simply because Middlebrook Creek has almost three times as far as Knob Creek to go to the mingling of their water in St. Francis River. The apparent discrepancy is actually supporting evidence for our interpretation. Scrutiny of the Ironton Quadrangle map will show several similar situations at valley-bottom divides.

Nothing in the geomorphology of the St. Francois subprovince, either in the original sculpturing or in the later exhumation, can be adduced to favor the concept of pedimentation. Not even incipient benching on Precambrian slopes descending to the Ozark peneplain's trace can be detected. The record everywhere is the work of concentrated run-off; i. e. streams.

SALEM PLATEAU

The area of Ordovician rocks centrally cropping out on the Ozark dome, as shown on geological maps of Arkansas and Missouri, satisfactorily depicts most of this large subprovince or section. Approximate boundaries are: the Missouri and Mississippi trenches on the north and east, the Gulf Embayment bluff on the southeast, the Boston Mountains scarp on the south, and the Eureka Springs escarpment on the west. This escarpment gradually lowers northward, becoming fragmentary, and finally disappears on encountering the Osage River valley. North and west of this intersection is a part of Fenneman's Osage section, or subprovince, of the Central Lowlands, here reclassified as a part of the Salem subprovince. It is underlain by Pennsylvanian and Mississippian formations, and even the bluffs of the master valley, the Missouri, show no older formations.

Considerable remnant areas of Pennsylvanian sediments interrupt the Ordovician pattern on the northern slope of the dome, and some small Mississippian monadnock tracts lie on the south slope. The eastern marginal portion of the section, between the St. Francois Mountains and the Mississippi River, possesses limited areas of Silurian, Devonian, and Mississippian rocks. Dips are steeper here than elsewhere in the entire province, and with several large, approximately northwest-southeast strike faults they produce a belted pattern tangential to this eastern slope of the dome and a series of marked cuestas in the topography. Notched by short, transverse stream valleys which lead directly to the Mississippi, these escarpment crests have skyline profiles quite unlike the evenness of interfluve summits throughout the rest of the section.

The two highest tracts of the Ozark topographic dome are near the eastern and western ends of its elliptical outline, the St. Francois summits being enclosed within the Salem's boundaries and the Springfield Plateau's east-facing Eureka Springs escarpment standing along the western boundary. The long axis of the structural dome approximates the crest of the topographic dome. The main divide separates those rivers flowing northward to the Missouri (Osage, Gasconade, Meramec, and their tributaries) from the southward-flowing streams (James, North Fork, Eleven Point, Current, Black, and their tributaries) that enter White River, which, far out on the slope of the dome, occupies in itself a considerable portion of the southern slope's drainage area. St. Francis River alone enters the Mississippi directly.

This major divide of the section or subprovince carries significant records of early events in the geomorphic history of the province, but little has yet been found there to contribute to its later valley-making sequences.

The Salem subprovince also receives drainage from the back slope of the northern part of the Springfield Platform (as delimited by Fenneman), via Osage River. White River along the southern flank brings runoff from the northern portion of the Boston Mountains. The James and Pomme de Terre Rivers have limited headwater areas on the extreme western edge of the Salem, from which they venture over into the Springfield Plateau. But they *return to* the Salem section before joining, respectively, the White and Osage Rivers.

Stream valleys of the southern slope of the topographic dome are deeper than those on the northern slope, and the plateau surface they incise is, therefore, more ruggedly dissected. In part, this reflects a more steeply sloping southern flank. In part, it is because drainage off the northern flank must flow many more miles, via the Missouri and Mississippi, to reach the low embayment than do the White and St. Francis Rivers.

Uplands of the Salem Subprovince

The Major Divide

The Salem subprovince, in its envelopment of the St. Francois Mountains, is highest immediately west of the Mountains. This, which is the Ozark province's major divide and is entirely on Paleozoic rocks, reaches altitudes of more than 1,500 feet A. T. close to the mountains and falls below 1,300 feet in only three places for the first 50 miles westward from the mountain subprovince. It thus is higher than many of the Precambrian summits. But it is a continuous feature followed by roads, not a congeries of separate hills like the St. Francois section. Its course across to the Eureka Springs scarp describes a huge zigzag, westward, southward and westward again, and its characteristics with their interpretation may now be considered.

For 25 direct miles west from the mountains, the country is exceedingly rugged (Edgehill, Boss, Stone Hill Quadrangles, Iron and Dent Counties) because of headwater erosion by Meramec River tributaries on the north and Black River tributaries on the south. The divide across this rugged country is a narrow, winding, forested ridge with an undulating crest line that totals 40 miles in length. In south-central Stone Hill Quadrangle (Dent County) where the south slope is in Current River drainage and only the extreme headwaters of Meramec River reach it, the summit is broader, and upland farms replace the forest. This broadening is much more pronounced in southern Salem Quadrangle (Dent County) where the altitudes remain at 1,300 to 1,350 feet A. T. with a scattering of isolated summits of 1,400 to 1,480 feet. Associated valleys are also broad and shallow, compared with those (Fig. 8) along the first 40 miles of the crest.

This Salem area, from which the subprovince has been named, is far from a tableland. Although not a rugged topography, every

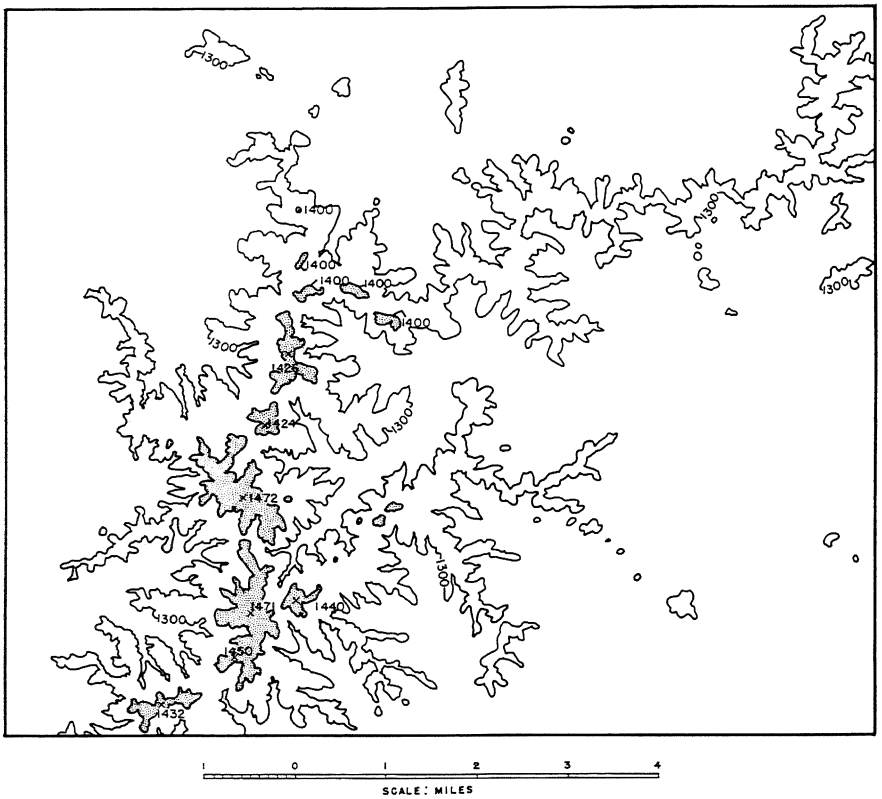

Fig. 8. Map showing Ozark peneplain remnants (shaded areas) on summit of main divide; Boss Quadrangle. A rugged topography of ravines and ridges, lower and younger than the peneplain remnants, has been omitted in the blank areas outside the 1,300-foot contour.

square mile is dissected in dendritic fashion. The original erosional plain, wholly in the Ordovician Roubidoux formation, is recognizable only in the rude summit accordance of a multitude of minor divides. None of these has a summit that is flat enough to be called a peneplain remnant.

But on the Edgar Springs Quadrangle (Phelps County) next west of the Salem Quadrangle, the marked change noted toward broader summits and associated open valleys grades into summit flats as much as a mile wide whose drainage slopes are as low as 10 feet per mile. Here, the course of the divide swings south for nearly 40 miles, and the upland flat continues for more than half of that distance. Altitudes remain at 1,300 to 1,350 feet except for a few isolated hills, one summit of which reaches 1,480 feet. This north-south stretch of the divide is a far better type area for the plateau than is the dissected region about Salem (Fig. 9).

Significantly, this flat-topped divide (shown on Licking and Raymondville Quadrangles, Texas County), which is underlain largely by sandstone of the Roubidoux formation, possesses an area about Licking of the next younger Ordovician formation, the Jefferson City. In more dissected country southward from Raymondville, the Jefferson City formation constitutes the flattish uplands westwardly to the Eureka Springs escarpment, the western margin of the Salem Platform. Thus, this upland plain is an erosional plain.

Virtually all rivers of the Ozark dome work in sedimentary formations and flow from older rocks to younger. The flat-topped interfluves also pass in downstream directions from older to younger formations. Thus, the maximum erosional removal of the original dome rock has been on the generalized structural summit. Yet, it is here that streams are smallest and can have done the least work in a noncyclic attack. It could be argued, of course, that the lower stretches of these rivers have long since ceased to degrade while the central uplands were wasted away by these streams which caught up with and even surpassed the lower river stretches in denuding the dome.

But these lower stretches have not ceased degrading; they are deep valleys with considerable bare rock cliffs in the bluffs.

It then could be argued: 1) that uplift of the central dome has been slow and continuous for most of post-Pennsylvanian time, while the marginal portions have lain too low for much erosion, and 2) that only recently, geologically, have the peripheral portions been rather rapidly uplifted relative to the denuded central parts. This sequence would account for the deep, rock-walled Missouri, Mississippi, White, Current and other such valleys leading from a greatly denuded domal center. This view appeals to us as a purely gratuitous idea built only to uphold the hypothesis of "dynamic equilibrium" and to escape the conclusion that peneplanation has ever occurred. There is no field evidence in its support, and the "dynamic equilibrium" hypothesis fails here to fit the facts.

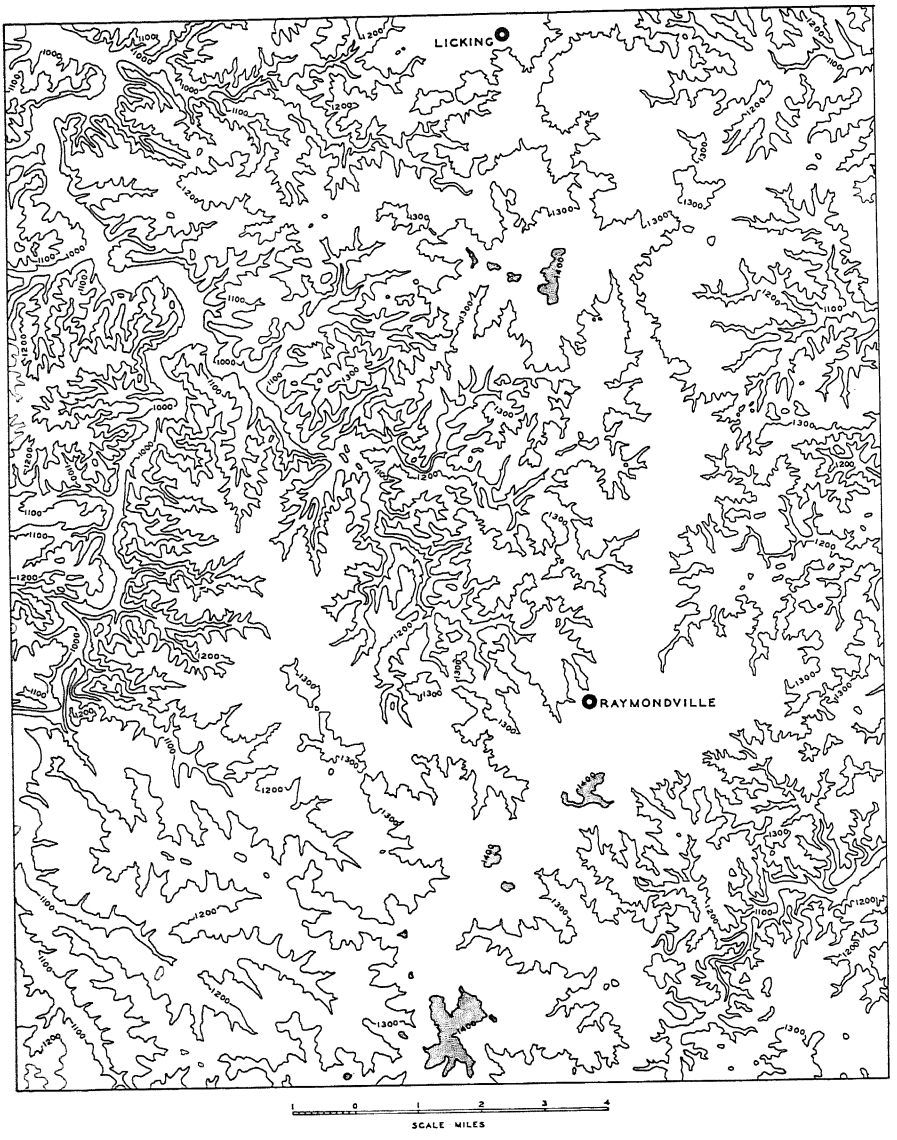

Fig. 9. Raymondville 15-minute Quadrangle, showing only the 100-foot contours. Most monadnock elevations on this portion of the Ozark peneplain are caught by the 1,400-foot contour (shaded areas). All remnants of the peneplain lie above 1,200- and most of their area is enclosed by the 1,300-foot contour. Many "island" and "peninsula" residuals among margining ravines indicate that this district was a broad and gently sloped peneplain interfluve between drainage of south-flowing Current River and north-flowing Big Piney River. The interfluve summit is continued for 12 miles farther north at and above the 1,200 feet A.T. (Edgar Springs Quadrangle) and there possesses the same diagnostic characters of monadnocks and of once

The conspicuous flatness along the Licking-Raymondville stretch of the main divide is lost for about 15 miles across Clear Springs Quadrangle (Texas County), the gently rolling summit there being narrower above the heads of a swarm of attacking ravines that are gnawing back from Jacks Fork of Current River on the east and from Gasconade River on the west.

Near Sterling (Wright County) and Cabool (Texas County, Cabool Quadrangle), the course of the divide swings to the west, average altitudes rise above 1,400 feet, and the width becomes variable. Long, flat-topped spurs project both north and south from the main divide. At Mountain Grove 1,465 feet A.T. (Mountain Grove North Quadrangle, Wright County), such a spur runs out for 10 miles northward into the Gasconade drainage without lowering below 1,400 feet A.T., and its flanking gentle valley slopes allow section line roads instead of the twistings required by the rugged topography of Clear Springs Quadrangle. Thence, westward to the Eureka Springs escarpment, the southern slope is consistently steeper so that at Mountain Grove (Mountain Grove North and South Quadrangles) the upland flat really lies on the north slope, and its high south edge is 1,500 feet or more in many places all the way to the great scarp.

Monadnocks

On this stretch of the main divide are several isolated hills, composed of Mississippian rocks that reach about 1,600 feet A.T. and clearly are but outliers of the Springfield Plateau whose flat summit does not quite reach 1,700 feet in this latitude. Dove Mountain monadnock, seven miles north of Mountain Grove on the spur noted and 100 feet high, has the same altitude as the main divide a mile south of town. Only on the east side of this spur are growing ravines dissecting its flat top and reaching the slopes of the monadnock.

From St. Francois Mountains to the Springfield Plateau, the province's main divide holds prevailing altitudes between 1,300 and 1,400 feet yet transects Gasconade dolomite, Roubidoux sandstone, and Jefferson City dolomite. Overall increase in altitude westward accompanies a stratigraphic rise, but the divide is not a remnant of a structural plain. Dissection of the flanks and narrowness of the crest are pronounced where streams lead in a few miles to deep river valleys. The Licking-Raymondville summit flat separates headwaters of north-flowing Gasconade and southward-

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greater widths. Thence northward, it is attenuated in places but identifiable as a continuous feature across portions of Rolla, Salem, Linn, Redbird, Bland, Gerald, and Hermann Quadrangles to terminate in the summit of Missouri River bluffs 100 miles from Licking. For the latter half of this distance the summit flat is on Pennsylvanian rock. Total descent is 325 feet. The river bluffs of Hermann are 450 feet high, a fact whose significance the proponents of dynamic equilibrium should ponder.

flowing Current rivers, and the low relief about Mountain Grove lies also at the very heads of the Gasconade system whose drainage has much farther to go; therefore, has lower gradients than that of North Fork on the dome's steeper, shorter, and more dissected southern slope.

The main divide thus is a remnant of an erosional plain that once extended across the entire dome except for a few dozen isolated summits residual from an earlier topography (Fig. 10). The remaining summit flats of that former erosional plain show that

Fig. 10. Lead Hill, a monadnock on the Ozark peneplain near Dunn on the main divide, Cabool Quadrangle. R. Zangerl, photo.

this truncation completed the removal of Pennsylvanian, Mississippian, and upper Ordovician rocks across the dome. The scattered monadnocks along the main divide and on some of its larger, less dissected spurs are all that failed to be reduced to the base level of the Ozark peneplain. These relicts of an earlier, relatively higher land surface, with their steep slopes rising above a low gradient summit plain, are not composed of more resistant rock than that removed in making the surrounding plains. Under "dynamic equilibrium" conditions of noncyclic erosional attack, they are impossible.

Some of the lower monadnocklike elevations are better described as remnants of Ozark late mature topography never quite reduced to base level. The region about Turtle (Stone Hill Quadrangle) is typical.

Only a minimum of concentrated wash has occurred and is occurring on these relics of a higher surface. No stream has ever undercut their flanks. The slope wastage and consequent bluff retreat that has reduced them to present dimensions has continued without interruption since the Ozark erosion surface was raised above its base level. Therefore, those with surrounding intact Ozark flats are still in the Ozark cycle and must so remain until advancing ravine heads of the Salem plateau's rejuvenation reach them.

Such residual hills occur in many places on the interfluve spurs that lead laterally off the main divide, particularly on the elongated upland spurs descending the gentler northern slope. Re-

lations and history of development there are the same as on the main divide. Only the altitudes are lower as the warped or tilted Ozark peneplain slopes down toward the northern periphery of the post-Ozark up-doming.

Heights of these isolated hills commonly vary in any group, and very few such hills or groups of hills have flat summits to suggest an earlier peneplanation.

It has long been accepted that the strikingly entrenched meanders of Ozark rivers are records of baseleveled stream courses and therefore testify to the actuality of the Davisian erosion cycle. To this conclusion the isolated hills add weight. They record the divides of the peneplain drainage just as the meanders record river courses at base level. Neither suffered shifting in the post-Ozark rejuvenation. Both testify to a widespread erosional reduction: one that brought, in places, even the very summit of that earlier dome form down to gently graded slopes.

Some Divides of the Northern Slope

Gasconade-Meramec divide.—The most instructive interfluve branching off the main divide of the Ozark dome separates Gasconade River drainage from the Meramec River's system. It is a northward continuation of the Licking-Raymondville high flat which promptly deteriorates to a raggedly outlined undulating upland as far as Rolla National Airport near Vichy, a distance of 40 miles. But at the Airport (Figs. 11, 12), the divide becomes a remarkably well preserved flat upland commonly called Lanes Prairie which is depicted on the Vienna (Maries County) and Red-

Fig. 11. Rolla National Airport near Vichy on the summit of Lanes Prairie monadnock on the Ozark peneplain. The prairie here is a remnant of the Springfield peneplain. R. Zangerl, photo.

bird (Gasconade County) Quadrangle maps. A constricted and lower tract in the summit north of Lanes Prairie separates it from another high, very irregularly outlined but unusually extensive remnant of the upland flat in the region about Belle (Maries County). Farther eastward a third upland, still smaller but prominent, is about the town of Canaan (Gasconade County). Both are shown on the Bland Quadrangle map. This eastward swing of the course of the divide continues to Owensville (Gasconade County) where there is another broadening of the summit. There it turns north again and continues to the Missouri River trench near Hermann.

The total distance along the crest is about 100 miles—a straight line from Licking to Hermann is 88 miles long—and the total descent to the summit of the Missouri River bluffs is 325 feet. The bluffs themselves are 450 feet high, a fact whose significance the proponents of "dynamic equilibrium" should ponder.*

This Gasconade-Meramec divide records as perfectly as any place in the province the radial slope of the peneplaned dome. It is one of the gentlest of such slopes, and three feet per mile can involve but little, if any, post-peneplain steepening. The divide does indeed approximately follow a radially oriented structural upwrinkle that is traceable northward across the Missouri River and out of the province into the glaciated country of northern Missouri. As will be shown, however, the divide was there before the gentle warping occurred.

The summit of the Gasconade-Meramec divide in Dent, Phelps, Maries, and Gasconade Counties (Salem, Edgar Springs, Rolla, Meramec Spring, Vienna, Redbird, Bland, Gerald, and Hermann Quadrangles) is supplied with monadnock elevations like those the major divide possesses. Some of these residuals also are scattered a bit off the main line. For example, Pilot Knob (Rolla 15-minute and Yancy Mills 7½-minute Quadrangles) which is often cited as a typical Ozark monadnock is on a lateral spur divide two miles to the west of the actual water parting.

The Ozark surface has been lowered varying amounts also, and proportionately more of it is gone from this Gasconade-Meramec divide than from the province's major divide. Its surviving remnants north from Licking emphatically are not residual from a structural plain for they cross Ordovician (Roubidoux and Jefferson City formations) and Pennsylvanian rocks. Therefore, the earlier and higher subparallel surface which the monadnocks record must be judged as erosional. Was it perhaps an earlier peneplain?

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*Hack (1960) says that "Parallelism between. . .profile of channelways and. . .intervening ridge crests argues against the existence of relict [peneplain trace] forms." Profiles of the broad summit interfluve flats and the Ozark's major radial rivers completely lack such parallelism. For example, the interfluve along the east side of the Big Piney River-Gasconade River, a spur of the main divide projecting northward from near Dunn, Cabool, and Sterling, descends quite uniformly 600 feet in its 125 miles of length and terminates in 400-foot bluffs of Missouri Valley while the closely parallel Big Piney-Gasconade River descends about 1,000 feet in that distance.

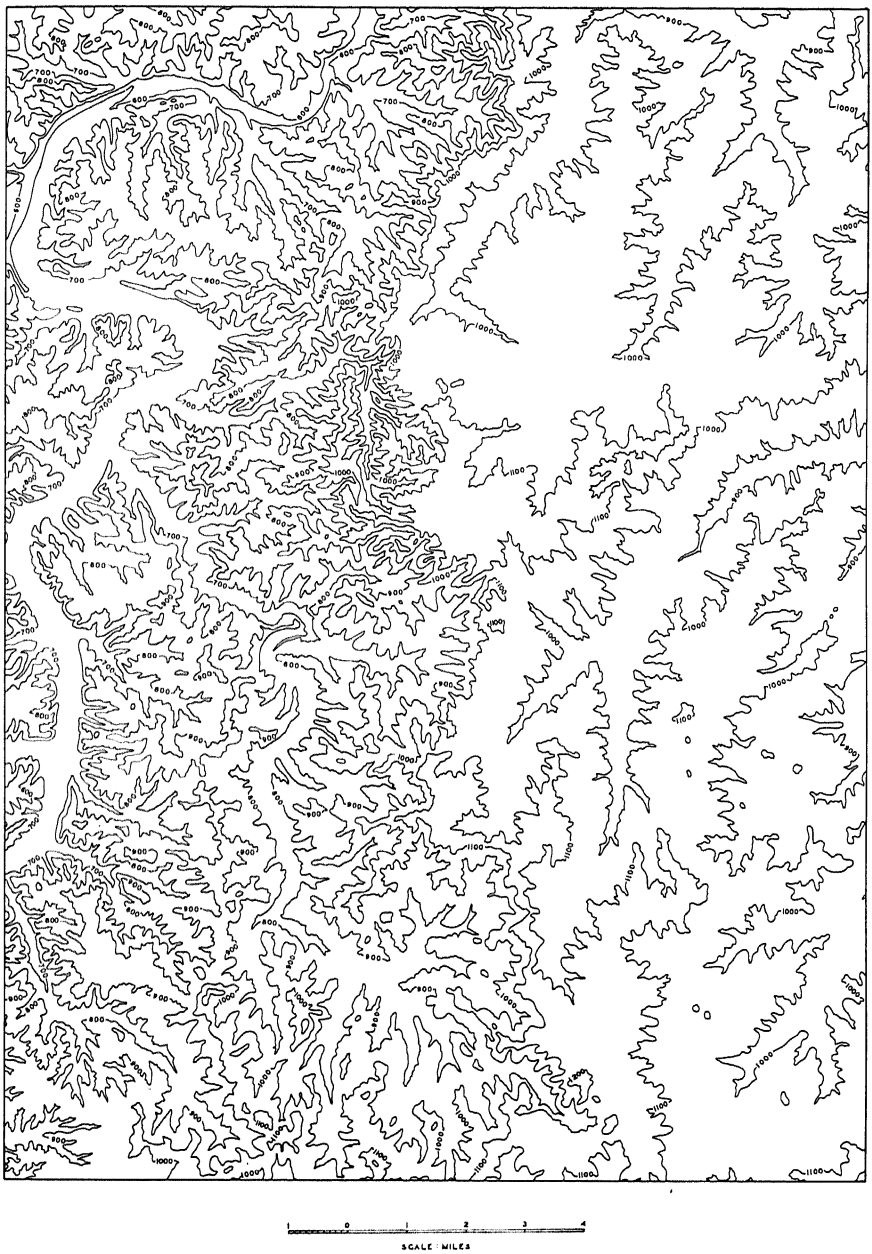

Fig. 12. Map of Lanes Prairie and environs. Only the 100-foot contours are shown; taken from the Vienna, Rolla, Redbird, and Meramec Spring Quadrangle maps. The Springfield peneplain remnant is largely within the 1,100-foot contour and its highest part rises to 1,200 feet on Meramec Spring and Rolla Quadrangles. The monadnock has gentle slopes northward down to the Ozark peneplain remnant at ca. 1,100 feet A.T. On the Meramec Spring Quadrangle however, the descent is 100 feet in half a mile. A prominent strath in Gasconade River valley lies at ca. 800 feet A.T. in the northwestern part of the area shown.

The outstanding one of these residual elevations above the Ozark peneplain trace is on Lanes Prairie. In extent of surviving upland flat, the Prairie is the most impressive example of its class in the entire province. It is unique in that this gently rolling prairie upland has *two* identifiable erosional surfaces, the higher one belonging to the category of the monadnocks although not bounded by the steep slopes that many possess. The extreme southeastern part of this higher surface, shown in the northwestern corner of the Meramec Spring Quadrangle map, is the highest part (1,200 feet A.T.) and there does possess a marked slope (100 feet in half a mile) descending to the Ozark peneplain surface.

The tract in the vicinity of the Rolla National Airport near Vichy (see Figs. 11, 12) ranges from 1,100 to 1,150 feet A.T., whereas, about Lanes Prairie store three to four miles farther north, the flat is close to 1,050 feet. Despite the lack of any abrupt, separating slope, there are two distinct flats. Should an abrupt slope be expected unless pedimentation made the surfaces or resistant beds crop out at the transition?

Additional evidence is found at the constriction between the Canaan and Owensville divide top flats where a drop of about 75 feet exists from west to east. Thus, the higher Canaan flat is the older and the Owensville flat is the Ozark trace. It is annoying for this interpretation, however, that the Fanning fault is crossed also in this constricted place and that the Owensville flat is on the downthrown side.

Nevertheless, the firm conviction follows from study of these upland flats north and east from Rolla to Owensville that the higher flat is a relic of the Springfield peneplain.

Although the Gasconade River which margins the west side of Lanes Prairie is only two and a half to six miles distant for 15 miles, and is 400 to 500 feet lower, not a drop of the Prairie's runoff enters this river (Fig. 12). The extreme western, high edge of the upland is the actual divide, and the Prairie's drainage all goes northward and northeastward in wide, shallow, low gradient valleyways essentially parallel to the Gasconade. Beyond the eastward curve of the divide, the north side of the Belle upland's margin possesses the same curious drainage pattern. Virtually all runoff goes to Bourbeuse River headwaters. Very little goes to the deep valleys on the north. This stream pattern can only be a survival of peneplain drainage. Heads of the minor waterways on the two uplands are working with little if any more gradient than they had before uplift when a marked lowering of base level allowed the Gasconade to carve its almost canyonlike valley alongside. There has been no "equilibrium" in erosional attack on the two strongly contrasted east and west slopes of these uplands for a long, long time.

An extraordinary feature of the Owensville flat is the abundance of stream gravel on this fragment of the Ozark peneplain. The district has many pits for refractory Pennsylvanian clay in filled sinks (Bretz, 1950), and half a dozen or so expose stratified,

well worn chert gravel up to 12 feet thick above the clay. These exposures are scattered over about eight square miles north and east of Owensville at altitudes of 900 to 940 feet A.T. In the egg- and nut-sized gravel (Fig. 13) are a few sandstone boulders (Fig. 14), as clearly local as the chert is clearly imported. Varying thicknesses of the deposits in different places suggest a central main course with marginal thinning on a gravel fan but only one valleyway is suggested under the gravels.

Thicknesses and areal spread do not seem to fit a logical picture of a peneplain stream. Fenneman once said (long after his 1909 St. Louis report) that nothing is less expectable on a peneplain than stream gravel. The erosional origin of the flat and its identification as an Ozark peneplain remnant seem well supported. What, then, explains this quantity of river gravel on an interfluve remnant of that peneplain?

The question is especially pertinent if we are to continue to accept the ideas that entrenched meanders of Ozark rivers mark the courses of those streams at an earlier base level, and that the divides of today have descended from the divides of the peneplain. Thus, if the Bourbeuse River's intricate, entrenched meanders upstream as far as the latitude of Owensville are a record of the Ozark cycle's Bourbeuse, the gravel on the peneplain's interfluve would seem to indicate: 1) that the shallow valley of Ozark time became completely filled and that its waste actually overflowed its divide locally, 2) that post-Ozark rejuvenation allowed the river to clear the valley, and 3) that the pattern now possessed by the entrenched meanders was initiated on the gentle gradient of that fill during the removal. Influx of the gravel would be imputed to initial uplift farther upstream and would be of short duration before the spreading effect of domal uplift started re-excavation by the Bourbeuse. Because much of the Bourbeuse drainage is from Pennsylvanian rocks which contain little chert, theory seems to require that the contemporary Meramec and Gasconade valleys farther south on the peneplain were also completely alluviated and that chert gravel from them crossed their divides as it did the Bourbeuse-Gasconade interfluve.

An objection to this theory is the apparent lack of high gravel terrace remnants lingering along the Bourbeuse. Indeed, all Ozark rivers should have experienced this brief episode of filling and should have traces of high gravel terraces.

The Ozark peneplain trace continues eastward from Owensville at 900 to 920 feet A.T. across the Gerald Quadrangle (Franklin County) beyond which, between Bourbeuse and Missouri Rivers, this divide gradually lowers and becomes so segmented by ravine heads that flat summits disappear. About 40 miles from Owensville, the Bourbeuse enters the Meramec. At Gray Summit, a few miles northeast of the junction, altitude of the divide is about 650 feet A. T., less that 200 feet higher than the Missouri floodplain six miles to the north and Meramec bottom land two miles to the south. Here the Missouri-Meramec divide, traced eastward, climbs

Fig. 13. Gravel on Ozark peneplain remnant near Owensville. Gerald Quadrangle. Gravel exposed in Peizuch pit, Sec. 11, R. 5 W., T. 42 N. Contact of gravel and clay is about in midsection. R. Zangerl, photo.

Fig. 14. Sandstone boulder with stream worn surface; Peizuch pit, Sec. 11, R. 5 W., T. 42 N. R. Zangerl, photo.

abruptly to 850 feet A. T. in ascending the escarpment which Marbut christened the Crystal (Fig. 18). Some interesting questions raised by the topography about Gray Summit are dealt with later.

Northward from Owensville, the Ozark peneplain trace is preserved at intervals on a north-south divide for 25 miles, to Hermann and Gasconade, its altitude (900 to 965) actually greatest within sight of the Missouri River trench. Some of the abrupt slopes of both sides of the trench are nearly vertical cliffs more than 300 feet high. Nine hundred to 941-foot summits on the north side (Washington Quadrangle, Warren County) carry the peneplain trace out of the province to disappear under a cover of glacial drift. Although the Missouri Valley floor is not constricted here, this crowding in of high bluffs on the valley cross profile constitutes a narrows, the cause of which is a gentle post-Ozark upwarping.

Again, the noncyclic limitation implicit in the "dynamic equilibrium" concept cannot be accepted. Two cycles are at once obvious, and as shown on later pages, there have been four lowerings of base level here, each consequent on an uplift after a diastrophic pause. Yet the earliest of these records of past base levelings is still intact in the higher part of Lanes Prairie, and that of the second or Ozark cycle still dominates the skyline and still affords almost as much in slopes favorable for agriculture as the valley bottoms.

Meramec-Bourbeuse divide.—The argument for two erosional surfaces in the profile of the Gasconade-Meramec divide is strengthened by study of radial profiles on divides within each of these two drainages. In the Meramec system, the rather broad summit with monadnocks at Rolla (Phelps County), has a northeastward extension as the interfluve separating Little Dry Fork on the southeast from headwater creeks of Bourbeuse River on the northwest. Its summit flat continues interruptedly for at least 50 miles, lowering in the downstream direction from 1,100 to 800 feet A. T., or six feet per mile. On it stand three prominent monadnocks near Rosati (Redbird Quadrangle) 80 to 150 feet above the general upland. U.S. Highway 66 follows the interfluve summit or is close to it for the indicated distance and crosses a flank of one of these monadnocks. The Leasburg fault crosses this divide, bringing Roubidoux against Jefferson City and its overlying Pennsylvanian rock, but the fault trace is undetectable in the summit flat carrying the town from which it is named (Leasburg Quadrangle, Crawford County).

The conviction that this summit flat, averaging less than 975 feet A.T. about the city of Sullivan (Sullivan Quadrangle, Franklin and Crawford Counties), was once an erosional lowland is testified to by its drainage features. The city, built on the rolling flat of wide shallow drainage lines, overlooks Meramec River, three miles distant, whose valley bottom is 300 feet lower here, 580 feet A.T. Drainage of the flat, however, does not enter the Meramec.

The creek (Winsel) flows subparallel to the brink of the Meramec's steep slopes for more than four miles and in one stretch is only a quarter of a mile from the brink. Thence the creek, entering Union Quadrangle, (Franklin County) turns from its northeastward course subparallel to the Meramec to follow a winding but prevailingly northward course for 12 miles (as Spring Creek) to join Bourbeuse River at 580 feet A.T. Thus the creek's drainage flows four times as many miles to reach 580 (and on one-fourth as high a gradient) as would have been possible had it crossed the Meramec Valley brink at its quarter mile close approach.

The Meramec-Bourbeuse divide in the vicinity of Sullivan is the very brink of Meramec Valley's steep dropoff, and the Sullivan part of the upland is all in Bourbeuse drainage area. Obviously the creek valley and river valley, despite the disparity in erosional attack, are not the same age, did not develop under the same regional conditions, and are not products of noncyclic erosion. The Sullivan upland is largely surviving Ozark peneplain topography, the course of the creek and the proportions of its valley on the Sullivan Quadrangle have been inherited from that peneplain, and the Meramec-Bourbeuse divide is not the "blunted" crest of an interfluve made by "dynamic equilibrium" of erosion on the two strongly contrasted slopes.

Big Piney-Roubidoux divide.—In the Gasconade drainage system, an elongated dividing upland extends northward from the Ozark province's major divide for about 50 miles, the Big Piney River on the east and Roubidoux Creek on the west (Cabool NW, Bado, Big Piney, and Waynesville Quadrangles, Texas and Pulaski Counties).

Because the two streams are subparallel and not more than 10 miles apart, this divide has suffered greatly from encroaching ravine heads on both flanks. But it still has undisputable summit flats, and on some of them stand monadnock elevations. The northward longitudinal slope of the crest descends from Dunn at 1,500 feet A.T. on the main divide to 1,000 in the Gasconade River bluff summits, or 10 feet per mile. Monadnocks at Dunn are 1,600 and 1,620 feet A.T. Three and a half miles to the north, one reaches 1,660 feet. Roby Lookout monadnock, about midway of the divide's length, is 1,481 feet A.T. with the adjoining summit flat a little below 1,300 feet A.T. The broadening of the flat at Fort Leonard Wood near the north end of the divide (Waynesville Quadrangle, Pulaski County) has several 1,100- to 1,129-foot summits, and Gospel Ridge, which is crossed by U. S. Highway 66, is 1,140 feet A.T. Minor water partings that radiate from Gospel Ridge are between 1,000 and 1,050 feet A. T. The dropoff in the Gasconade River valley at the terminus of this divide is 250 feet in less than 1,000 feet horizontal.

Gasconade-Osage divide.—One of the several infacing cuestas or asymmetrical divides that make imperfect and only partial encirclements of the structural dome constitutes the Gasconade-

Osage divide which closely parallels (or is paralleled by) the Gasconade River for more than 50 miles across portions of Laclede, Camden, Pulaski, Miller, Maries, and Osage Counties. It is held up by the edge of the Jefferson City dolomite. The river is quite asymmetrically placed in this part of its drainage area for all tributaries of consequence come from the southward. The north or dip slope of the cuestalike divide is Osage River territory, and the same asymmetrical drainage pattern appears there also; Osage's long tributaries flowing northward and only short ones coming in from that side of the river. The summit of this cuesta (Linn, Vienna, Tavern, Richland, and Stoutland Quadrangles) is truly a divide but does not separate parallel streams as in the case of Big Piney-Roubidoux divide. It has a line of interrupted summits, extending from Lebanon to Linn (88 miles), that descend northeastward along the cuesta crest from 1,300 feet A.T. near Lebanon to 950 feet A.T. at Linn, or four feet per mile. Orientation of this profile is about midway between radial and tangential to the main dome structure, but it marks the course of one of its major rivers for that distance. The greatly convoluted entrenched meanders of the Gasconade (Fig. 33) seem to argue that the river had this diagonal course on the Ozark peneplain. The asymmetry of its drainage system, the confining cuesta closely parallel on the northwest, and the high altitudes of the cuesta summit are difficult to explain unless the Ozark peneplain itself had a cuestalike divide adequate to keep the river in this diagonal course. The Ozark was not the perfect peneplain that Fenneman had earlier envisaged.

In these separated summit altitudes along the cuesta, there is one tract about Helm and Dixon (north part of Waynesville Quadrangle and of Pulaski County) where a group of monadnocks stands 100 feet and more above the prevailing altitude of the truncated crest. A flattish summit about Helm seems best considered as a slightly modified remnant of the older, upper erosion surface.

Helm is directly north of Gospel Ridge and, although nearly 12 miles farther downdip, is 75 feet higher. Its hill trails out northward as a subordinate divide between Maries and Little Maries Rivers, tributaries of the Osage. The dividing ridge carries 1,100- to 1,200-foot altitudes for eight more miles and, 14 miles north of Helm, is as high as the Big Piney-Roubidoux divide at its terminus (1,000 feet) and higher than any surface east or west in either Gasconade or Osage drainages. Lanes Prairie's higher part, however, stands above the eastern skyline, although 15 miles distant. The Maries-Little Maries divide is the trace of the Ozark peneplain as is the cuestalike divide from Lebanon to Linn. Above their level rise the Dixon and Helm monadnocks.

The asymmetrical, cuestalike, Gasconade-Osage divide gradually loses character southwestward, diagonally up the slope of the topographic dome. It is marked enough between Richland and Stoutland to have been used as part of the sinuous boundary separating the southeastern projection of Camden County (about 45 sq.

mi.) from adjacent Laclede County. From Stoutland southwest, the divide's asymmetry gradually changes to symmetrical proportions as the summit of the topographic dome is approached. At Lebanon Airport, 15 miles from Stoutland, its altitude is 1,300 feet A.T., an undulatory rise of 150 feet. Thence to Marshfield, nearly 30 miles farther, it rises to 1,494 feet A.T., a gradient of nearly seven feet per mile. Enroute, it has at Phillipsburg, a group of hill summits up to 80 feet or so above its surrounding broad top. A better term for them than "monadnock" would probably be "late mature Ozark".

Marshfield four-way divide.—Marshfield (Niangua Quadrangle, Webster County) is as critically situated for geomorphic interpretations as any place in the entire Ozark province. Headwater members of four river systems radiate from its site. The Niangua flows northward to the Osage. The Pomme de Terre flows westward, although it eventually joins the same main stream. The Gasconade flows northeastward directly to the Missouri. The James flows southwestward to White River.

Thus, four important divides also radiate from Marshfield, the southern one traceable into the major divide of the province near Mansfield (Wright County). From Marshfield to Mansfield, this divide is the Eureka Springs escarpment. The Gasconade and Niangua courses are entirely in the Salem (or Ozark) subprovince, Pomme de Terre River and Turnbo Creek, a tributary of the James, flow *across* the trace of the Eureka Springs scarp (here much dissected into spurs and outliers) and thus enter the Springfield subprovince.

A mile downstream from the junction of Turnbo Creek with the James is a bench of streamworn chert gravel nearly 200 feet lower than Marshfield. It is located on the crossing by the creek of the trace of the scarp. This gravel, derived in part from the Ozark surface, was being carried across that trace into Springfield peneplain territory.

Similarly, stream gravel lies above the floodplain of the Pomme de Terre at its crossing of the Eureka Springs scarp trace and is equally lower than Marshfield. Both Turnbo and Pomme de Terre are genetically in watergaps at these crossings, and at the latter there is a scarp summit a mile distant (Northview Hill) that is nearly 200 feet higher than the floor of the "gap". In addition, there is a stream-cut notch or windgap about 15 miles southeast of Marshfield (shown on Mansfield NW Quadrangle map, Fig. 15) where a high gradient Gasconade tributary immediately east of the scarp apparently has pirated a former James headwaters stream and by vigorous later erosion has so remade the topography that only the notch, 80 feet deep, records the occurrence.

Without question, the Gasconade-Osage divide southwest from the latitude of Linn up to Marshfield is the trace of the Ozark peneplain on the Salem subprovince. Without question, the Gasconade and Niangua Rivers are lineal descendants of that peneplain's

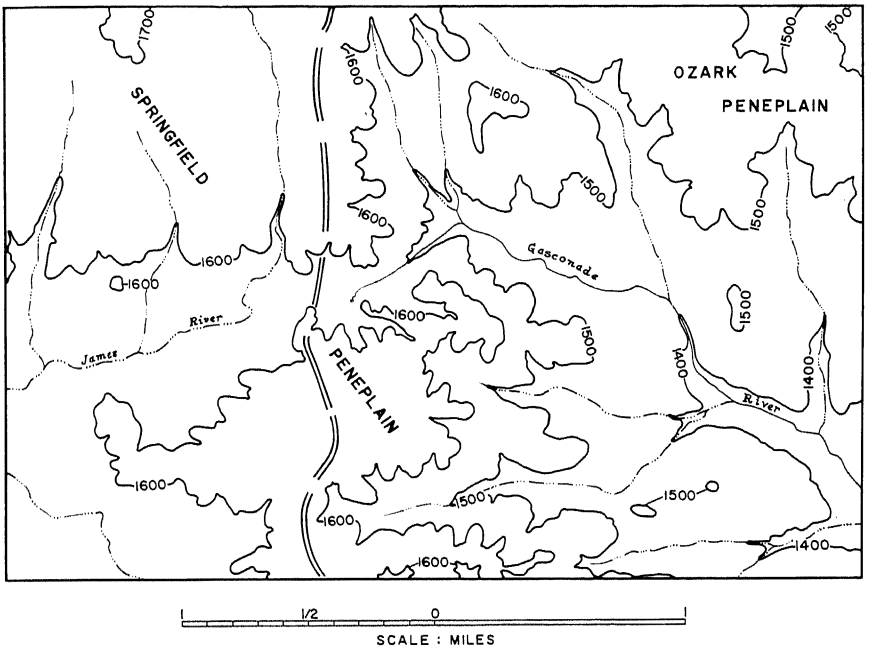

Fig. 15. Map of windgap in Eureka Springs escarpment at head of James River; Mansfield NW Quadrangle. Parallel lines indicate position of divide.

drainage. Without much question, the creeks that flow to the Pomme de Terre and James Rivers possessed essentially present courses before the escarpment had become cut up so badly here. There is only a very remote alternative possibility that they, flowing on the gradients provided by the back slope of the Eureka Springs cuesta, could have cut through by headward erosion and taken possession of a few square miles of the lower Salem plain.

Another significant item in the Marshfield drainage problem is that both Pomme de Terre and James Rivers *return* to the Ozark peneplain of the Salem province. The Pomme de Terre weaves in and out across almost any boundary one might wish to draw between the two geomorphic units all the way to its junction with the Osage. The James does not return until it reaches the Eureka Springs escarpment in Stone County.

Yet the profiles of both these stream courses are adjusted to the Ozark peneplain.

Numerous important questions are raised by the geomorphic features and relations at and about Marshfield. One is the relative ages of the two summit plains, Salem and Springfield. Are they parts of the same peneplain, separated during the Ozark cycle as now by a cuesta, and is the greater height of the Springfield because of greater distance its streams had to travel to reach the sea? If the Ozark peneplain is younger than the Springfield's sum-

mit plane, how much retreat of the separating scarp has occurred since the Ozark's rejuvenation, i.e. how close to the foot of today's escarpment can Ozark remnants be identified? Has considerable piracy of Springfield's early drainage occurred because of scarp retreat during the Ozark peneplain's development? Is there an adequate record of the Ozark cycle in the westward drainage off the Springfield Plateau? Was development and enlargement of numerous windows down through the cherty Mississippian that once covered the dome an important factor in making the Ozark peneplain and in leaving the isolated Mississippian hills and monadnocks? How could the Ozark cycle, which left only scattered monadnocks along most of its divides, have left an almost uninterrupted wall miles in length along one margin? Is there any evidence that pedimentation pushed a scarp back to present position from a central initiation on the dome?

These questions will be considered and answers attempted when the Springfield Platform is treated in more detail.

Osage-Missouri divide.—The Ozark peneplain is traceable westward up the Osage, South Grand, Blackwater, Lamine, and other drainage lines on what Fenneman described as the Osage section of the Central Lowlands province. Half a dozen Missouri counties are involved, lying north of Fenneman's Springfield section of the Ozark province, south of Missouri River and northwest of his Salem subprovince. The region clearly records the same geomorphic history as the Ozark province, adds several items regarding stratigraphic and valley histories, and lacks any physiographic break between it and the Ozark province to the southeast. Fenneman's boundary, therefore, is ignored, and this portion of the Osage section is considered as an extension of the Salem.

The Osage River downstream from Warsaw (Benton County) bisects a large area in Camden, Miller, and Morgan Counties that has Ordovician Gasconade in its valleys, Roubidoux in its interfluves, and is completely ringed by Jefferson City. A continuous belt of the Jefferson City formation, extending northeast from Lebanon to the mouth of the Osage, separates this area, which is in effect a low, subordinate, structural dome, from the northwest flank of the larger feature. The Lake of the Ozarks lies entirely within this minor dome whose northern structural and topographic slope is held up by Jefferson City dolomites as far north as the Mississippian overlap in southern Cooper and northern Moniteau Counties. The head of this slope is the east-west divide between south-flowing Osage tributaries and various north- and northeast-flowing smaller streams that follow the slope more or less directly to Missouri River. This divide is asymmetrical like that of the Gasconade-Osage, and the Osage River, like Gasconade River, is offcenter in its drainage area. The divide summit carries remnants of the Ozark peneplain that are only slightly altered by the ravine heads of younger streams.

The eastern end of this divide with surviving summit flats is between South Moreau Creek and Osage River (northeast Eugene Quadrangle, Cole County) at 800 feet A.T. Traced upstream (southwesterly), it rises to 900 feet in eight miles, where just north of Eugene it carries a broad hill of Mississippian rock up to 1,000 feet A. T. West from this town, the altitude drops back to 900± feet as the crest undulates over smaller and lower hills separated by broad northward draining erosional sags much older than the present ravine heads encroaching from the south.

From Eldon (Miller County) westward to the west edge of the Gravois Mills 15-minute Quadrangle, the undulating upland flat rises from 943 to about 1,045 feet in 30 miles, or four feet per mile. The southern margin of the upland describes a series of broad reversing curves along the brink of the abrupt southern dropoff into the intensely dissected Osage valley slopes. The northern margin is a series of long, northward-pointing, gently sloping, flat-topped fingers between north-draining creeks, all being Ozark cycle topography though not as thoroughly reduced to planeness as the province's major divide summit between Licking and Raymondville or about Mountain Grove.

On the western margin of the Gravois Mills 15-minute Quadrangle is a long, nearly north-south ridge of late mature Ozark character that stands transverse to the length of the divide and reaches 1,165 feet A.T., nearly 100 feet higher than the divide's summit flat itself. This ridge has a surprisingly long southeast projection for 13 miles out into the dissected Osage slope while holding 1,000-foot altitudes and carrying half a dozen 1,100-foot elongated elevations along its axial line (Fig. 16). The hill nearest the distal end of the ridge, reaching 1,142 feet A.T. at Proctor Lookout Tower, is almost as high as is the ridge at its intersection with the Osage-Missouri divide but projects fully nine miles out into the Osage valley south of the intersection.

This is a very unusual trace of a valley slope dating back to the Ozark cycle (well shown on Gravois Mills 15-minute and Proctor Creek 7½-minute quadrangle maps). It approximates 10 feet per mile from the late mature summit topography at the north end to, or close to, the bottom of the Osage Valley of the Ozark cycle (900 A.T.) at the south. It means that the Ozark peneplain had river valleys at least 60 feet deep, perhaps more. The gradient of this ancient valley's side slope lies within the range of longitudinal gradients on divide tops already considered. If a "plane" surface must contain all straight lines drawn between any two points on it, the Ozark erosional surface should never be spelled "peneplane". In round numbers, the different surfaces recorded in this ridge are 1,100± for the monadnock elevations, 1,000+ for the peneplain trace, 900+ for the valley bottom of peneplain time and 800+ for a later, narrow old valley bottom (the Osage strath, described in the following section).

There are notable changes in the divide westward beyond Cole Camp (Cole Camp Quadrangle, Benton County). The Osage River

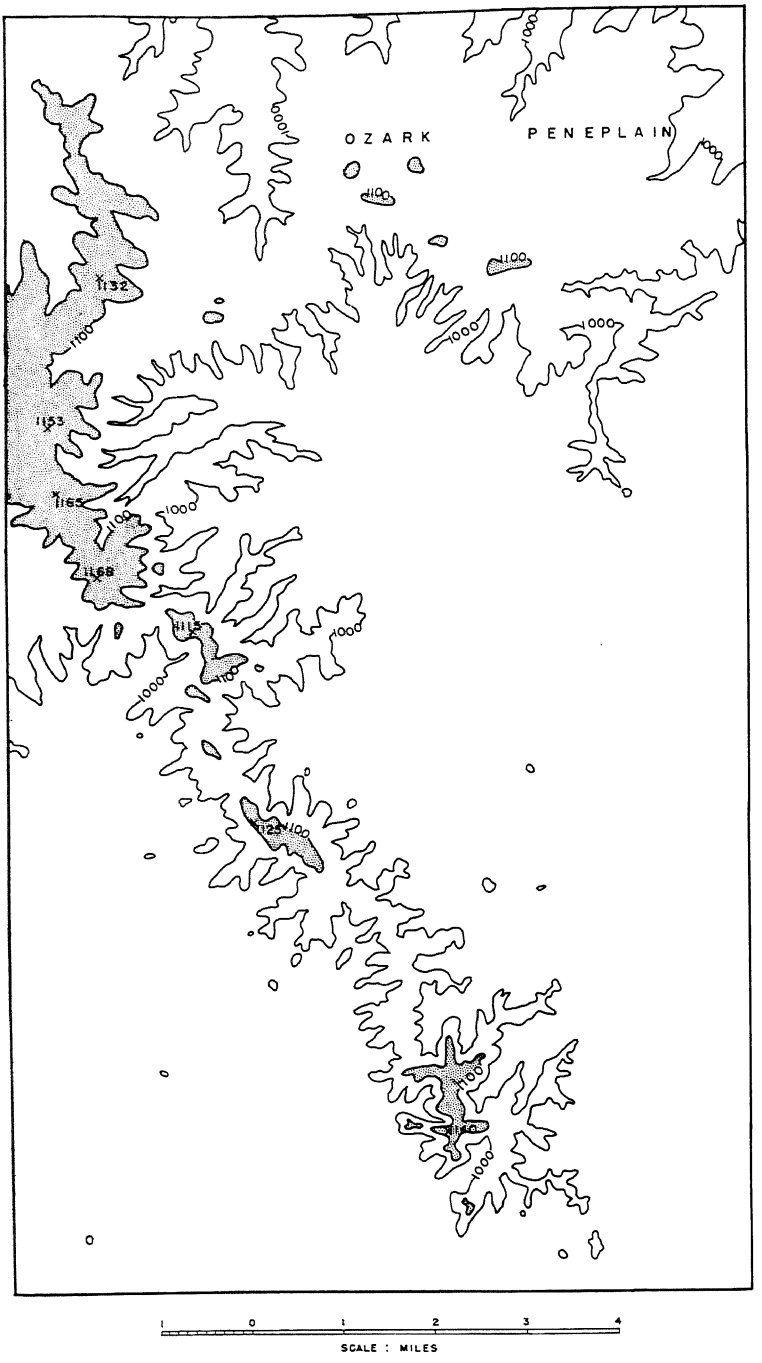

Fig. 16. Map of ridge on slope of Osage River valley; Gravois Mills Quadrangle. Shaded area is late mature Ozark cycle topography, low monadnocks in origin. Blank areas bordering the ridge and below 1,000 feet A.T. are occupied by a wilderness of ravines and ridges younger than the topography shown.

and the summit of the divide no longer run closely parallel because the Osage approaches from the southwest, and the divide runs west and northwest. Also, it here leaves Ordovician rocks and, thence, to the state line lies on Pennsylvanian. Lacking a deep major river valley close to it, the asymmetrical character of the divide disappears. It is readily followed across parts of 13 7½-minute quadrangle maps* with 10-foot contours, separating headwaters of the South Grand, an Osage tributary, from those of Lamine and Blackwater Rivers and a number of creeks flowing northward to the Missouri.

A critical area of the divide is depicted on the Green Ridge 15-minute Quadrangle (Pettis County), the Lincoln and Lincoln NW 7½-minute Quadrangles (Benton County) the Cole Camp 7½-minute Quadrangle immediately to the east, and the Bahner 7½-minute Quadrangle on the east of Green Ridge.

The environs of the city of Cole Camp have broad, erosionally made flat uplands at 1,000 feet to 1,100 feet A.T. which are developed on the Ordovician Jefferson City formation. Bahner's broad, centrally located peneplain remnant on its radially drained divide reaches 1,000 feet in a few places, but its southern margin (1,050 feet) is continuous with a rise southward on Cole Camp Quadrangle to the limited 1,100-foot summit flats above noted. West from Cole Camp, upland altitudes decrease in five miles to 930 feet at Cole Camp Junction on Lincoln Quadrangle. Green Ridge's extreme southeastern corner shares with Lincoln and Bahner in a limited 1,050-foot flat upland, 1,040-1,050 feet A. T.

Thus at this cornering there are two upland flats with a vertical separation of approximately 150 feet, although Ozark late mature gradational slopes lie between. Here are lingering remnants of the Springfield peneplain surrounded by much less dissected Ozark peneplain surfaces.

The State Geological Map shows that, on the Lincoln Quadrangle, the lower plain about and south from Cole Camp Junction passes from Ordovician formations to Mississippian and Pennsylvanian rock without any evidence for this in the topography; i.e., that the surface is a peneplain whose relative altitudes and degree of dissection indicate it as Ozark in age.

In the total distance of 50 miles across 13 7½-minute quadrangles, the Ozark divide is successively on Cherokee, Marmaton, and Pleasanton formations, all of Pennsylvanian age, yet it shows no topographic breaks across boundaries. The average altitude of the summit tracts along this divide across the nine eastern-most of the quadrangles named in the accompanying footnote decreases westward fairly uniformly from about 960 to about 910 feet A.T. although the direction followed is *upstream* for the drainage ways (Big Creek and South Grand River) that approximate parallelism with it. Significance of this curious and apparently anomalous

*Crockerville, Cole Camp, Lincoln, Lincoln NW, Windsor, Leeton, Chilhowee, Holden, Kingsville, Elm, Strasburg, Tarsney and Chapel Hill.

relationship is discussed under post-Ozark geomorphic records (p. 106).

The Kansas City group overlying the Pleasanton contains the Bethany limestone described by Marbut as an escarpment maker. North from Kingsville Quadrangle, there is an abrupt rise in altitude of about 100 feet along the long, fairly direct, north-south divide which crosses the Elm Quadrangle (Johnson County) and which separates Osage drainage from Blackwater drainage. Its summit rises northward from 950 to 1,000 feet A.T. in the southern part of the quadrangle to 1,050 feet at the north edge. A mile and a half farther north on Chapel Hill Quadrangle (Johnson and Lafayette Counties), the altitude is 1,080 feet plus and is a smoothly contoured, flattish summit whose runoff goes to three drainage areas as depicted on the State Drainage Map; Blackwater River, South Grand River and an area containing a number of streams, including Blue River, Little Blue River and Sniabar Creek, that flow north directly to Missouri River. Although the Bethany escarpment is not a divide maker, it figures largely on this change in altitudes. The divide we have been tracing westward from Ordovician onto Pennsylvanian rocks carries Ozark peneplain altitudes as far as Kingsville Quadrangle and thence on Elm and Chapel Hill Quadrangles, climbs the Bethany scarp whose hills and ridges fall into a fair accordance for an interpretation as Springfield peneplain records.

The west-running interfluve from the Chapel Hill three-way summit retains 1,030- to 1,050-foot altitudes across Lake Jacomo Quadrangle. Thence across the extreme southeastern corner of Lees Summit Quadrangle, it reaches 1,065 feet A.T. It there swings westward onto Raymore Quadrangle (Cass County) to rise from 1,060 to 1,110 feet and to cross Belton Quadrangle to the Kansas-Missouri state line with altitudes of 1,110 feet A.T.

If one should suspect that the upland on the Bethany scarp crossing (Elm and Chapel Hill Quadrangles) is structurally determined, this westward and southward tracing for 35 miles after leaving the Bethany scarp (as Marbut defined it) with such uniformity of increase in altitude across diverse members of the Kansas City group of formations, should lay such suspicions at rest. The summit altitudes of this gently sloped, broad-topped divide record the Springfield peneplain. Indeed, there is no part of the eight quadrangles west of Elm and Chapel Hill that was ever reduced to the Ozark peneplain.

This Bethany escarpment (Fig. 17) is only a greatly attenuated relic of what presumably was a fairly continuous scarp earlier in the Ozark cycle. It is now the shredded margin of a much dissected upland of hill units, separated by valleys leading to both South Grand and Missouri drainages. The alignment of its marginal groups of hills is at a high angle to the orientation of the divide, the two lines crossing approximately in northeastern Strasburg Quadrangle. The hills run from southwest Cass County to north-central Lafayette County where the Missouri trench

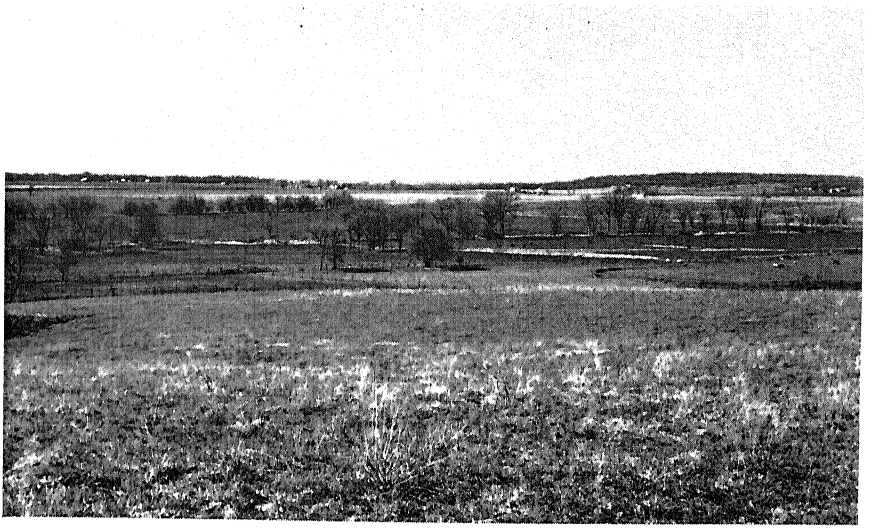

Fig. 17. Bethany escarpment overlooking Ozark peneplain. R. Zangerl, photo.

intersects the trace of the scarp. Numerous monadnocks scattered for miles out on the Ozark peneplain to the east (Knobnoster, Cornelia, Odessa North, East Lynne, Harrisonville, Mayview, and Austin Quadrangles) are records of the retreat and fragmentation of an originally continuous escarpment.

The Bethany scarp offers a suggestive near parallel to the Eureka Springs escarpment. Its broad summits back from the frayed eastern margin carry an erosional surface that cannot be argued as possibly of the same age as the lower Ozark plain in front. Some of these summit flats, safe thus far from the aggressive ravine heads, carry broad, gently graded drainage grooves which seem to be largely unmodified relics of their runoff before ever a scarp was initiated farther east. The present divide, departing so markedly from the rude alignment of the 1,050- to 1,120-foot flat-topped hills, is the product of streams whose heads have eaten back into the once continuous upland. Several such headwater valleys have suffered no rejuvenation since the Ozark peneplain was uplifted. Their gradients are adjusted to the erosional plane that is traceable in interfluve summits westward from Eugene in Cole County to the Kingsville Quadrangle in Johnson County.

This dissected and higher summit plane held up in part by the Bethany limestone is the fragmentary relic of a pre-Ozark peneplain. Hershey, who argued on other grounds for the existence of two peneplains in western Missouri, was right. There is a Springfield peneplain, distinct from the Ozark surface, in this part of Missouri which Hershey did not traverse.

In homogenous rocks, contiguous peneplain surfaces that lie at two different levels and, therefore, are of different ages should have transitional separating tracts in which the topography would

be late mature of the second cycle. Steep slopes, however, like those between well-marked Ozark and Springfield flattish tracts in this region, are consequences of harder rocks under the upper surface and weaker rock in the basal part of the slope. The steep slope of the Eureka Springs scarp and its monadnocks farther east, separating Ozark and Springfield surfaces there, is similarly conditioned.

Near the cornering of Cass, Jackson, Johnson, and Lafayette Counties where the divide descends southeastward from the Bethany upland, altitudes are less than 1,050 feet, lower than anywhere else westward along the Bethany outcrop belt. Were the divide an original feature of the upper peneplain, those summits should logically be as high as anywhere else.

What relation does the Missouri River trench bear to these upland remnants of the Springfield peneplain? Seven 7½-minute quadrangles west of the Bethany escarpment trace bear witness that this peneplain extends to Kansas City and Independence with altitudes of 1,000 feet on the very brink of the 250-foot cliffs of the river valley (North Terrace Park, Kansas City Quadrangle, and River Boulevard, Liberty Quadrangle). On the north side of the river, three more such quadrangle maps show cliffs 150 feet high with altitudes of 1,000+ feet only three miles farther north. On the Parkville and Wolcott Quadrangles west and upriver from Kansas City, cliff summits are 950 to 1,010 feet A.T., and the land rises to altitudes of 1,000 to 1,050 feet within a mile of the floodplain. These uplands record the Springfield peneplain.

Upland altitudes north of the river are adequate to carry conviction that a dissected Springfield peneplain lies under the glacial drift in portions of Platte, Clay, Ray, and Clinton Counties. According to Marbut, they must lie above and back of the east-facing Bethany escarpment north of the river.

If a Missouri River entered the state here during the Springfield cycle, all subsequent erosion has made a valley bottom of today less than two miles in minimum width, an absurdly small figure to harmonize with such an age. Most of this narrowness is upstream from the junction of Kansas (Kaw) River. Here is a complicated problem which involves Pleistocene events and will be treated later (see p. 124).

If it be accepted that headwaters of the drainageways off the Springfield remnants of this district are: 1) graded to the Ozark peneplain beyond the Bethany scarp, and 2) have not yet been reached by the post-Ozark rejuvenated streams, then it follows that the Ozark peneplain is the product of stream degradation, of downwearing according to the Davis geomorphic scheme and is not the result of scarp retreat by the back-wearing procedures involved in pedimentation.

Eastern Divides and Escarpments

The belted appearance on the State Geologic Map of the eastern part of the Salem section of the province results from

erosional truncation of the most steeply dipping and most extensively faulted Paleozoic formations of the Ozark country. The northwest strike of formations and of major faults is rudely parallel to the Mississippi Valley almost as far north as Kimmswick where the dips decrease and the outcrops widen thence to the junction of the Missouri Valley with the Mississippi. Upstream along the Missouri as far as and a little beyond Jefferson City, the river flows along the generalized strike. Except for St. Louis County and the northern part of Jefferson County, these two master valleys have dominantly Ordovician rocks to the west and south and Mississippian and Pennsylvanian rocks to the east and north. A prominent exception is the Lincoln Hills along the west side of the Mississippi north of the junction of the Missouri (Lincoln and Pike Counties). Also the Missouri leaves this generalized course near Gray Summit, Franklin County, to flow northeast past St. Charles, and after joining the Mississippi beyond their junction returns to the strike course outlined. St. Louis County, almost wholly on Mississippian rocks, is not included by Fenneman in the

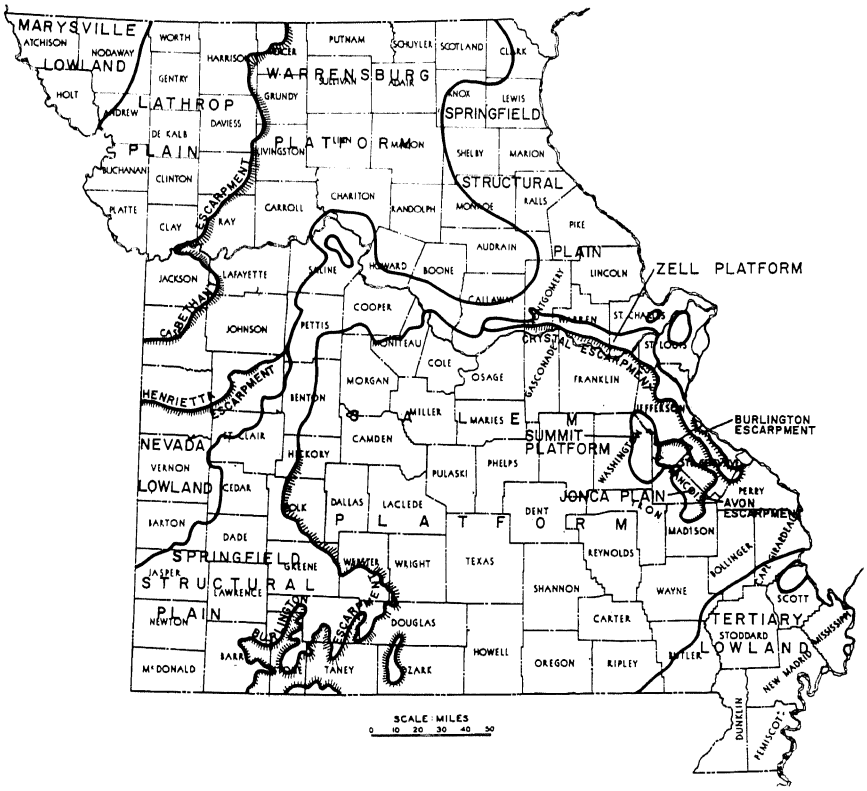

Fig. 18. Map of Missouri showing physiographic belts and escarpments, after C. F. Marbut, 1896, pl. 2.

Salem subprovince. In its geomorphic history, however, it is essentially a part of the Salem and will here be included.

Marbut named and outlined three escarpments northeast of St. Francois Mountains (Fig. 18). Structurally these are cuestas determined by outcropping edges of resistant formations in the easterly dipping Paleozoics. The most prominent of them, called the Burlington for the formation that holds it up, is also the most nearly continuous. Marbut considered it to enwrap the Ozark dome on the north, east and west and thus, with an interruption between Callaway and Hickory Counties, to be continuous with the Eureka Springs escarpment.

Because the drainage east of the St. Francis and Big Rivers is by a number of short, easterly flowing streams, crests of all the nearly north-south cuestas of this district are notched by cross valleys. Strike faulting has caused other interruptions in altitudes and in continuity. Very few and very limited summit flats beveling the structure can be found here from which to read the history of former base leveling.

Directly east of the St. Francois Mountains (Perry, Bollinger, Cape Girardeau Counties), however, the outcrop belts are much wider than in the area of the broken cuestas (chiefly in Ste. Genevieve County). The headwaters of south-flowing Castor River (northwestern Higdon 15-minute Quadrangle) present a very good record for both the Ozark and Springfield cycles.

About 20 square miles at the headwaters of south-flowing Castor River (Higdon 15- and 7½-minute Quadrangles, St. Francois, Ste. Genevieve, and Madison Counties) is an upland of moderate slopes compared with the St. Francis drainage on the west (see Fredericktown Quadrangle), Saline Creek on the north, and Whitewater River on the east. Around the three-quarter periphery (west, north, and east) of this limited upland (strikingly outlined on the Higdon 7½-minute Quadrangle by the contrast between the uncolored cleared areas of the flattish upland and the green colored forested steep slopes of its environs), slopes descend *steeply away* from the Castor headwater drainage but only *gently into* it. Ravine heads on these steep slopes are vigorously driving back into the Castor's area. Although not a flat interfluve, such as have been considered previously, the upland has an old topography which, significantly, is perched high above its indicated surroundings. Raggedly outlined and steeply sloped interfluves elongated north-south separate it from St. Francis River on the west and Whitewater River on the east and join at the northern dropoff into ravine heads of Saline Creek to make the broad, arcuate tract of gentle slopes centering about Womack and 1,050 to 1,100 feet A.T. (Fig. 19). The 1,000-foot contours run southward on the two interfluves bounding Castor drainage for six to 10 miles though only about four miles apart.

Saline Creek tributaries have made the most marked inroads on this highlying headwater drainage of Castor River. "Island" hills among them record the former northward extent of the high

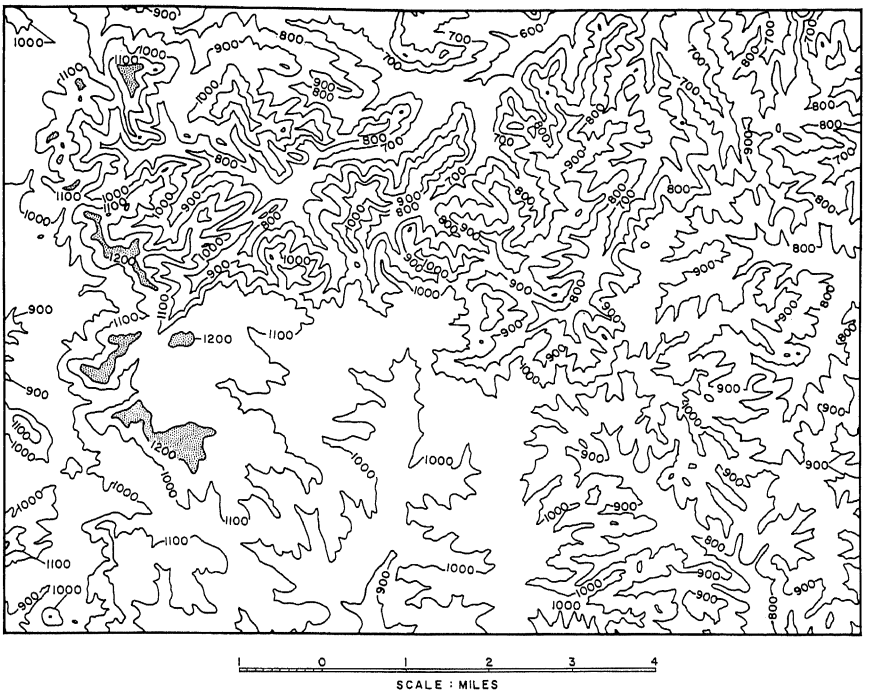

Fig. 19. Map of the Womack area in Castor River headwaters; Higdon and Fredericktown Quadrangles. Shaded area enclosed by 1,200-foot contour is a remnant of the Springfield peneplain. Remainder of upland is Ozark peneplain and late mature Ozark topography.

plain, and the face of Marbut's Avon escarpment constitutes the 200-foot (maximum) westward descent into the Little St. Francis drainage. The upland tract under examination is on the gentle back slope of the Avon cuesta.

Events that made this arc of flattish upland along the brink of the highly dissected country of Saline Creek drainage seem clear. The interfluve summits and this arc are all that remain of earlier erosion surfaces at the cornering of the three counties. The showing on a topographic map is almost dramatic. Fenneman (1938) used it to illustrate "the rolling Salem upland". Most of this high tract is modified Ozark.

But there remains consideration of the 1,200- to 1,240-foot flat summit at the north end of the western bounding interfluve, the St. Francis-Castor divide. On both Higdon and Fredericktown Quadrangles, it has 1,100-foot overlaps into each of the three counties. Although mostly in slopes, there is one flat area at 1,240 feet, nearly 100 feet above the interfluve summits diagnosed as Ozark peneplain remnants. With confidence, this area and adjacent gentle slopes are interpreted as Springfield peneplain remnants, essentially monadnocks on the Ozark surface.

The long, southward, longitudinal slope of the eastern interfluve bounding Castor River headwaters probably contains elements both of the original peneplain slope (for the southward drainage must be inherited) and of its subsequent warping. It continues across Marquand Quadrangle (Bollinger and Madison Counties) and ends on the eastern edge of Zalma Quadrangle in a salient of the Embayment bluffs near Greenbrier 160 feet above the alluvial plain of the Mississippi. Its average gradient is close to 10 feet per mile.

But the western bounding interfluve, which follows the crest of the Avon escarpment as far as that feature is identifiable has no consistent southward descending longitudinal gradient until well over on the Coldwater Quadrangle (Madison County). Instead, it is a row of knobs and irregularly elongated hills with separating streamless notches (three of them 100 feet deep) extending southward 12 miles to the north margin of the Coldwater Quadrangle (Madison County). Summits begin at 1,240 feet at the north, hold 1,100-foot altitudes for three miles, and nearly 1,100 feet for four more miles. A row of 1,000-foot isolated hilltops succeeds for five or six miles, beyond which the ridge passes into the Coldwater Quadrangle, promptly rises to 1,040 feet and expands into a broad upland of a few square miles about Miller Chapel, an arcuate area about the headwaters of Twelvemile Creek. Neglecting a few Precambrian knobs, the divide descends to 900 feet A.T. in four or five more miles, whence its summits hold a uniform gradient of about 10 feet per mile across the Greenville Quadrangle to terminate in headlands averaging about 600 feet A.T. which overlook the alluvial plain from the summit of the 250-foot Embayment bluffs on the Puxico Quadrangle.

The irregular summit north of Miller Chapel is largely late mature Ozark topography. The headwater upland at the Chapel is the largest residual Springfield fragment yet identified southeast of the St. Francois Mountains. The 1,240-foot summit near Womack is on Eminence (Cambrian) dolomite, the Miller Chapel flat on Gasconade (Ordovician) dolomite, and their correlation by altitudes and gradient (1,240 to 1,040 feet in 15 somewhat crooked miles) indicates an erosional, not a structural, origin.

Crooked Creek on the Marquand Quadrangle is named from an intestinelike, twisted valley unrelated to any encounter with Precambrian rock while cutting its 150-foot gorge near Glen Allen. From other entrenched meanders, now considerably modified, along St. Francis, Castor, and Whitewater Rivers, a lower original gradient of the Ozark peneplain than that read from the present divide summits is indicated.

Stream-rolled pebbles on the summits of two Ozark peneplain remnants occur along the present St. Francis River course in Wayne County south of the mountain group. One locality is the roadcut for the old U.S. Highway 67 route about two miles south of Coldwater (Coldwater Quadrangle), the other is about two miles south of Lodi (Greenville Quadrangle) at top of the cut made for

the new U.S. Highway 67 route. In both cases, there are vastly more angular than water-worn chert fragments in the residual clay. It seems proable that both hilltops have been lowered by weathering and solution, with such settling and reworking of an original residuum that the stream pebbles have become dispersed throughout the upper part of the mass. Neither occurrence can be called a gravel deposit, but both do record a south-flowing ancestral St. Francis River during the Ozark cycle.

A broad, flat, major interfluve between the Big and St. Francis drainages on the Farmington Quadrangle (Ste. Genevieve and St. Francois Counties)—the Jonca Plain of Marbut and now known as the Farmington Plain—is reminiscent of the Licking-Raymondville divide top but differs in having higher instead of lower country on two opposite sides. The Avon escarpment shares in the higher land on the east, standing 150 feet above the Farmington flat, and unnamed hills on the west rise 200 feet above. The water parting across the plain, sinuously trending northeast-southwest, climbs up the hills on both sides, a behavior comparable to that of divides in the nearby St. Francois Mountains. Width of the flat is approximately eight miles, and its altitude is mostly a little above 900 feet

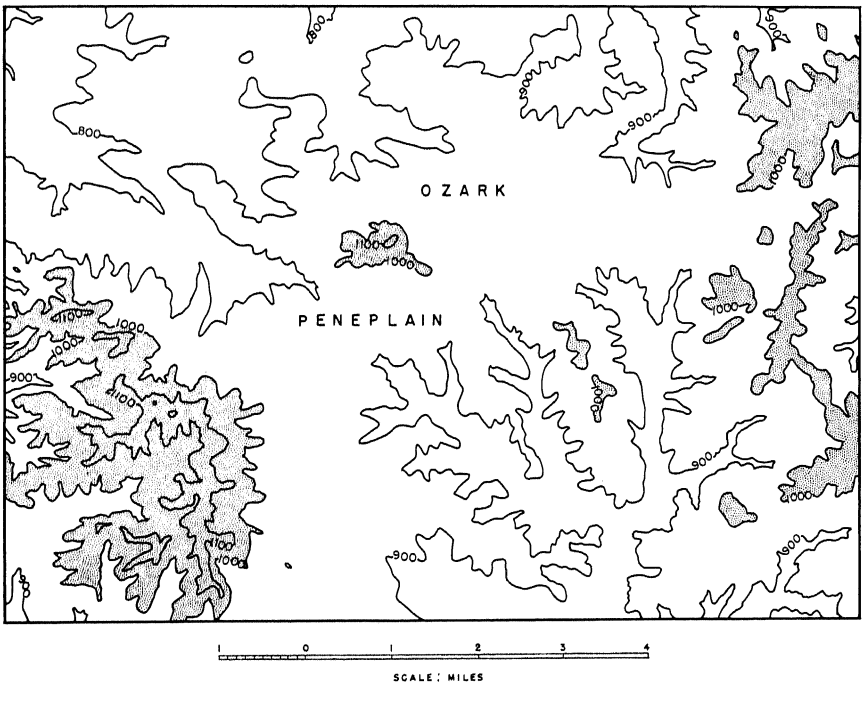

Fig. 20. Map of Farmington or Jonca plain; Farmington Quadrangle. The Farmington or Jonca peneplain is a baseleveled divide on the Ozark peneplain between north flowing Big River and south flowing St. Francis River drainages. Shaded areas are late mature Ozark topography.

A.T. In midwidth is a small hill as high as the bounding uplands. No Precambrian rocks are involved in any of the eminences (Fig. 20).

The minor valley heads on the north and south sides of this Farmington interfluve plain are broadly open. Farther downstream along them appear steep, high walls and a marked narrowing. Creeks on the northern slope, tributary to Big River, have about twice the gradient of the creeks flowing southward. The north-south distance across the smooth, unfurrowed divide itself is half a mile to a mile between map-shown creek heads. With a 100-foot, midlength hill, this interfluve flat is clearly established as a peneplain remnant. Its altitude and degree of development and preservation identify it as Ozark in age.

The summits of the escarpment to the east and the irregular hills to the west approximate the height of the midlength hill, and their altitude and character place them in the category of late mature Ozark topography. Some summits may be but slightly reduced residuals of the Springfield peneplain.

If the Farmington plain is genetically a part of the Ozark peneplain there should exist a complete gradation from its 900- to 1,000-foot surface down Big River drainage and out into the Salem plateau's flattish summits. A traverse along this route, across parts of the Farmington, Bonne Terre, Vineland, Tiff and Fletcher Quadrangles, reveals that interfluve altitudes of entering tributaries, taken fairly close to the tops of creek and river valley bluffs, do indeed fall into a not far from uniform descending profile. In 25 miles, altitudes drop from 900 feet on Farmington Quadrangle to about 750 feet on Fletcher Quadrangle, a gradient of 6 feet per mile.

Richwoods Quandrangle (Jefferson and Washington Counties) adjoining Fletcher on the west, has a conspicious, rudely equidimensional, flattish upland with only local and radially oriented drainage. The 800-foot contour makes a definite boundary between the upland's gentle slopes and the steep descents into ravines tributary to Big and Meramec Rivers, except for the south side where some residual hills rise to 900 feet plus. The central tract of this broad-topped part of the Big-Meramec interfluve is itself 900 feet plus and is only four or five miles west of Big River.

Ozark peneplain remnants about Sullivan (Sullivan Quadrangle, Franklin and Crawford Counties) west of Meramec Valley and tangentially located on the same northeastward regional slope of the dome, lie between 900 and 1,000 feet A.T. The Richwoods upland thus is another lingering remnant of the Ozark peneplain.

In contrast with the 6-foot per mile gradient obtained from interfluve summits along Big River drainage, that of the Big River-Terre Bleue Creek-Salem Creek valley bottom is nearly 15 feet to the mile. Again it becomes clear, as on the Gasconade-Meramec divide (see p. 37), that Hack's comment on significance of parallelism in interfluve and valley bottom gradients has no application in the Ozarks. That supposed parallelism does not exist in this entire

province, and the existing departure cannot be explained by erosion under conditions of dynamic equilibrium.

East of the Avon escarpment lies a rough region drained directly to the Mississippi. Identification of old erosion surfaces there is unsatisfactory. The strongly accented Burlington and the weaker Crystal escarpments, cut by water gaps, cross this dissected region at right angles to its Mississippiward slope.

Traced south from Farmington Quadrangle on to the Fredericktown Quadrangle, the Farmington Plain with its simple slope drainage pattern disappears among a flock of Precambrian hills. If the Ozark surface is to be found in northern Fredericktown Quadrangle, it is on the 900- to 950-foot flattish divide between north and northwest-flowing Back Creek and the headwaters of south-flowing Little St. Francis River. A profile projected southward thence to the St. Francis would be in harmony with the one reported earlier (see p. 27) along Stouts Creek above Lake Killarney shut-in.

Central Fredericktown Quadrangle has a striking upland flat of three to four square miles called The Flatwoods, with radial drainage to five named creeks. The 1,000-foot contour encloses it and, except for three small Precambrian knobs, it is nowhere higher than 1,060 feet A.T. Altitudes, topography, and drainage are best interpreted as recording a minor interfluve area on the Springfield peneplain, 100 to 150 feet higher than the projected plane of the Ozark surface in its latitude A smaller upland flat at comparable altitudes, the Wachita Mountains in part, three to four miles to the northwest, is separated from The Flatwoods by a narrows of St. Francis River, a gorge of post-Ozark age. The Missouri State Geological Map shows the tract as all Precambrian rock, apparently a baseleveled area. Most of the Precambrian hills of the region are still buried, however, and most of the existing narrows were yet to be cut when the Springfield peneplain was completed.

A sink-infested plain about Perryville, east of Farmington, lies too low to belong to the eastward descending slope of the Ozark peneplain and will be dealt with later (see p. 125). But the summits of the Mississippi River bluffs in Illinois do definitely belong. On Chester and Campbell Hill Quadrangles (Missouri and Illinois) are broad uplands surrounded by a labyrinthine complex of ravines. These uplands all stand above 600 and some above 700 feet A.T. Major creeks on them flow away from the Mississippi until gathered into Marys River.

Horberg (1950) mapped this tract as part of his Lancaster-Calhoun-Ozark peneplain which there slopes eastward toward his lower and younger central Illinois erosion surface. Flint (1941) argued that the course of the Mississippi from St. Louis to Cape Girardeau is antecedent to the uplift of the peneplaned eastern flank of the Ozark dome, but his theory involved only one peneplanation.

The peneplaned divide crossing the Farmington Plain is about 950 feet A.T. Both Big and St. Francis Rivers then, as now, swung far to the north and to the south and had very indirect courses to the Mississippi, while on the east side of the north-south divide bounding the plain on the east, today's streams reach the great river only 15 miles or so from this divide.

Thus, the Avon escarpment divide then, as now, was unsymmetrical, and any trace of the Ozark peneplain in this direct eastward drainage would be lower than the Farmington Plain at the same distance from the scarp summit. This argument is developed in order to justify the selection of the broadened tract about Weingarten and New Offenburg (Weingarten Quadrangle) as Ozark peneplain remnants not greatly reduced. Altitudes there range but little above and below 800. The airline distance thence to the 700-foot hilltops north of Chester, Illinois, is 18 miles and the slope of the restored surface thus is only about five feet per mile. But this airline is somewhat diagonal to a radius of the post-peneplain warping and, furthermore, it crosses what must have been a broad, shallow, Ozark cycle Mississippi Valley in this peneplain west of Chester. The peneplain slope, therefore, probably was greater than this figure.

If the summit flat at Sprott, on the north-south divide between the Farmington Plain and Weingarten, altitude 1,040 feet, were chosen as an Ozark remnant, the distance would be 25 miles and the eastward descent 260 feet, about twice the previous figure. But this Sprott summit is nearly 100 feet above the divide across the Farmington Plain, and if it is an erosional flat it is much better interpreted as a Springfield peneplain remnant.

Crystal escarpment.—For recognition and tracing of his escarpments, Marbut depended on cross country views aided by a few 50-foot contour maps and some railroad altitudes. In places, these escarpments are difficult to follow on the later topographic maps. Also Marbut noted that in places he did not have the opportunity to make continuous tracings. Weller, S. (1928) renamed the escarpments from the formations responsible and indicated tracts of discontinuity (in Ste. Genevieve County) because of faulted belts. The intermediate scarp of this county—Marbut's Crystal in part at least—was Weller's Joachim-St. Peter escarpment. Though broken into a series of separate hills and crossed by river valleys in some stretches, the Crystal can be readily traced from the Mississippi Valley slopes near Pevely and Herculaneum (Kimmswick Quadrangle, Jefferson County) northward to the Missouri River valley in southeastern Augusta Quadrangle (Franklin and Warren Counties).

On the Illinois side of the Mississippi Valley, across from Herculaneum, the bluff summits are highest close to the brinks, as on the Chester and Campbell Hill Quadrangles farther south, and the bedrock surface, sloping eastward under the glacial drift and loess, carries the trace of an erosional beveling made before

the warping of the Ozark peneplain and the beginning of the post-Ozark Mississippi Valley.

The northwestern diagonal course of the Crystal escarpment across the Kimmswick Quadrangle is determined by a fault whose northeastern downthrow side carries the upland, here 300 to 400 feet above Sandy Creek valley at the foot of the escarpment. Known here as Sand Ridge, the Crystal escarpment is even better shown on the Belew Creek Quadrangle (Jefferson County) as an asymmetrical divide, the summits of Mississippian rock overlooking a dissected plain on Upper Ordovician to the southeast, 300 to 350 feet below the crest.

By the criteria defended in this study, the crest line and back slope of the Crystal escarpment in northern Jefferson County carries an indisputable record of the Springfield peneplain. It is well shown on Belew Creek, Herculaneum, House Springs, and Maxville 7½-minute Quadrangles by a striking accordance in altitudes of minor interfluve crest lines distributed along both the Crystal escarpment (Belew Creek Quadrangle) and the Burlington escarpment (Maxville and House Springs Quadrangles). The pattern, best recognized when traced out on the maps with colored pencil, is a direct reflection or consequence of the innumerable ravine systems which, rudely fernlike or treelike in ground plan, drain the northeasterly slopes of both escarpments. These ravines have so largely destroyed the original erosional plane that the flattish tops of the remnants, ranging from about 900 to 940 feet or so A.T. are almost all much attenuated. The most marked surviving portion, High Ridge on House Springs Quadrangle along State Highway 30 and only 23 miles from St. Louis Post Office, is thickly dotted with residences. The pattern of this remnant could be compared to an octopus with six arms, for all dissecting creeks (Bear, Sugar, Saline, Williams, Antire, and Little Antire) are radially distributed. Most residences stand above 900 feet A.T. and the central and highest part of the tract reaches 938 feet A.T.

The longest arm of this summit tract extends miles off to the southeast and, on adjacent Maxville Quadrangle, expands to another octopus of nine arms, also ranging from 900 to 938 feet A.T. and carrying many residences along State Highway 21.

On the crest of the Crystal escarpment itself are a few small tracts as high as 960 feet A.T. and one that reaches 974 feet. These are monadnocks on the Springfield peneplain.

Dissection of the slopes of both escarpments has been so intense that there is little hope of identifying remnants of the Ozark peneplain on the back slopes of either escarpment.

The argument for peneplain origin of the summits noted lies not alone in the indicated accordance of altitudes. A restoration of the vanished plane crosses the edges of a half a dozen or so recognized Paleozoic formations, here faulted and tilted out of any approximation to horizontality.

West of the Crystal escarpment, the minor interfluves on Belew Creek Quadrangle which are taken to be remnants of Big River valley's lower slopes at the end of the Ozark cycle are about 650 feet A.T., and the peneplain remnants closer to the foot of the scarp are 700 to 750 feet. Such figures, however, are only indefinite approximations because of some tracts of late mature Ozark topography, now monadnocklike in character, and because of a pretty thorough ravine and creek dissection in post-Ozark time. But as a whole, the Ozark surface there is 150 to 200 feet lower than the Springfield on the escarpment summit.

From Belew Creek Quadrangle, the trace of the escarpment describes nearly half a circle with concavity to the north as it crosses the south half of Pacific Quadrangle and approaches Meramec Valley. There is but little constriction, however, of that valley at the intersection.

Cuesta character reappears in the northeastern corner of the St. Clair Quadrangle (Franklin County, Figs. 21, 22, 23) where a south-facing crenulated steep front of the upland drops 100 to 200 feet to the low saddle between Meramec and Missouri valleys at Gray Summit. Thence northward, the trace of the escarpment

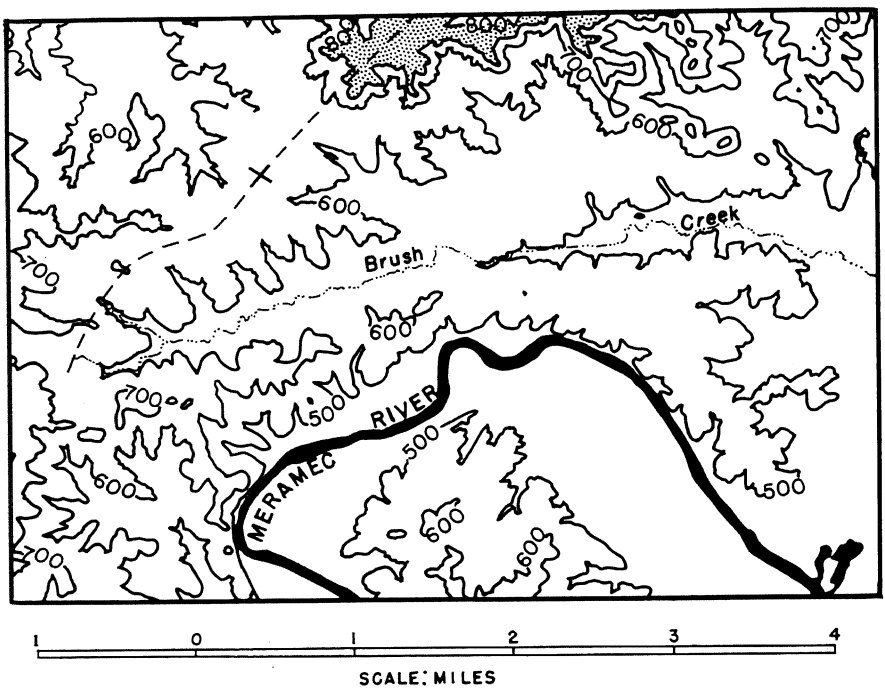

Fig. 21. Map of Crystal escarpment and Gray Summit lowland; St. Clair Quadrangle. Beveled remnant of the escarpment (extreme northern part of figure) is interpreted as a remnant of the Springfield peneplain. The low pass (marked x) on the divide between Missouri and Mississippi drainage ways is post-Ozark in age.

passes to the north side of Missouri Valley without perceptible effect on the valley bottom width.

As the short creeks flowing east across the escarpments in the latitude of Farmington Plain must have had their courses established before ever the cuestas were etched out, so the Meramec and

Fig. 22. Crystal escarpment seen from near Gray Summit; St. Clair Quadrangle. The upland, back from the escarpment, carries records of the Springfield peneplain and remnants of the Ozark peneplain. The foreground flat is presumably a Pleistocene course of the Missouri River. R. Zangerl, photo.

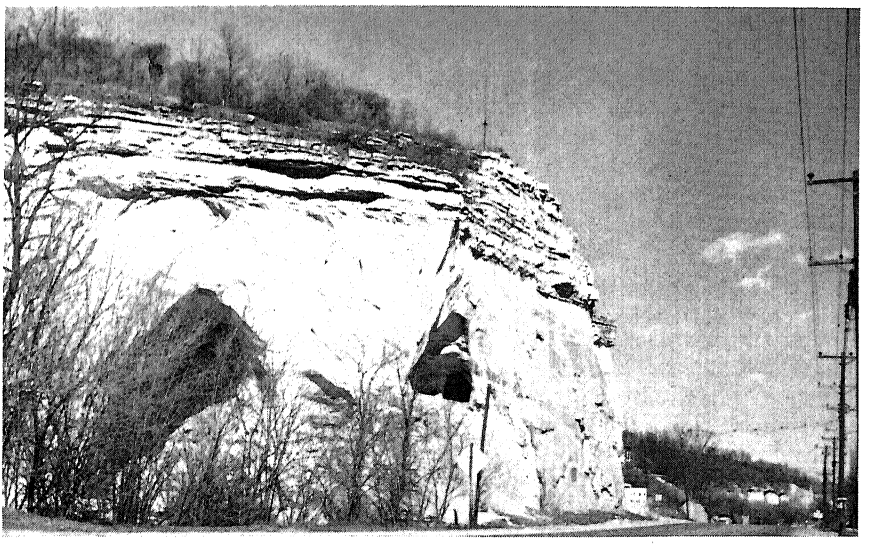

Fig. 23. Crystal escarpment sharpened by mining and road excavation near Pacific. R. Zangerl, photo.

Missouri crossings must be explained. On whatever earlier topography these stream courses were initiated, it then had no cuestas. Nor was it a structural plain, for the summit of the Crystal cuesta is held up in places by Upper Ordovician rock as well as by the prevailing Mississippian limestone. Where the scarp is well developed, summit altitudes range between 800 and 900 feet for the 50 miles traced in preceding paragraphs. These stream crossings of escarpments in the eastern part of the Salem subprovince can find no rational explanation in a noncyclic experience with the contrasted rock formations and structures they have encountered.

St. Louis region.—The peninsular area of St. Louis County and of northeastern Jefferson County, included between the Missouri and Mississippi Rivers and bounded on the southwest by the Crystal escarpment, is held up by Mississippian and Pennsylvanian rocks. The stream-eroded surfaces slope northeastward from 800- to 860-foot summits along the scarp trace to the tops of the Mississippi bluffs (cliffs in places) at about 500 feet A.T. Some modification of the bedrock topography has resulted from Pleistocene deposition and erosion, but in general Fenneman's interpretation of a sloping peneplain surface is adequate. The breakoff down into the two river trenches ranges from 100 feet along most of the Mississippi side to 200 feet at the northern tip of the peninsula. Little of the peneplain can be identified beyond accordance of summits.

One tract of unusual interest, however, is a gravel deposit near Grover on the Eureka Quadrangle in the extreme western and highest part of the area. The gravel was reported by Fenneman who noted another exposure about four miles to the northeast in a 40-foot hill whose summit is 760 feet and a third occurrence in excavations 16 miles to the northeast in a low hill on the peneplain at altitudes between 700 and 740 feet.

Rubey (1952) found 30 feet of gravel exposed at the Grover locality with south-dipping foreset bedding in units 12 feet thick. Pebbles and cobbles were noted as being largely of chert, but some metamorphic quartzite, jasper or jaspilite, and vein quartz were reported. One piece of quartzite was recorded as being 24 inches in diameter.

In the present study, a red quartzite boulder was found that weighs more than 100 pounds and is penetrated thoroughout by Liesegang bands. Of the two sources ever previously suggested for quartzite in the Grover gravel; namely, the Sioux of western Minnesota and the Baraboo of south-central Wisconsin, this strikingly marked boulder could have come only from Baraboo, 300 miles distant in a direct line.

A previously unreported occurrence of stream gravel in this region is at the intersection of Wildhorse Creek Road and State Highway 100 where six feet of well sorted chert pebbles is exposed in a road cut less than three miles from the Grover pit. The altitude is 820 feet, the highest yet found. The hill containing it is on an

interfluve that may have been a local divide on the Ozark peneplain.

It seems quite unlikely that the original gravel mantle was 90 feet thick (top of Wildhorse gravel to bottom of Grover pit) or that warping in that distance introduces an error. It is more likely that there were two episodes of gravel deposition, separated by a time of erosion. And it is clear that a vigorous transporting agent imported the quartzite boulders and cobbles from far north.

The various facts can be harmonized if the 820-foot gravel be considered to record a pre-Ozark cycle and to have lingered on, protecting this hilltop during the development of the Ozark peneplain. Then uplift of that peneplain rejuvenated a trunk stream, presumably the early Mississippi, sufficiently to bring in the cobbly and bouldery quartzites. Remnants of the Lancaster peneplain of the Baraboo region, correlated by Horberg with the Ozark-Calhoun peneplain, are 1,200 to 1,250 feet A.T. From today's altitudes, this yields a descent of only 500 feet in 300 direct miles to Grover. Differential movement between the source areas and the site of deposit to produce a better gradient can be called on only gratuitously. Flotation in ice masses or in tree root entanglements can be visualized. Perhaps quartzite fragments had made a good part of the 300-mile trip under pre-Dodgeville conditions whose record is now lost. The only conclusion here ventured is that the cobbly Grover gravel is an early product of the rejuvenation that closed the Ozark cycle of erosion and that the transporting stream flowed southward along the general course of today's Mississippi.*

The Ozark peneplain trace can be satisfactorily identified on the Bourbeuse-Missouri divide as far east as the vicinity of Union where its altitude (860 feet A.T.) indicates a gradient from the Owensville region of six feet per mile. The peneplain trace along the Bourbeuse-Meramec divide has a gradient as far as the St. Clair region (830 feet A.T.) of six feet per mile. Because the first divide noted is nearly tangential to the dome, it has the least component of post-Ozark tilting and, therefore, most nearly records the original slope of the peneplain. Eastward beyond Union and St. Clair, the trace is lost in later and lower erosional slopes.

The distance across this lower country from both Union and St. Clair to the Crystal escarpment east of Gray Summit is about 15 miles. Gray Summit itself is the lowest place in the Meramec-Missouri divide, 650 feet A.T. The top of the scarp just to the northeast is 851 feet A.T. Eastward projection of the Owensville-Union profile reaches the Gray Summit tract at an altitude of 740 feet A.T. The original gradient probably was somewhat flatter because farther down the peneplain slope. The Grover gravel tract, 25 miles from Union or St. Clair and at 760 feet A.T., would allow a grad-

*The Grover gravel lies but a few miles outside the limit reached by glacial ice in St. Louis County and conceivably could be an outwash deposit of Nebraskan age, its materials garnered largely from a preglacial cherty residuum. This suggestion springs from features of a glacial deposit at Blue Lick Church, southwestern Marshall Quadrangle, Saline County, where, at the southern limit reached by Nebraskan or Kansan ice, a rubbly accumulation of chert with a very few dense greenstone and red quartzite fragments records the glacial scrapings from the preglacially weathered Burlington limestone.

ient of five feet per mile for the vanished Ozark in the interval. From this it seems to follow that the crest of the Crystal escarpment overlooking Gray Summit (851 feet) should be grouped with the ridges north of Allenton as a Springfield peneplain remnant.

No other monadnocklike elevations have been identified along the 50 miles of the Crystal escarpment above considered. There are monadnocks of indisputable character, however, 45 miles to the southwest on the Meramec-Big divide (northwest corner of Potosi Quadrangle and northwest corner of Berryman Quadrangle) that rise 100 to 200 feet above neighboring flat-topped interfluves; also a considerable group of them is in southwestern Berryman and adjacent Steelville Quadrangles (Crawford County). If the gently sloped summit of Little Pilot Knob (extreme northwest corner of Potosi Quadrangle) is a record of the Springfield cycle, the unusual height of its subcentral hill (300 feet above the Ozark trace) may mean that it remained a monadnock of modest height, perhaps 100 feet, above the Springfield base level in this drainage. The Rosati monadnocks, already noted (p. 43), are about 60 miles distant on the Meramec-Bourbeuse divide.

Residual hills like these are to be expected on divides nearer headwaters than is the St. Louis-Jefferson County region. But it was truly surprising to find that both northern Jefferson and western St. Louis Counties possess upland tracts that rise above the trace of the Ozark peneplain as projected northeastward from Meramec-Bourbeuse divide and eastward from Bourbeuse-Missouri divide. This trace is more than 100 feet too low to coincide with those ragged but flat-topped and accordant ridge crests on the Eureka Quadrangle (St. Louis County). Fenneman's early study (1909) found but one peneplain record in the St. Louis region, but since he later (1938) considered the Ozark and Springfield surfaces on the western slope of the dome as one and the same, he could have done the same here.

The element of surprise (and a hesitation in interpreting these eastern areas) has been born of the unexpectable survival of the oldest erosion surface of the dome so close to the three major drainage lines of the Mississippi, Missouri, and Meramec Rivers.

The wide, flattish tract about Pond and Grover (Eureka Quadrangle, St. Louis County) stands 750 to 800 feet A.T. and another dissected but broad expanse between 750 and 775 feet A.T. lies north of Grover. In contrast, the flattish ridge crests in central Eureka Quadrangle rise in many places to and above 850 feet and the ridge north of Allenton has a 900-foot summit. From these facts, we conclude that the Pond-Grover tract is an Ozark remnant and that the attenuated higher ridged interfluves farther west and southwest are residual from almost complete destruction of the Springfield peneplain here, and are surviving late mature Ozark topography.

That the Springfield surface once existed across the St. Louis County peninsular area and continued north of the Missouri Valley is clearly shown in the Lincoln Hills where Luckett Ridge and asso-

ciated hills (Elsberry Quadrangle, Lincoln County), with gently modulated summit slopes, rise 100 to 170 feet above a wide expanse to the west of Ozark flat interfluves at 800+ feet. A 960-foot elevation here is only three miles from the Mississippi floodplain at 445 feet A.T. The Ozark peneplain on Elsberry Quadrangle cuts across several Paleozoic formations involved in the Lincoln fold without any topographic evidence of the fact. A flat-topped, south-pointing interfluve terminating near Old Alexandria Church (Elsberry Quadrangle) transects, a little south of Auburn, a belt of steeply tilted formations which pass from Plattin (Ordovician) at the north to Burlington-Keokuk-Fern Glen (Mississippian) on the south. This belt is scarcely more than a mile wide, yet shows not the slightest topographic effect of the half dozen formations involved. Also, a long gentle rise northward, up the slope of an Ozark interfluve, is readily identified from the topographic maps and from a traverse of U. S. Highway 61. Although drift-covered, it is a bedrock slope, an interfluve inherited from the Ozark surface. Its gradient from the latitude of Troy (Troy Quadrangle, Lincoln County) to Bowling Green, (Bowling Green Quadrangle, Pike County) is 10 feet to the mile, and it appears to show no post-peneplain deformation such as Rubey (1952) found along the Cap au Gres faulted flexure across the river in Illinois (Brussels Quadrangle, Calhoun County). Traced southwestward from these Missouri Quadrangles, a very broad and gentle sag is detectable between the Lincoln Hills country and the upwarp near Hermann and Gasconade. Some tilting may, therefore, exist in the gradient of this Troy-Bowling Green interfluve east of Cuivre River drainage.

Although thick loess deposits on Illinois bluff summits may have determined the minor drainage noted as eastward away from the Mississippi, the bedrock surface also slopes away. Because the Mississippi course, antecedent to the uplift of the peneplain, lies west of these bluffs, the eastward slope can be a gradient of the original Ozark surface.

Rubey named the summit peneplain of Brussels and Hardin Quadrangles from Calhoun County, Illinois, in a manuscript dated 1931 and correlated it with the Ozark peneplain. Horberg (1950) accepted this correlation, as does the present study. But Horberg refused Rubey's correlation of the Calhoun-Ozark with the Dodgeville peneplain of Wisconsin. He considered that the lower and better recorded Lancaster peneplain there is the Calhoun-Ozark, and extended the use of that name as far south as the Shawneetown Hills of southern Illinois (Horberg, 1950, p. 91). This conclusion is followed here, and the very fragmentary Dodgeville is correlated with the equally fragmentary Springfield. Nothing has ever been identified in Missouri, Illinois, or Wisconsin as recording a Boston Mountains summit plane.

Pediment cliffs have been described by King (1953) and others as originating from tectonic displacements and as migrating back into higher country without respect to differences in the kinds of rock involved. The Crystal escarpment, however, generally has the

weak St. Peter sandstone in its basal slopes, and, thus, is stratigraphically determined. Its curvilinear course fits stratigraphic control, unlike the accepted picture of pediment scarps. Indeed, this feature in the southern part of the Pacific Quadrangle is only an irregular row of semi-separated hills. Retreat on the Belew Creek Quadrangle is beheading ravines on the back slope and leaving notches. In another mile of retreat, this stretch will also become a row of hills.

Retreat of the Crystal scarp has been down off the Ozark dome, and locally this has left projecting spur ridges and isolated hills behind the retreating front. Retreat has not moved into higher country to leave a plain of denudation in its wake as pediment scarps theoretically do. In its present expression, it has two major river crossings, both streams flowing with the generalized dip, therefore, toward the scarp trace. No such crossing can be imagined without a pre-scarp erosional plain on which were the original stream courses. The Crystal escarpment is not a record of pedimentation processes.

The Burlington escarpment of Marbut is not a continuous cuesta. Part of Marbut's delineation involves only valley cliffs (Lincoln and Pike Counties along the Mississippi and half a dozen Counties along the Missouri). Some stretches of Mississippian limestone margining older rocks are cleanly truncated down to a peneplain level. The Burlington hills in Ste. Genevieve County and the Eureka Springs escarpment west of the dome summit are the only cuestas held up by Mississippian rocks.

Tipton Summit Flat

The southern half of the Tipton Quadrangle (Moniteau County) is an illustration of the total lack of topographic expression of the edge of the Mississippian rocks in this part of Missouri. Here, seven named creeks plus their tributaries, radiate in all directions from a flat upland tract which, with the out-pointing interfluves, approximates 15 square miles above the 900-foot contour but nowhere rises above 965 feet A.T. (Fig. 24). That this is a peneplaned surface is evident from the State Geological Map, for part of the tract is Ordovician and part is Mississippian rock. It is a portion of the north-sloping Ozark peneplain already described on the Gravois Mills and Eldon Quadrangles. The drainage clearly is inherited from that peneplain and, except on the west, headwaters are essentially still in the Ozark cycle. The interfluve gradients are as low as three and a half feet to the mile.

The full thickness of the Pennsylvanian System and, for part of the total area, a portion of the Mississippian System also, totaling hundreds of feet, has been removed by the erosion that has made the flat upland (Fig. 25). If the drainage pattern of this part of the dome has not been drastically altered during the erosion, the Tipton area has remained in a region of small streams much

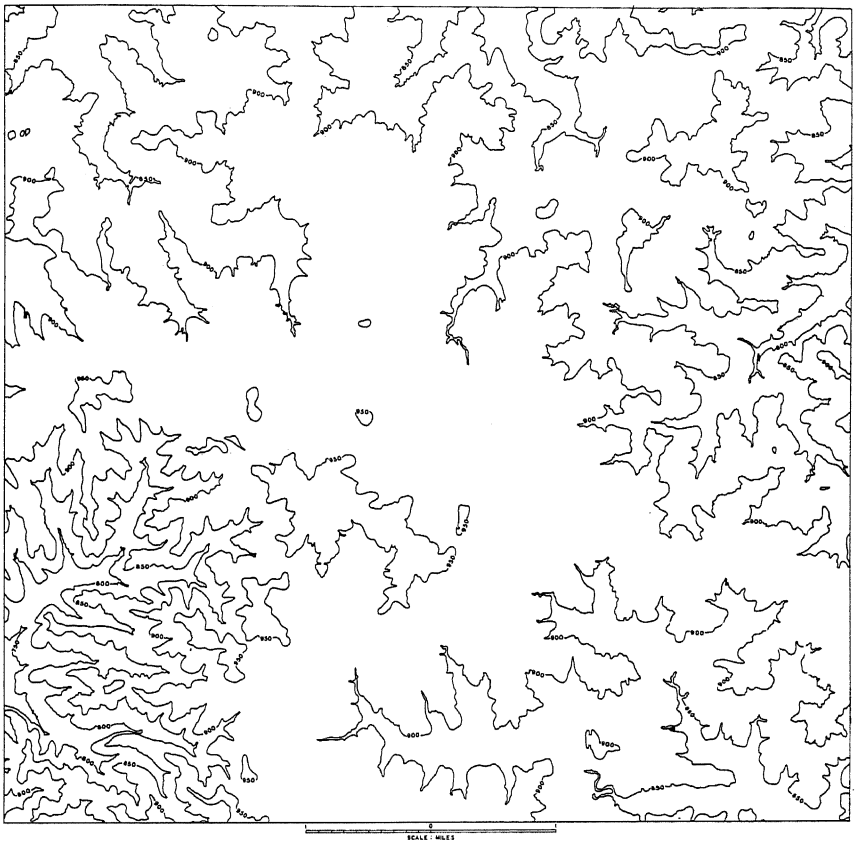

Fig. 24. Map of Tipton summit flat; Tipton Quadrangle. The flat interfluve was eroded down during the Ozark cycle entirely by its radial creeks.

like, if not identical with, the present drainage. By only the most remote possibility has it ever been traversed by a major stream.

By the noncyclic concept, the present summit flat has descended through a long upland flat history, lowered hundreds of feet only by the erosional agents that operate in such interfluve situations while the nearby streams (Petite Saline and Moreau Rivers) have lowered their valley bottoms only 200 feet more than weathering and rainwash have lowered the summit tract.*

By the two cycle concept, the flat is a base-leveled surface still surviving the destruction wrought by streams rejuvenated through regional uplift and consequent lowering of their base level. The rejuvenated margins of the flat now descend 150 feet in a mile.

*Holmes (1964) in a recent critical examination of Hack's concept of dynamic equilibrium, says that "surfaces of river planation may be included in a peneplain by courtesy, but only if they are bordered by, and continuous with, a real peneplain formed by downwasting of the interfluves." Holmes also stresses what Hack has missed in Davis' papers; the fact that Davis considered "base-leveling of the crest lines [as well as] of the lowlands" (Davis' words) in peneplanation.

Fig. 25. Tipton summit flat seen from the southwest; Tipton Quadrangle. R. Zangerl, photo.

Tipton's history is but a concisely displayed example, an epitome, of the history of many flat uplands of the Ozark province comparably isolated from main drainage lines. They are local "highs" interrupting the general slope simply because that Ozark peneplain was not everywhere brought down to a uniform smoothness. It was, however, base leveled as far as its minor radiating streams are concerned. Only the slope wash drainage of a peneplain reduced this broad summit to its present flatness. For such areas, the Tipton tract may be taken as the type.

Southeastern Slope and Embayment "Islands"

Although all southeastward-trending interfluve profiles of the Ozark peneplain trace are abruptly terminated in the summit of the Mississippi Embayment bluffs (the "Ozark Escarpment" of some reports), it appears that certain isolated hill groups (Fig. 26) some miles out in the alluvial plain also carry the trace and that profiles can be safely projected across separating lowlands. The Paleozoic formations in the northern parts of these "island" hills are direct southward continuations of the broad belts in Cape Girardeau and Bollinger Counties, already noted. Six such hills or groups of hills are shown on the State Geological Map. On the large ones, Paleozoic formations, traced southward, go under Cretaceous and Tertiary sediments of the early Embayment, and the Ozark peneplain trace truncates them as well. The "islands" are separated by strands of the alluvial plain, former routes of Mississippi River water under conditions that have been variously explained (Branner, Matthes, Fisk, etc.) and surely are later than Ozark peneplanation. These lower gaps are now used by St. Francis, Black, Castor, and Whitewater Rivers beyond their crossing of the Embayment bluffs.

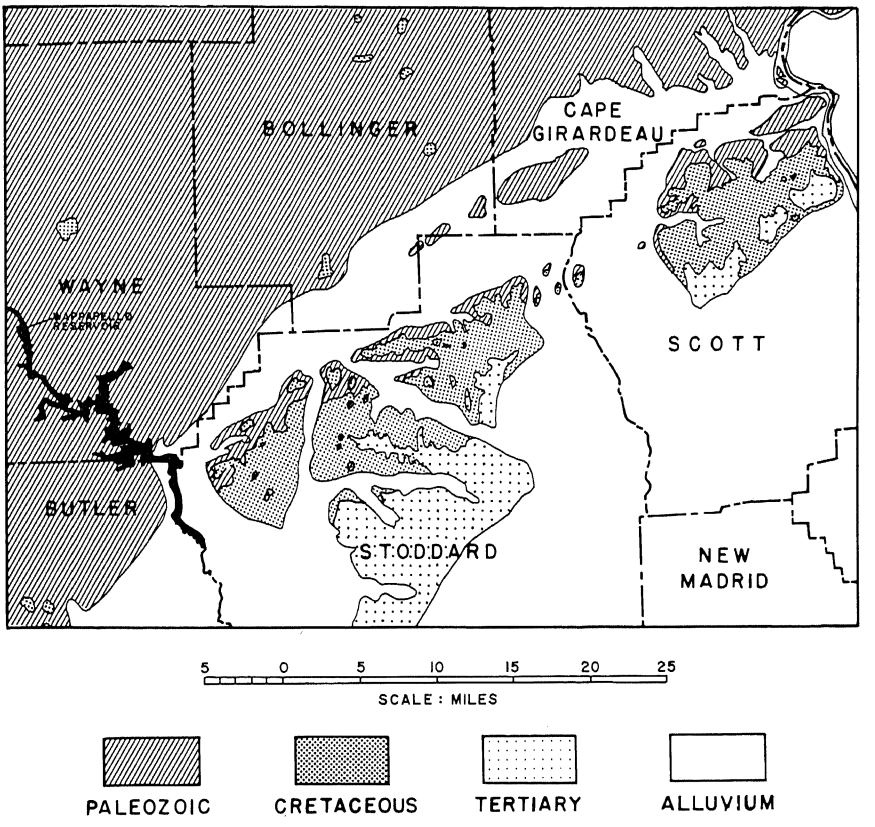

Fig. 26. Embayment "islands" in southeast Missouri; after Missouri State Geologic Map, 1961.

The northeastern of these hill groups (Benton Hills in northern Scott County) has the largest expanse of Paleozoic rocks and the best showing (Morley and Thebes Quadrangles) of truncation that involves also Cretaceous and Tertiary rocks. No flat summits remain, but altitudes of 560 to 600 feet occur on the Kimmswick, St. Peter, Silurian, Devonian, Cretaceous, and Tertiary formations alike. Altitudes on the "mainland" four to five miles to the north are prevailingly near 450 feet on the bluff summit farthest east (on Cape Girardeau Quadrangle) and are 500 to 520 feet farther west near Dutchtown. Raggedly outlined on the contour map, the interfluves, traced northward, rise to the 500's and 600's. This is the Ozark peneplain's southward component of slope, and the summits of the Benton Hills "island" belong in the same category. Thus interpreted, the Ozark peneplain is younger than the youngest Tertiary formation involved, the Wilcox. This point was first made by Marbut.

Comparable altitudes exist on the other "islands" in this plexus of alluvial channelways as far south as extreme southwest

Bloomfield Quadrangle (Stoddard County) 30 to 40 miles downvalley from the Benton Hills. The direction is roughly tangent to the slope of the Ozark trace on the mainland. Identification of the peneplain here, lying in the same projected profile, makes it clear that the alluvium-filled Mississippi Embayment valley has no record here of localized post-Ozark subsidence and obviously any earlier erosion surface must have been above the present hilltops on all of these "islands" of Paleozoic rock.

The buried Paleozoic surface, southeast of these islands, known from well logs (Grohskopf, 1955), has a much steeper slope than recorded in the Ozark interfluves, its average being 35 feet per mile. Furthermore, this surface, according to Grohskopf's well log studies, truncates six Paleozoic formations whose dip is a little less steep. It, therefore, is a downwarped peneplain surface of pre-Ripley Cretaceous age.

Does this surface record the Boston Mountains cycle or the Springfield-Dodgeville? One supposition is that it is the older surface and that the "pre-Tertiary erosion interval" (Grohskopf, 1955, p. 20) records the Springfield cycle. At any rate, the Springfield would be pre-Wilcox in age.

Field evidence denies the idea that the Embayment bluff is a fault scarp, as some have suggested. But the well log data clearly indicate a pronounced downwarping in or just to the southeast of the row of "island" hills. They date the downwarping as pre-Cretaceous in large part, although sharp local movement of post-"Lafayette" age has been reported (Stewart, 1942) near the east end of the Benton Hills. These facts indicate the existence of an asymmetrical hinge line near the alluvial fill and subparallel to the Embayment scarp. On this hinge, the positive Ozark region has risen while the negative Embayment has subsided. Isolated outcrops of "Gulf coastal plain sediments" as much as 20 miles northwest of the scarp do not invalidate this concept.

A group of high, raggedly outlined, stream-dissected hills and knobs in east-central Cape Girardeau Quadrangle has some summits above 700 feet A.T. One, at 800 feet, is only three miles from the Mississippi River whose flood plain there is about 350 feet A.T. On the Illinois side of the river directly east of this group is another group of outstanding hills, chief among which is Atwood Ridge, 897 feet A.T. and 550 feet above the Mississippi Valley floor only half a mile distant. These elevations rise a few hundred feet above the trace of the Ozark peneplain about them, therefore belong to the category of monadnocks. But their locations are rather extraordinary for in the less than 10 miles which separate them lies the flood plain of the master stream of middle North America.

The hills are composed of no more resistant rock than their lower immediate surroundings and thus cannot be comparable to outlying St. Francois knobs and hills. The Mississippi has held its course here since the days of the Ozark peneplain. Was it here during the Springfield cycle?

Fragmentary remains of a former sedimentary cover for the Paleozoic rocks, reported only as Cretaceous or Tertiary, are known a little farther north than this district. If they lie on high interfluves, they may well be a record of a deltaic flat of Cretaceous age. On such a flat, the Mississippi of that time could have been shifted in the succeeding uplift from its Springfield course to become superimposed on a less reduced portion of the peneplain. The 10 miles between the two hill groups may thus approximate the width of the Mississippi Valley on the later developed Ozark peneplain. Like the Lincoln Hills monadnock, these outstanding elevations still linger on closely margining uplands.

An extensive, old upland topography in southwestern Carter County, with overlaps into Butler and Ripley Counties, represents an eastward sloping portion of the Ozark peneplain now in drainage slopes which, although post-peneplain in age, are themselves older than the hungry ravines besetting them. The towns of Grandin, Hunter, and Ellsinore (Grandin and Williamsville Quadrangles) lie within its area (Fig. 27). Like Lanes Prairie in Gasconade drainage, the upland's water parting is close to the western edge, and virtually all drainage flows diagonally across its gentle southeastward slope away from the brink of a steep westward descent by short ravines to Current River gorge, 300 to 400 feet deep, along its west side.

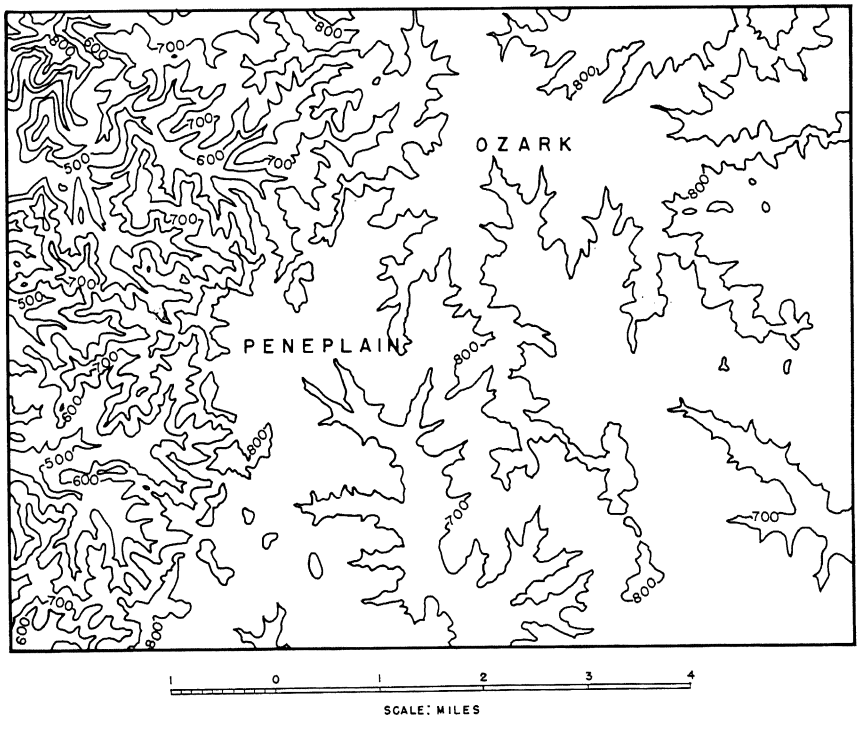

Fig. 27. Map of Ozark peneplain in Grandin Quadrangle.

These ravines are nowhere longer than four miles; most of them make that descent in two or three miles. In contrast, the southeastward slope of the upland, from the high (800 feet A.T.) western edge to termini of the broad top's interfluves at approximately 700 feet has less than half the gradient of the Current's ravines.

Thus, there are topographies of three different ages in this upland district: 1) the original plain now recorded only in these interfluves (Hilltop, east of Ellsinore, is a flat remnant), 2) the broad open creek valleys (Grandin is down in one of them), and 3) the active margining ravines of the present erosion cycle.

The traces of the original plain as marked by the 700-foot contour may be found in more than 50 small isolated areas above 700 feet, strung out beyond the southeastern tips of the interfluves. Many of the interfluves, separating tributaries to Black River to the east, carry their characteristic broad flattish tops down to 600 feet A.T. The entire record lies in the east half of the Grandin Quadrangle and the west half of the Williamsville Quadrangle. Current River has cut 400 feet deep in the uplifted peneplain here. Its southward course has been inherited from that peneplain and, although not spectacular, is truly an antecedent course diagonal to the southeast direction of maximum tilt to which the plain's minor drainages are adjusted.

Further evidence for this conclusion may be found in several attenuated spurs of the upland which run out westward for two miles and more between the Current's vigorous ravines, and have their *highest* parts near their termini. They record a former westward extension of the southeast sloping plain.

All the traits of the Ellsinore-Hunter-Grandin area are duplicated, except as to actual proportions and altitudes, on Doniphan and Naylor Quadrangles immediately to the south. With no changes in relative altitudes or character of local features, the dissected plain on the Doniphan Quadrangle passes from Roubidoux sandstone to Jefferson City dolomite, thus disposing of suspicion that this plain is structural.

Southern Slope

Current River valley across Grandin and Doniphan Quadrangles (Carter and Ripley Counties) may be taken as the boundary between the southeastern and southern slopes of the Salem Plateau. Consideration of the southern slope's geomorphology may best begin with an instructive upland plain, residual from an earlier topography, which lies in the northern half of Summersville Quadrangle and is shared by Texas and Shannon Counties (Fig. 28). It is nearly as large as that about Ellsinore and Grandin, approximately 10 by 12 miles overall, has the same gentle eastward and southeastward slope of its somewhat dissected surface, the same record of former greatness in strings of small isolated tracts with altitudes comparable to the plain's interfluve tips, the same shallow and widely open drainage ways that drop off into sharply

cut marginal ravines, and approximately the same generalized gradients of the broad, low interfluves. It is a widening of a subordinate divide that runs southeastward from the Licking-Raymondville summit flat and lies between ravine heads of Jacks Fork and Current River drainage. The slope from Raymondville to Summersville is four and a half feet per mile.

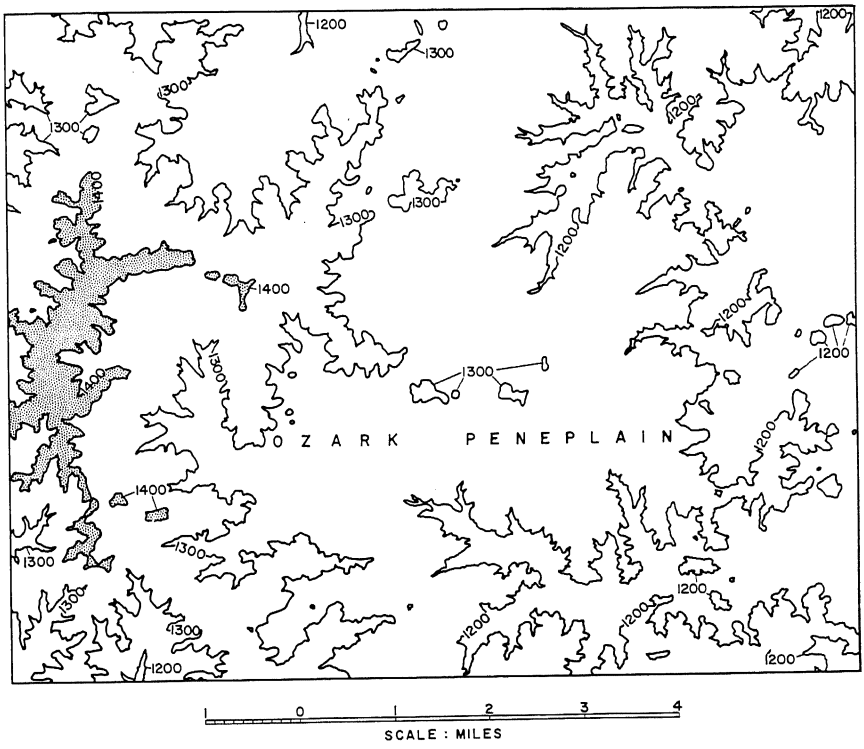

Fig. 28. Map of Summersville upland flat and ridge; Summersville and Clear Springs Quadrangles. Shaded area is late mature Ozark topography, monadnocklike in origin.

This Summersville plain differs from the Ellsinore-Hunter-Grandin area in one important item. It has no deep river gorge along the west side with a maze of tributary ravines separated by long, narrow, high-topped interfluves. Instead, it possesses a north-south ridge along four miles of its western boundary, a ridge 150 feet and more above the high western edge of the upland plain. This ridge (on adjacent Clear Springs Quadrangle) has ravined slopes draining *to* the upper edge of the plain. Although these short ravines are not as narrow or steep-walled as those now dissecting the outer margins of the plain, their gradients are four times as steep as that of the waterway which they join to cross the upland.

The Summersville tract, like the Ellsinore-Hunter-Grandin tract, has topographies of different ages and conditions of origin. The broad rolling plain is but an extension of the summit upland in the zigzag described by the major divide of the Ozark dome. The four-mile long, 150-foot high ridge belongs to the category of monadnocks on that divide and is, therefore, a record of an earlier surface. It lacks flattish tops, but its length atones for that. Its summit, 1,460 feet A.T., cannot be far below the trace of the Springfield peneplain, as the four isolated 1,400-foot summits as much as a mile east of the crest line show. The minor ravines on its slopes are survivors of the Ozark cycle, unaware that that cycle has been ended by uplift and by consequent rejuvenation farther downstream.

Two points remain for consideration. May the plain be structurally determined instead of being a record of base leveling? May the plain be the product of pedimentation backwearing instead of peneplain downwearing?

The State Geologic Map clearly and finally answers the first query. The plain is crossed midwidth (east-west) by the irregular boundary between Jefferson City formation on the west and Roubidoux formation on the east. It is an erosional plain.

For an answer to the second query, one looks, as he did on the Licking-Raymondville summit flat, for the relatively steep slope of a flattish upland that would record truncation by cliff retreat, then for the retreating cliff. The ridge west of Summersville might serve theory here, but among many residual elevations above the Ozark surface it stands almost alone in its linearity. All others, which must be of the same genesis (except the Eureka Springs escarpment and river gorge cliffs) are essentially lone hills, exceedingly unlikely to have been left by pediment retreat. A defender of pedimentation here must admit the almost total extinction by cliff retreat of an earlier topography on the summit of the Ozark dome, his pediment plains on both north and south surprisingly coinciding in altitude as they finally met at the scalped summit.

Objections to a noncyclic interpretation of the topography of the Ellsinore-Hunter-Grandin and Summersville tracts are the same as those raised for the Lanes Prairie-Belle tract (see p. 37). "Dynamic equilibrium" in erosional reduction of these uplands has not occurred. The contrasting land forms clearly record successive changes of base level through time.

A significant botanical item should be noted in discussing this question of origin. Steyermark (1953, p. 15) has found in sinkhole ponds in the Missouri Ozarks a "startling number of plants (species) whose main distribution is confined wholly or chiefly to the Atlantic or Gulf Coastal plains or—the Mississippi Embayment". He concludes that they "represent the last remnants of—the flora of the swampy peneplain", their survival made possible in the now uplifted and well drained Ozarks only because of sinkhole swamps and ponds on the undissected interfluves. Thus, the lowland plain on which they originally spread was a moist plain. It was

not eroded under conditions of aridity or semiaridity and is not a product of pedimentation processes.

The city of Alton (Couch Quadrangle, Oregon County) is central within a three quarter circle, concave southward, of united interfluve ridges (all in the Eleven Point River drainage) that consistently maintain an altitude of 900 feet, or more A.T. This partially encircling upland is too much dissected to deserve appellation as an Ozark peneplain remnant. Yet its summits come close to the original peneplain trace, here sloping southward with a gradient, measured along its interfluves, of approximately 12 feet per mile.

This southward descending profile, on reaching 800 feet A.T. in southern Couch Quadrangle, abruptly rises 100 to 200 feet over a minor escarpment in the Jefferson City formation to traverse a small upland of gentler slopes, all above 900 feet and culminating at 1,040 feet A.T. The nearest 1,000-foot elevation upslope (northward) along the interfluve is 12 miles distant and is in the Ozark profile of Alton's encircling divide. Thus, the minor escarpment in southern Couch Quadrangle is a lingering remnant of an older surface, obviously a survival of the Springfield peneplain.

A deposit of rounded gravel of unique character is exposed in a cut along Supplementary Road CC, Howell County (secs. 17 and 20, T. 24 N., R. 9 W.). Although on a hilltop remnant of the Ozark peneplain, it appears to antedate that erosion cycle and perhaps all earlier erosional history now recorded in Ozark geomorphology. There are sparingly distributed pebbles and cobbles of light colored quartzite in the dominantly chert gravel, and some of the cherts closely resemble novaculite.

The deposit is unique in that two gravel members, each tightly packed with deep red clay, are separated with sharp, clean contacts by about 20 feet of yellowish, pebble-free clay and that these three members stand *vertically.*

The interpretation here advanced is that the roadcut is a part of a "filled sink", in the making of which an overlying gravel was bodily engulfed. The yellowish clay, by this view, is a completely altered block of Jefferson City dolomite (the country rock) or even some younger calcareous formation existing here when the sink was made. The red clay appears to have infiltrated down into interstices of the gravel during much later time.

Filled sinks of the Ozarks (Bretz, 1950) containing refactory clay and masses of pyrite and hematite, date back to the existence of a Pennsylvanian cover of the dome. This curious deposit may be that old. It also may be a Cretaceous gravel. Only by coincidence does it now lie in the profile of the Ozark peneplain.

A westward tracing and correlation of conspicuous peneplain remnants on the south slope of the dome is here attempted. It must be done by projecting a profile *across* intervening valleys which will intersect them and their interfluves at high angles. The profile of the Ozark peneplain, thus obtained, rises continuously toward the high country of the Eureka Springs scarp. Precise figures

cannot be given because all interfluves have a southward longitudinal slope, but in two parallel, east-west rows of 15-minute quadrangles, from the Embayment to the Eureka Springs escarpment (about 150 miles), the maps show the Ozark peneplain trace rising westward about 800 feet. Its expression is less and less that of a rolling upland with widely spaced contours. Identification depends more on rows of small, separate, flat-topped tracts with properly related altitudes strung along the minor interfluves.

Another criterion for recognition of relics of the two peneplains is the scattering of monadnock knobs and raggedly outlined ridges 100 to 200 or more feet above the surrounding interfluves. On the maps they look much like the monadnocks of Mississippian rock on the dome's major divide west of Sterling and Cabool. But except close to the big Eureka Springs scarp, these strongly accented features are of Ordovician, not Mississippian, rock.

No summit flats safely attributable to surviving old land surfaces remain on these hills, but altitudes of the larger ones come close to a Springfield profile across the western half dozen of these quadrangles. Thus interpreted, the former Springfield plain for 40 to 50 miles east of the Eureka Springs scarp was cut on Ordovician rocks, therefore, was not a structural plain.

The largest of these Ordovician residuals from a Springfield peneplain stands in northwestern Gainesville Quadrangle (Figs. 29, 30). It is one of the largest groups of monadnocks anywhere on the Ozark surface, about seven miles long, up to five miles wide, and it stands about 300 feet maximum above radiating interfluves among 20 named creeks and hollows that drain the tract. Dissection has made 17 named knobs, hills, ridges, and mountains out of its

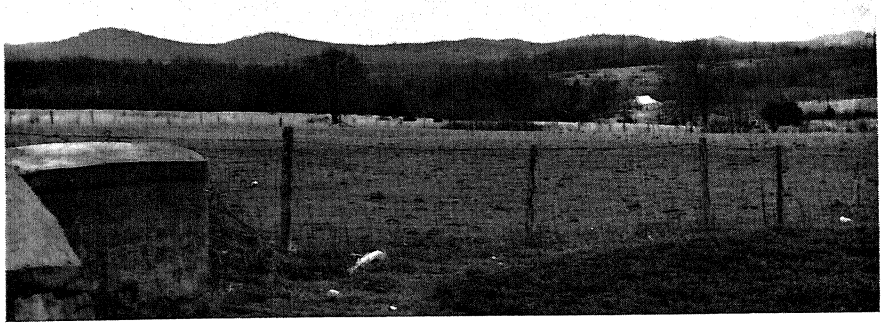

Fig. 29. Skyline of part of Gainesville monadnock group. Flat foreground is a remnant of the Ozark peneplain on the summit of one of the interfluves separating headwater ravines of Barron Fork. R. Zangerl, photo.

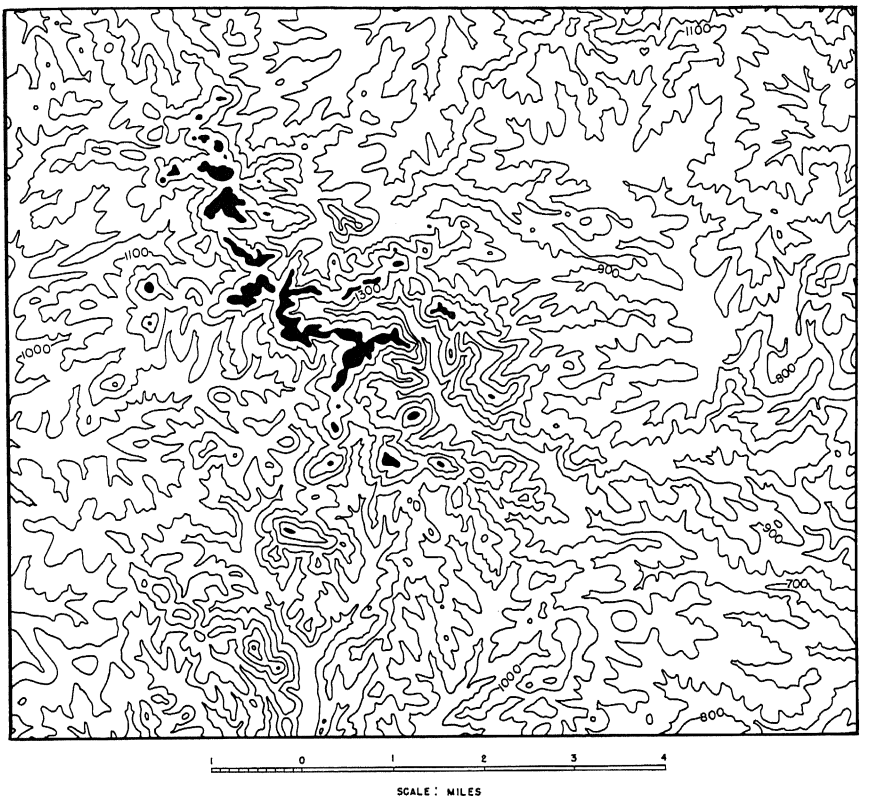

Fig. 30. Map of Ozark monadnock group; Gainesville Quadrangle. Shaded summits are remnants of the Springfield peneplain. Interfluve summits in dissected surrounding country record the former Ozark peneplain here. Post-Ozark stream dissection has also segmented the former ridge into 17 named summits.

original mass. The Eureka Springs escarpment, capped with Mississippian limestone, is more than 25 miles farther west, and its brink averages about 100 feet higher than the summits of this compound monadnock of Jefferson City dolomite. The seven highest hills carry caps of basal Mississippian rocks.

Twenty-five well-distributed summits of this residual upland carry a closed 1,400-foot contour, and the highest is only 1,486 feet. This makes a persuasive picture of a former upland erosional flat whose altitudes is just about what the Springfield peneplain trace should have across this quadrangle.

Although steep slopes descend to adjoining Ozark-topped interfluves, these same slopes descend also into ravine heads cut well below the Ozark peneplain trace. The detailed dissection seems to have been consummated largely during the present cycle, but the larger lineaments of the group's intricately convoluted outline and the isolation of outlying knobs date back to the Ozark cycle and are

clearly records of its headwater stream erosion. Nothing in the ground pattern gives any countenance to the idea that pedimentation processes isolated the large hill group. There is no suggestion of a former bounding cliff that was retreating before an advancing pediment and now is cut up by streams under succeeding humid climates.

Contact of the Ozark and Springfield peneplains in the extreme southwestern part of the Salem section is difficult to draw on the topographic maps. The large relief provided by the Eureka Springs escarpment and the transecting White River valley has bred a huge progeny of deep ravines between narrow divides of various and varying summit altitudes. They cut up the scarp slope and the Ozark surface alike to make as rugged a country as anywhere in Missouri. There are summits of 1,100 and 1,200+ feet on Protem Quadrangle within three miles of White River which there is 600 feet A.T.

Further difficulty comes from the transitional character of the Ozark surface in proximity to the break and from the fact that creeks on the Springfield's back slope ignore the steep descent to the adjacent Ozark surface and flow directly to White River. There are also great southward-pointing prongs from the Springfield upland, now reduced to undulating ridge crests, that still carry altitudes only a little below that of the upland.

A sinuous crest line for the scarp above all the rugged slopes —essentially the divide at the head of the drainage on its own western back slope—lies well back of the greatly dissected eastern slope itself. It is quite unlike what one would expect from the State Geological Map alone.

If the Eureka Springs scarp has not retreated in post-Ozark time, its ridged and ravined slopes logically must belong to the Ozark surface. For evidence on that question, one should begin well east of the scarp's influence on spurs and intervening valleys, should identify the Ozark surface there, and should then trace it upgrade along the streams to ascertain, 1) if it extends back in a kind of terrace or bench system between high spurs from the scarp or 2) if it rides up on minor interfluves of the transitional slopes.

The best place to start is at the large Gainesville group of monadnocks above noted. Eleven hundred is a good round figure for flat-topped residuals of the Ozark peneplain there. Westward tracing for about 10 miles encounters Little North Fork of White River where altitudes of the local interfluves descend for that crossing (north half Thornfield Quadrangle, Ozark County) to 1,000± feet, recording the Ozark peneplain's valley here as 10 to 12 miles wide and about 100 feet deep. Continued on west to the Protem Quadrangle (Taney County), the profile encounters a sinuous northeast-southwest ridge with numerous lateral spurs, the main ridge summit being for 10 miles almost continuously above 1,400 feet A.T., approximately at the Springfield level. It is one of the largest compound monadnocks of Mississippian rock in the province.

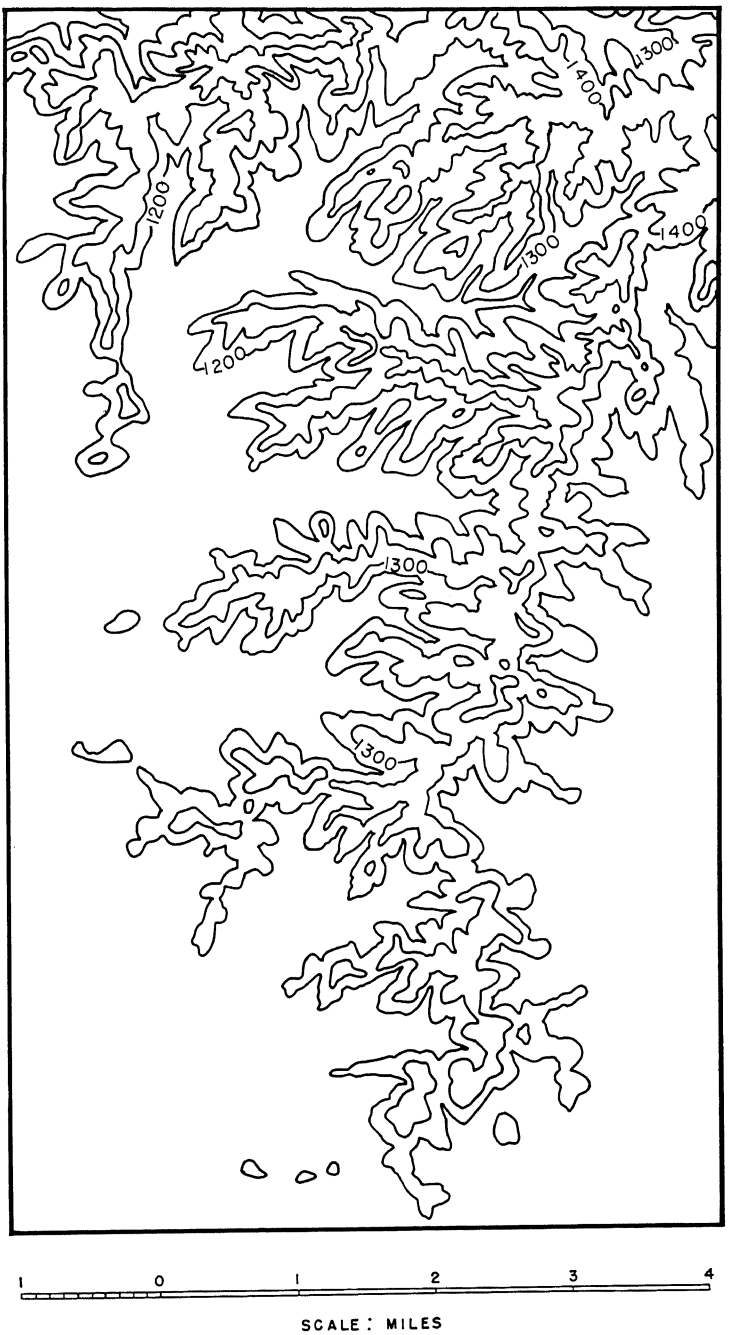

Fig. 31. Map of an asymmetrical ridge in Bradleyville Quadrangle. A much ravined spur remnant of the Springfield peneplain with margining Ozark peneplain remnants (blank area) now considerably dissected.

But the dissected Ozark plain may be followed northward on to the Ava Quadrangle, thus to go around the north end of the ridge and to find to the west that headwaters of Little North Fork are but slightly above 1,200 feet. Here one may cross on broad interfluves westward to Beaver Creek headwaters. The bypassed ridge is an outlier of the Eureka Springs scarp isolated through development of the lower erosional plain that lies in the Ozark profile near the Douglas-Ozark county line. The Bradleyville Quadrangle map shows an extensive, gently rolling, upland plain from 1,200 to 1,300 feet in Beaver Creek drainage. Roy, Goodhope, and Red Bank are on this north-south elongated plain. With rising altitude and more marked local slopes, it is traceable northeast as late mature Ozark topography to the city of Ava.

West from Beaver Creek headwaters, another spur ridge with summits of 1,400 to 1,500 feet must be crossed (Fig. 31). This ridge is still an integral part of the Springfield upland. Bench lands of Beaver Creek at 1,100 and 1,200 feet come close to the steep climb up this ridge in western Bradleyville Quadrangle. On the State Geological Map, the Jefferson City outcrop comes equally close to the Mississippian rock of the steep slope, and stratigraphic control is obvious here with probability that sapping of the Jefferson City below the cherty Mississippian has made this unusually sharp break. Nevertheless, this upper Beaver and Little Beaver Creeks drainage is largely on Ozark peneplain surfaces.

Across this large spur ridge of western Bradleyville Quadrangle, the profile enters Swan Creek drainage. The subordinate interfluves that project westward from the ridge into this creek valley are several times as long as those on the eastern side where sapping is suspected. Little that bears on the present problem can be identified in that dissected headwater drainage. The southernmost hills, 1,200 to 1,800 feet A.T., are only three miles from White River (about 600 feet A.T.) on both Protem and Mincy Quadrangles. Satisfactorily identifiable Ozark remnants cannot be traced around past this greatly eroded southern tip. The large spur ridge can be crossed, however, in a wide gap a mile north of the Christian-Taney county line, and here the Ozark plain is 1,100+ feet in the flat-topped spurs both east and west of the ridge.

Once this surface is recognized, its fragments can be followed down the valley of Swan Creek as the flat, but not level, tops of minor ridges to a noteworthy broadening about Taneyville and Dickens (Forsyth 7½-minute Quadrangle) at approximately 1,000 feet A.T. The entrenched meanders of both Beaver and Swan Creeks' lower courses apparently are descended from the surface. If correctly traced and identified, *the Ozark peneplain becomes a strath* west of Protem and Bradleyville Quadrangles, ramifying back up in the White River drainage; a strath so dissected as to be recognized only from accordance of summits of the minor divides separating the post-strath ravines carved in it. The longitudinal profiles of these divides, if traced northward away from the river, rise gradually up the equally dissected slopes of the older, outer,

White River valley until, on the Fordland and Ozark Quadrangles, they blend into remnants of the Springfield peneplain.

Unexcelled views of remnants of this strath are obtained in descending to Branson along either of two highways from the north (Fig. 32). Its appearance is that of a much dissected upland with a relief of 300 feet, although its hill and ridge tops are 400

Fig. 32. Interfluve whose flat top records White River strath, equivalent of the Ozark peneplain. Bounding ravines are concealed by forest. Seen from a spur of the Springfield peneplain carrying the highway at Chula Vista, Branson Quadrangle. Field and house are 300 feet below the observer and 300 feet above Lake Taneycomo. R. Zangerl, photo.

feet lower than the Springfield summit at Reeds Spring (Reeds Spring Quadrangle) or Stutts (Spokane Quadrangle) some 15 miles to the north and northwest. Higher spurs like Indian Ridge and Dewey Bald (Garber Quadrangle) and Compton Ridge (Table Rock Dam Quadrangle) interrupt the general plane of the valley-contained hilltops.

The total descent of U. S. Highway 65 from Stutts to Branson is 700 feet along the interfluve separating Roark Creek and Bull Creek drainages. In the first eight miles, the highway grade descends 136 feet (from 1,436 to 1,300 feet). Within another mile, it drops 200 feet to 1,100 feet, in another two miles 100 feet to 1,000 feet, and in the next mile and a half it reaches 900 feet A.T. The first eight miles are on the profile slope of the wide valley of ancestral White River on the Springfield peneplain. The descent of 200 feet in a mile represents the break where the top of the Ozark cycle's valley slope cuts the older surface and is stratigraphically comparable to the Eureka Springs escarpment. Descending from 1,100 feet A.T., the highway leaves the crest of the interfluve and takes a diagonal course down to altitude 1,000 feet. This summit at 1,000

feet is presumed to be a record of the Ozark cycle's White River valley floor.

A better record of that geomorphic surface is found along State Highway 76 between the Branson Airport and a drive-in theatre a few miles west of Branson. The interfluve followed by this highway separates Roark Creek from Fall Creek, and its nearly flat summit for more than two miles (Garber Quadrangle) lies between 1,020 and 1,040 feet A.T. Post-Ozark trenching accounts for the remaining descent to the river (Table Rock Reservoir level is 916 feet A.T., and Lake Taneycomo is 700 feet A.T.).

Hershey probably viewed the White River's geomorphic record from this highway route when he identified his "duplex valleys."

Nowhere on the Branson or Garber Quadrangles traversed by this profile is there a suggestion at 1,100 to 1,300 feet of a retreating cliff or bluff such as the concept of pedimentation would require. The spurs of summit ridges surviving from the old valley floor, such as Indian, Chestnut, and Beachler (Day, Garber, and Garrison Quadrangles) are well developed at those altitudes *away* from the main White Valley (i.e. *facing* the Springfield peneplain *upland* remnants). They bespeak tributary valleys of Bear, Bull, and Roark Creeks at that earlier stage.

The almost incredible convolutions of the present White River meanders are not inherited directly from the Ozark strath but, like comparable meanders of the Gasconade, Osage, and other northern slope rivers, have descended from a later strath in all these valleys.

The Dickens Ozark upland projects southward as a peninsular hill between White River and Beaver Creek (Forsyth $7\frac{1}{2}$-minute Quadrangle). The summit area at the south end is scarcely 100 feet lower than Dickens, and although less than a mile from the junction of the two streams, that junction is more than 300 feet below this peninsular tip. This slope from Dickens is the profile of the Ozark peneplain's White River valley slope. The 980-foot summit at the peninsular's tip is a remnant of the Ozark White River's valley bottom, a fragment of the strath in question. It is 10 miles downstream from Branson where the same feature is about 1,020 feet A.T., a present-day gradient of four feet per mile

This tracing of the Ozark peneplain westward from the Embayment to the Eureka Springs escarpment has involved a different approach from that used in study of the dome's northern slope. Instead of following valleys and divides, the route followed has crossed them at high angles. Yet the resulting interpretation has been the same. The most striking differences have been that, on encounter with higher margining land at the extreme west, the Ozark surface ceases to dominate divides and grades into much dissected straths which are old valley cross profiles of a major river (the White) that attained base level during the Ozark cycle but never reduced its margining upland to peneplain slopes.

In this survey of the Salem section's contributions to geomorphic history of the Ozarks, two widely distributed and significant

features have not thus far been mentioned. They bear especially on the question of peneplanation versus pedimentation (pediplanation) for the Ozark erosion surface. One is the ever-present upland residual soil, the other is the abundance of caves in calcareous formations of the subprovince.

Variations in thickness of regolith mantle throughout the Ozarks are difficult to explain in precise terms. Some highway cuts may show the residuum to be the full depth of excavation, 30 feet or more, while in adjacent cuts with comparable altitude, height of hill, slopes, and rock involved, the bedrock may carry only a few feet of overburden. Some contacts may show deep and extensive penetration of the red clay along crevices. Elsewhere, masses of rock appear to be entirely surrounded by the waste of long-continued weathering. Some cuts may show "ghost" outlines of former stratification, contorted by differential settlement. Sandstone strata overlying calcareous rock may be fairly intact but show an anticlinal form fitting the outline of the hill. No consistent differences between the waste accumulations on Springfield and Ozark surfaces have been recognized.

The soil is typically pedalfer, mostly a red clay with abundant chert fragments and is indubitably the insoluble residue from many feet of once-overlying limestone or dolomite. Its thickness varies of course, but many roadcuts across hilltops, 10, 20, even more than 30 feet deep, find only regolith. Wells have reported 150 feet of residuum in some lower places on peneplain remnants, presumably thickened there by accumulations of slope wash. The red clay soil is the result of down-wasting. It is quite unlike the mantle of coarse waste which pedimentation stripping leaves, and the only possible escape by the proponent of pedimentation from this conclusion is to interpret it as made later under climatic conditions more favorable for the weathering that made it.

The numerous caves of the Salem subprovince are likewise difficult to explain as arid climate products. They contain a record which refutes the idea that humid epochs may have preceded or interrupted times when pedimentation conceivably occurred. Their record is of a long pause after cave excavation, during which they were largely, some even completely, filled with an unctuous red clay that could have come only by downward infiltration of the finest fractions of an overlying residual soil. Cave-making in the Salem section occurred under phreatic conditions (Bretz, 1953, 1956) when an adequate overlying relief produced a deep circulation from its uplands to its lowlands. The passing of these conditions, recorded by the clay fillings, came about as that relief was reduced and the subwater table circulation thereupon died away. The reduction was the consequence of down-wearing, accompanied by production of a deep mantle or residuum, source of the gritless red clay of the caves. Pedimentation has no place in this sequence. Only peneplanation could bring about cessation of cave-making circulations and inauguration of the epoch of cave filling. By the same token, no noncyclic erosion can produce the long-con-

tinued stagnation of a phreatic circulation that is recorded by these Ozark cave clay fills.

Some Valleys of the Salem Subprovince

Hack (1957, p. 90) argued that "the rate of removal of bed material [stream load] from the channel at any place diminishes" as stream gradients flatten from continued erosion toward a stable base level. Under this condition, he argued, chemical weathering on contributing slopes would become relatively more important than mechanical, and interstream divides would become "blunted" from the "knife blade" shape which would result from stream erosion alone. At such stage "the products of chemical weathering form an appreciable part" of stream load (Hack, 1957, p. 90).

To be acceptable for the Ozarks, "dynamic equilibrium" must explain how the blunting of earlier "knife blade" ridges can have produced the mile-wide erosional plains on interfluve summits that are high above present base level and are margined by steeply walled river valleys and their vigorously headward eroding ravines. It must explain how chemical weathering on the summits has amazingly outrun mechanical weathering on the steep, even cliffed, margining valley walls. The noncyclic hypothesis completely fails to account for these features.

Clearly decipherable histories of major river valleys draining both north and south slopes of the Ozark topographic dome begin with the drainage ways inherited from the Ozark peneplain. There are enough remains of the Ozark original slopes to show that the peneplain was not a flat on which "the streams wandered—somewhat aimlessly" (Fenneman, 1909, p. 53). Minor interfluves that lead off the main divides into today's larger valleys repeatedly carry a profile surviving with little alteration from the slopes of such major valleys on the peneplain itself. They were shallow, wide open, and broad bottomed valleys. Approximate original gradients are determinable only where their courses were tangential to the domal warping that followed their making. Because the outline of the post-Ozark doming so nearly coincided with that of the earlier post-Springfield uplift, radial courses were obviously steepened. Much has already been cited to show this and need not be repeated. Four north slope river systems will be considered in enough detail to make clear their late histories.

Gasconade River Valley

The Gasconade River's headwater creeks take drainage northward from 100 miles of length along the dome's main divide, a stretch that involves one of the re-entrant angles in the zigzag already noted. Monadnocks along this 100 miles attest the inheritance of this course from a pre-Ozark divide. The peculiar southward extension of the Gasconade's territory is not an invasion of an earlier, longer, southern slope of the dome by headward erosion

during the Ozark cycle. If that divide migrated at all during this cycle, it was shifted northward because of the higher gradient creeks of Current, Eleven Point, and White Rivers.

Another peculiar thing in the Gasconade drainage pattern is a "waist line" only eight miles wide in the latitude of Lanes Prairie and Vienna. The immediate cause of this constriction is the Lanes Prairie remnant of the Springfield peneplain on the east and, only 15 miles farther upstream on the west side, the Helm-Dixon group of monadnocks. Why these Springfield records have survived so far down the north slope of the divide and so close together with a trunk line river between is a question not readily answered from the topography alone. If structural or stratigraphic factors are involved, the details have not yet come to light. A somewhat comparable problem exists along the Mississippi Valley north and northeast of Cape Girardeau (see p. 74) although a plausible solution there can be suggested.

No Ozark river excels the Gasconade in wealth of entrenched meanders, although they are poorly developed in the compressed valley stretch just noted (Vienna Quadrangle, Maries County). Upstream on the cornering Waynesville Quadrangle and on the Richland Quadrangle, next upstream, the tortuous writhings of the river are enclosed by 200- to 250-foot cliffs on the outside of river curves and by strongly ravined slopes on the concavities outlined. These meander-enclosed peninsulas average a little less than two miles in axial (longitudinal) dimensions, and nowhere do their

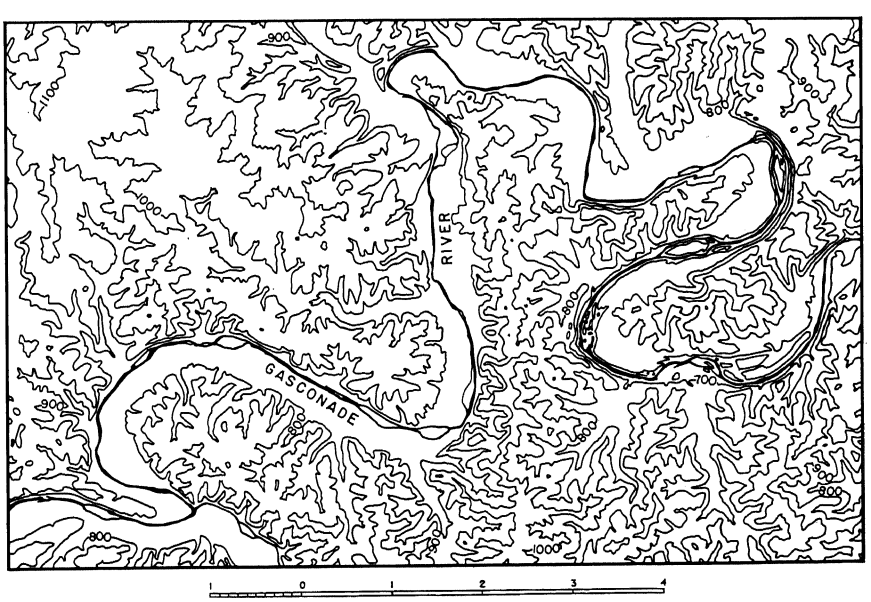

Fig. 33. Map showing asymmetry of meander outlined peninsulas; Waynesville Quadrangle.

tops stand 300 feet above the river, thus, they are much below the Ozark peneplain trace. All of them inside a well-proportioned meander have an asymmetrical ravine system whose local divide is close to if not actually on the brink of the upstream cliff against which the meander impinges. Thus, most ravines head almost within sight of the top of the cliff, yet flow away from it. In a few cases, ravine heads have been lost by cliff recession, leaving notches in cliff summits and shallow gaps across the peninsulas. Such ravines as descend the cliffed side are rarely a fifth as long as those on the relatively gentle back slope (Fig. 33).

Yet, as shown by axial profiles, there has been very little meander enlargement since the Gasconade flowed at the level recorded in the peninsula summits. Not more than the terminal fourth or fifth of their lengths is the result of slipoff in 200 feet of deepening. They are only slightly ingrown meanders and are largely inherited from a Gasconade Valley strath whose remnants are now found only in the summits of the peninsulas (Fig. 34).

Fig. 34. Gasconade Valley strath seen from Potts on U. S. Highway 50, Linn Quadrangle. The observer is 175 feet above the strath and 325 feet above the river floodplain. The main skyline is the Ozark peneplain above which rises Lanes Prairie monadnock carrying the Springfield peneplain trace. R. Zangerl, photo.

But what explains that consistent asymmetry in cross section? Imaginary restoration of the last 100 feet eroded in deepening would require some restoration of a cliff face, thus moving it out into the present river channel's location. Therefore, the river of that time, 100 feet higher, was somewhat back on the gentler and now ravined slope of the next peninsula upstream. Repetition of this theoretical reversal of the river's deepening will yield a low peninsula of symmetrical cross section. The asymmetry has developed because these inherited meanders, instead of becoming larger,

have shifted bodily downstream. The slipoff slopes are not so much on the peninsula tips as they are on the downstream side of each well proportioned peninsula!

This asymmetrical character, diminishing in size, is continued far up the Gasconade (see Big Piney Quadrangle, Pulaski and Texas Counties) and is accompanied by longer terminal slipoff slopes and a proportionately wider flood plain. Downstream past the constricted place, it reappears on the Morrison Quadrangle (Osage and Gasconade Counties). Throughout the full length, the restored plane on which the meandering took origin lies 100 to 150 feet lower than the trace of the Ozark peneplain in any one cross section. Width of this old valley floor appears to have been but little more than that of the largest compound meanders, like the group in central Waynesville Quadrangle. The old valley was definitely narrower between Lanes Prairie and Helm-Dixon Hills.

Here, then, is a clear record of a double valley, the older one developing a wide flood plain with striking meanders which it bequeathed to its successor. These peninsulas, if unravined, would present an outstanding strath more than half way up from the present river to the Ozark peneplain trace.

This is presumably the "younger peneplain" that Marbut reported in 1904. His correlation with Hershey's outer valley along White River is in error because that dissected strath is itself of Ozark age.

The valley bottom level at the stage recorded by the post-Ozark strath is uniform in width; uninterrupted by peninsular projections inside meander loops. The river thus must have reached base level and for a long time have devoted its energy to shifting meanders and trimming off such peninsulas as may have developed during the previous valley deepening. This is the reason for saying that the entrenched meanders of today are inherited from the strath stage and are not descended from peneplain meanders.

In this old valley floor of the Gasconade River is the record of a long pause during post-Ozark uplift of the dome; therefore, of two separate diastrophic movements. The Gasconade's dissected post-Ozark strath has a gradient somewhat less than that of the present river, although presumably steepened by the later movement.

Scrutiny of the topographic maps noted will show another consistent feature of the Gasconade Valley. For upwards of 100 feet above the river, all slopes are steepened, many are even cliffed. Some of the tiny interfluves between ravines on the gentler downstream sides of the meander-enclosed peninsulas have cliffed termini. The Roubidoux sandstone in which this minor cliffing occurs tends to have more rounded slopes under weathering attack than does the overlying Jefferson City dolomite. Yet here, it has steeper slopes. Such are taken to record a still more recent and slight rejuvenation of the river.

Bourbeuse and Meramec River Valleys

If the geomorphic history read from the Gasconade Valley is correct, it must be found in other river valleys of the north slope of the dome. Bourbeuse River's intricate meandering (Gerald and Union Quadrangles, Gasconade and Franklin Counties) is associated with the same features; so are those of the Meramec (Steelville and Leasburg Quadrangles, Crawford County). Both show more development of the original meanders toward the enclosed type, and both lack a marked nipping of the tiny peninsular interfluves. But the dissected straths are as conspicuous as those along the Gasconade and are equally independent of rock control.

No Missouri river traverses more formations or more tilted structures in the same short mileage than does the lower Meramec across southern St. Louis County. The disturbed belt east of the Crystal escarpment contains shale, sandstone, limestone, and dolomite formations ranging from Jefferson City Ordovician to middle Mississippian. To this lithologic diversity and the structures involved may be ascribed the variations in character of this lower stretch of the Meramec in its crossing of Manchester and Kirkwood Quadrangles (St. Louis County). The valley possesses no suggestion of meander-enclosed peninsulas. However, the Pacific Quadrangle (Jefferson County) has two excellently developed peninsular projections, one of which has become a "lost hill".

Osage River Valley

Ozark peneplain remnant flats on northeast Rocky Mount Quadrangle and the north central part of Stoutland Quadrangle (Camden and Laclede Counties) are respectively 900 to 1,000 and 1,000 to 1,100 feet A.T. Between them is the Osage Valley, 400 to 500 feet deep. Peneplain slopes down toward the valley are readily identified on the minor interfluves between the Osage's tributary ravines on all the 7½-minute quadrangles involved in this cross section (Hugo, Camdenton, Green Bay Terrace, Gravois Mills, Proctor Creek, Lake Ozark, Sunrise Beach, Bollinger Creek, Bagnell).

The bottom of the valley of peneplain time is preserved today in summits of some of the peninsulas among the tight curves of the river. Its altitude averages 900 to 940 feet A.T. A narrow but continuous cross-sectional stretch of the old valley floor is still intact on the ridge followed by State Highway 5 from the Lake of the Ozarks nearly to the north edge of the Sunrise Beach Quadrangle. Thence northward, the ridge crest becomes a profile of the peneplain's *valley slope* and is followed by Supplementary Road H on Proctor Creek Quadrangle (Morgan County) up to the very little modified original divide on north central Gravois Mills 15-minute Quadrangle (Morgan County, see Fig. 16). This remarkable ridge has already been noted (p. 49).

The Osage possesses but few adequately preserved flat-topped portions of an outer valley floor which is incised in the peneplain

trace and in turn is deeply cut by the modern river. But its reality is obvious in the summit accordances seen from a hundred viewpoints along the lake. One good remnant of this outer valley floor is traversed by State Highway 134 (Lake of the Ozarks State Park) in Toronto Quadrangle (Camden County) where flat-topped spurs with 840- to 860-foot altitudes abut rather sharply against a notched ridge at the peneplain's valley bottom level of 900 to 940 feet (Fig. 35). Another is the upland area about Damsel, on north central Camdenton Quadrangle (Camden County) at 840 to 880 feet. Bagnell Quadrangle also has a well shown remnant in the northeast corner at 840 to 880 feet, and most of the two peninsulas within the loops of the striking S curves of the inner valley in cen-

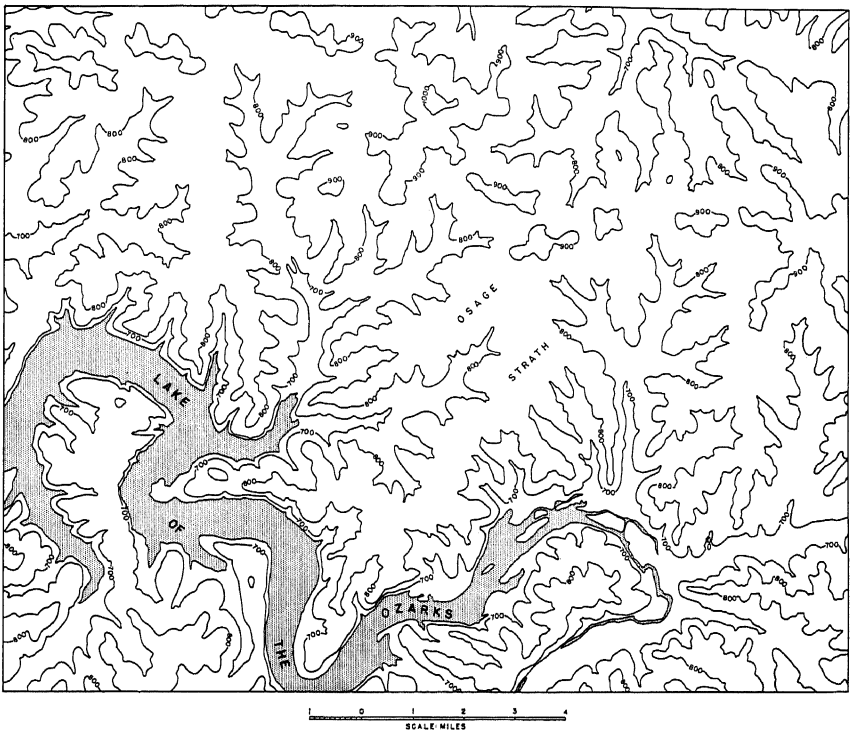

Fig. 35. Map of part of Osage outer valley floor, Toronto and Bagnell Quadrangles.

tral Lake Ozark Quadrangle (Morgan and Camden Counties) have been trimmed down to 800 to 840 feet. Marbut (1907) reported rounded chert gravel on the outer valley floor in Morgan County 250 feet above the river or somewhere between 840 and 900 feet A.T.

The extensive dissection already noted makes it difficult to map the old valley floor upstream although, again, its presence is obvious in profile views in the field. The Iconium Quadrangle (St. Clair County) west of the head of the lake, has definite Ozark peneplain

remnants well back from the river at 930 to 960 feet and the Valhalla Quadrangle immediately to the north has truncated summits of peninsulas within tight curves of the Osage River at 800 to 850 feet, approximately the same altitude as those near Bagnell Dam, 128 miles distant along the meander route.

If identifications are correct, these altitudes indicate that the peneplain trace *descends westward, upstream* as Tarr (1924) believed, but that the outer valley remnants record almost no gradient. One concludes that upwarping in the local bulge on the northwest flank of the Ozark dome was repeated on a smaller scale in the later uplift.

It is interesting to note that the cross sectional asymmetry of the peninsulas among river loops possessed by the Gasconade, Meramec, and Bourbeuse Rivers is equally well shown along the Osage. An earlier hypothesis was that downstream migration of the meander loops on these three rivers was because of down tilting along the valley lengths. The Osage route, however, was uptilted in the downstream direction and has so remained through all subsequent events.

As in the three rivers noted, it seems clear that the entrenched meanders of the Osage date from the partial cycle recorded in the wide, post-Ozark, outer valley, not from the Ozark peneplain.

Traced upstream, westward, the gorgelike character of the inner valley decreases until it vanishes in St. Clair County. Farther upstream, the wide, shallow, flat bottomed valley has abundant active meanders, crescentic lakes, and deferred tributary junctions in striking contrast with the Lake of the Ozarks stretch. This portion will be discussed in a later section (see p. 107).

The Osage-Missouri junction is 70 miles downstream from Bagnell Dam and eight miles downstream along the Missouri from Jefferson City. Hershey's perceptive eye saw a "duplex valley" at Jefferson City which he correlated with the White River strath already noted. Seen from viewpoints on summits north of the river (near Clayville School along U. S. Highway 63, and near Holts Summit on the old route of U. S. Highway 54, Jefferson City Quadrangle), the floor of the outer valley along the Missouri is a conspicuous feature, apparently as much dissected as that along the White. But it is the homologue of the post-Ozark strath of the Gasconade, Bourbeuse, Meramec, Osage, and other rivers of the north slope of the dome, whereas the White River feature is itself at the Ozark base level, down in a valley in the dissected Springfield peneplain. Minor interfluves with flattish summits downstream from both Bagnell Dam and Jefferson City record the strath at heights of about 200 feet above the rivers. The Ozark peneplain trace lies 100 to 150 feet higher.

The entrenched meanders of the Gasconade, Bourbeuse, Meramec, and Osage Rivers involve grave difficulties for the noncyclic hypothesis of "dynamic equilibrium". These meander patterns are not structurally controlled, like those which Hack (1959) described for the Shenandoah River. They must record very low gradients

only a little above base levels and, with their accompanying straths, must also record a recurrence of uplift to rejuvenate those drainage routes. If one refuses to accept this, the only feasible explanation for the meandering patterns is that they developed on Pennsylvanian rocks, on the gentle slopes provided by the earliest uplift stages of the Ozark dome. Then one must consider that they have persisted while these rivers have deepened their valleys for many hundreds of feet, in some cases down into Cambrian rocks. By such a view, uplift of the dome must have been continuous, a view impossible to harmonize with the nonstructural straths in all the major valleys.

Significant details of the Missouri Valley's history are treated in a later section.

SPRINGFIELD PLATEAU*

Definition.—Fenneman (1938, p. 652) defined this section as "that part of the Ozarks which is underlain by rocks of Mississippian age". He clearly stated that it has a peneplaned surface truncating structures and formations. Apparently he favored Hershey's idea that the peneplanation occurred when the Boston Mountains peneplain was made and that it remained at base level while the Bostons were later uplifted. Fenneman (1938, p. 660) also considered the Ozark peneplain "as genetically the same as the Springfield upland". By his view, the Eureka Springs cuesta, a much elongated monadnock of the Ozark cycle, carries no summit record of any earlier peneplanation.

The present study departs somewhat from these interpretations, holding that there is a record of a pre-Ozark peneplanation on the summit of the great scarp at intervals from the Arkansas line to the Kansas City region and that this earlier base level (Springfield), as well as that of the Ozark cycle, is identifiable on the flanks of the Bostons.

Relations with Salem Plateau and Ozark peneplain. — The steep eastern face of the Eureka Springs cuesta (Fig. 36) and, to the eye, the almost imperceptible gradient of interfluve summits descending the cuesta's western slope are likely to give the westbound traveler the impression that the Springfield Plateau is a step above the Salem Plateau. The high eastern marginal portions of the Springfield do indeed stand in places 100 to more than 200 feet above adjacent Salem surfaces. Relief of this order however is limited to places where residual flats of the older Springfield (Dodgeville) peneplain still linger just back of the scarp brink and overlook Ozark (Lancaster, Calhoun) peneplain remnants to the east. Actually, the main divide of the province, which carries the

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The Missouri Geological Survey does not include the Springfield Platform under the general term of "Ozarks". But its geomorphic history is an important part of the entire region's physiographic evolution and, like the Shawneetown Ridge of Southern Illinois, the Lincoln Hills north of Missouri River, the Boston Mountains of Arkansas and that part of Fenneman's Osage Plains (the Prairie Plains) in Missouri, it will be treated in this study.

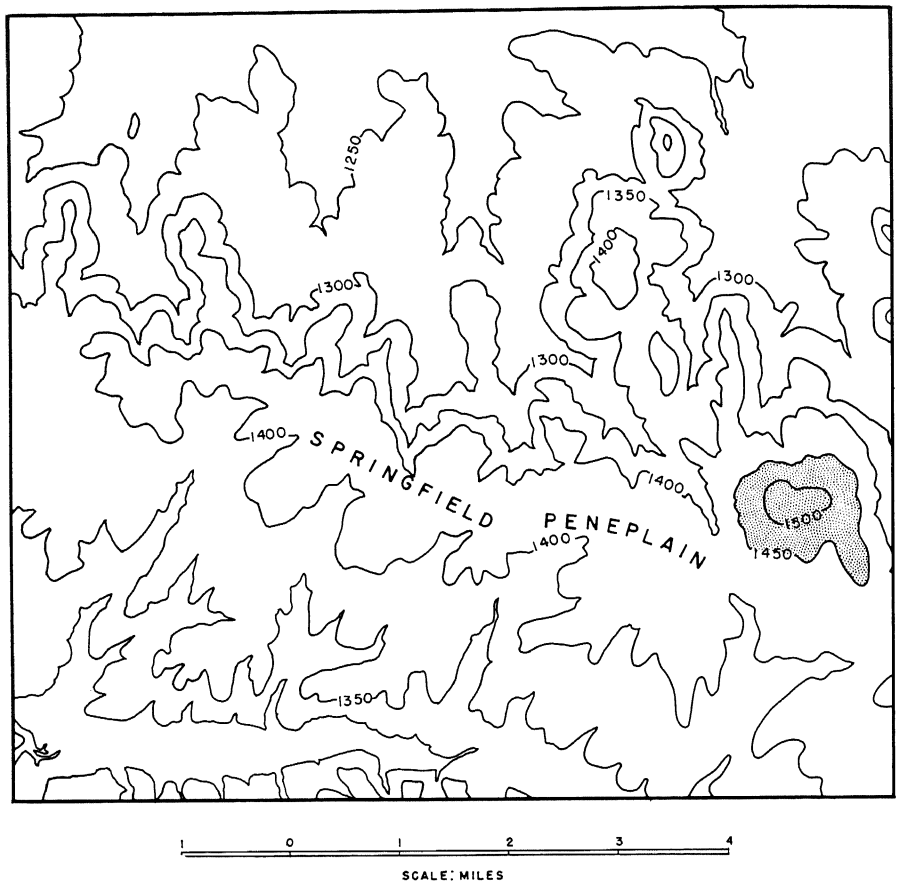

Fig. 36. Map showing Eureka Springs escarpment, Springfield peneplain, and a monadnock (shaded area) in the Bassville Quadrangle.

Ozark suface, holds the 1,400-foot altitudes with scarcely a break eastward to the St. Francois Mountains while the approximately 1,600-foot altitudes of the narrow fragments of the Springfield peneplain on the cuesta summit gradually descend downdip westward with little change in character and blend into Ozark peneplain surfaces at about 1,400 feet. Continued westward, the Ozark peneplain trace descends to 1,200 feet and then to and below 1,000 feet before the Oklahoma and Kansas state lines are reached.

This is the warped surface at the western end of the Ozark dome. Interfluves between its west-flowing streams have steeper longitudinal profiles than those already examined on the dome's northern slope. Fenneman was right in considering that most of the Springfield Plateau records the Ozark peneplain. There is a considerably larger proportion of that erosion surface remaining in the drainage areas of Shoal Creek, Spring River, and the headwaters of north-flowing Osage tributaries than anywhere else in

Missouri. This is because the longer courses of these streams have forbidden the deep and intense dissection which characterizes the Ozark peneplain east of the Eureka Springs escarpment. Only White River drainage in the extreme southwestern counties has a favoring short course to the Mississippi so that its tributaries, working in a high portion of the uplift, have produced the most rugged country of the Ozarks (Cassville and Shell Knob 15-minute Quadrangles and the 7½-minute quadrangles that replace the old Forsyth 30-minute Quadrangle).

Although this western slope is held up by Mississippian and Pennsylvanian instead of Ordivician formations, rock control is not the determining factor.

Stream derangements.—These Springfield flat summits along the escarpment brink, constituting a divide today, are segmented remnants of a divide on the Ozark peneplain just as are the monadnocks in the long row connecting the St. Francois Mountains with the Eureka Springs escarpment. Paucity of evidences for stream piracy indicates that, in retreat of the scarp, the more favored streams of the steeper eastern slope have captured nothing more from the western slope than additional runoff areas. The only drainage patterns suggesting piracy are afforded by the courses of Flat Creek in Barry County and Muddy Fork in Barton County.

Flat Creek (Cassville, Shell Knob, Monett, Aurora Quadrangles) heads on Springfield surfaces south of Cassville, and its fairly straight north-by-northeast course for about 15 miles is a valley bottom of the Ozark cycle, bounded on both sides by Springfield-topped interfluves. Near McDowell (Monett Quadrangle) the stream's course describes a right-angled turn toward the east, and the valley narrows as the creek enters a post-Ozark valley that is followed thence to the James. If piracy has occurred at this angle, some traces of a former course northward and presumably northwestward should exist. The topography gives no hint of this, and the only expectable evidence, therefore, would be old stream gravel on the Springfield peneplain remnants.

Muddy Fork flows northwest for more than 20 miles to an acute angled turn southward, near Lamar, whence it flows southward for another 20 miles. The northwest course is semiparalleled by all other streams in this region, reflecting an original course on an early upwarping of the Ozark dome, and all enter the Osage-Missouri system. But Muddy Fork water flows to Spring River and thence to the Arkansas River on the opposite side of the dome. Interfluve summits fall into the trace of the Ozark peneplain and any piracy that may have occurred here (first suggested by Marbut) is subsequent to the post-Ozark uplift. But this seems impossible as a consequence of that very gentle deformation in this region. The suggested piracy in Flat Creek can be ascribed to headwater erosion on the Eureka Springs scarp face, but any Muddy Fork piracy must have had a different cause.

A northwest projection of the Chesapeake fault (Lawrence County, Halltown Quadrangle), as shown on the State Geological Map, closely parallels the first 10 miles of Muddy Creek's northwest course. If this projected line is continued as far as the acute angle above noted, still lying closely parallel to Muddy Creek, it follows an interfluve separating Muddy from headwaters of Horse Creek, the two subparallel creeks being only four to six miles apart. In about the latitude of Muddy's acute angle, the course of Horse Creek describes a right-angled turn in almost exactly the opposite direction. Precise explanation of this curious drainage pattern eludes us, although a line of deformation marked by the Chesapeake fault is very probably involved.

A gravel deposit in Newton County, nearly west of McDowell in Barry County is too distant and too much out of line to be tied in with any former course of Flat Creek. It might be another record of a shifted Shoal Creek. Twelve feet of sorted and stratified gravel of worn chert pebbles is exposed here in a roadside pit along State Highway 86 in the north half of Section 30, T. 25 N., R. 29 W. (Ritchey Quadrangle) at an altitude of about 1,240 feet; an Ozark level bounded in part by Springfield peneplain remnants (Oliver's Prairie). The depositing stream flowed either northwest or southeast. The gravel is indubitably a product of a larger stream than any now in the district, but reconstruction of this earlier drainage and any suggestion for the cause of its derangement can only be guesswork. It does record the fact that such derangements have occurred well west of the Eureka Springs scarp in post-Springfield time.

Another problematical occurrence of undoubted stream gravel on the Springfield Plateau is a few miles north of the City of Springfield in the central part of Section 4, T. 29 N., R. 21 W. (Bassville Quadrangle) and all of nine miles west of the Eureka Springs scarp. The altitude is between 1,270 and 1,290 feet, nearly as high as Ozark peneplain remnants nearby and, thus, is imputable to a stream on that surface, presumably the South Dry Sac now trenching 150 feet into that plane a short distance away. The gravel is fine-textured near the bottom of the section, considerably coarser toward the top.

A problem here is the obviously impossible amount of rounding of chert pebbles in the few miles they could have traveled along the earlier Sac from the present site of the divide. This feature can be explained by hypothesizing an adequate westward retreat of the scarp face and, thus, a comparable shortening of the original Sac. A windgap notch in the scarp about 25 miles distant, earlier noted as on the Mansfield NW Quadrangle, (see p. 47) might be considered a record of an Ozark cycle shortening of the Sac.

Another problem lies in the occurrence of a few highly polished but unrounded pebbles in the fine basal gravel of this deposit. The polish extends into concavities of the pebble shapes.

Since all the fine gravel is of chert of similar texture, it appears that the glossy surfaces were made before these polished

pebbles entered the aggregate. Similar highly polished but angular small chert pebbles have been found in the sand of a small "boiling" spring of the Ozark country, obviously the product of continuous agitation in the sand. It was equally apparent that some pebbles could escape from the spring to the nearby streamway to become mingled with unpolished pebbles. Perhaps this procedure has occurred during deposition of the old gravel near Springfield.

The striking contrast between smoothly rounded, polished pebbles in older gravels of the Ozarks and the lack of such characteristics in modern stream gravels constitutes a problem for which we have no definite answer. The problem is well pointed up by a deposit on the lower slope of the Big Piney Valley on Devils Elbow Quadrangle (NW¼ SW¼ SE¼ sec. 24, T. 36 N., R. 11 W.). It is a mixture of unworn chert pebbles and very well rounded and polished pebbles with associated layers of sand, sandy clay, and clayey silt. Obviously two very unlike experiences with streams are recorded. The worn fraction of the gravel is certainly not a product of the Big Piney during the last 75 feet of vigorous valley deepening. These worn pebbles are presumed to have been washed in from peneplain upland deposits.

The failure of modern streams adequately to round their transported chert gravel can be imputed to: 1) brevity of experience in the stream, 2) turbulence with consequent fragmentation, and 3) frost splitting. If the polished pebbles are from old peneplain gravels, they should date back to some time in the Tertiary when, presumably, the region had a frost-free climate. Yet they have escaped soil frost fragmentation during the Pleistocene.

The polish may be subsequent to the rounding, may be a record of abrasion from compaction in a clay or silt matrix before the Big Piney of the present erosion cycle obtained them.

Less of a stream derangement and more like a simple stream shifting is recorded by worn chert gravel on a hilltop in the south-central part of Section 6, T. 39 N., R. 29 W., Bates County. It is 15 miles by road southeast of Butler and less than 10 miles from the Osage River. The district has characteristic Ozark peneplain topography at about 950 feet A.T., is but little dissected by the Osage system's valleys, and bears a monadnock group whose flat summits stand 50 to 75 feet higher and grade off into late mature Ozark topography. The gravel is strewn over the largest summit and on several acres in the south-central part of Section 6, T. 39 N., R. 29 W. It has been removed in quantity for road making. What now is a hilltop certainly once was a valley bottom. This is the only known occurrence of indisputable stream gravel on any Springfield peneplain remnants.

Seven miles distant, in Section 21, T. 38 N., R. 30 W., another chert gravel is found on a hilltop at 950 feet, the Ozark peneplain altitude.

Character of dissection.—The western flank of the Ozark dome, lacking a major deep marginal river valley, is but little dissected

as compared with the north, east, and south flanks. Recognition and differentiation of successive erosion surfaces on this flank is a more difficult task than elsewhere in southwest Missouri because the striking contrast between Ozark and Springfield peneplains east of the escarpment is scarcely approached on the Eureka Springs cuesta's back slope. Differentiation is best obtained along the larger valley-ways of Elk River, Shoal Creek, and Spring River. Even there, interfluves have largely lost the older surface except close to the summit of the cuesta divide. On this, it consists of a great ragged curvilinear pattern strung along the cuesta top from Arkansas well over into Osage drainage.

Not alone are there long fingers of the Ozark surface reaching back up into the valley heads of the three streams noted on the gentle western slope of this divide; there are also embayments in the steep eastern face at the Ozark level, and some have been cut through to join the west-draining valleys. This is particularly true farther north along the gradually lowering scarp. Such saddle-like places are not as low as the Ozark peneplain and are considered to be late mature Ozark topography or transitional areas between the Springfield and Ozark peneplains. None shows good evidence of origin as a water gap.

The eastward bulging convexity of these Springfield uplands carries the highest altitudes of both peneplains, the Springfield remnants being above 1,600 feet in northwestern Douglas, southeastern Webster, and southwestern Wright Counties. Altitudes of 1,740 feet are reached in both Webster and Wright Counties. This high tract is hublike to streams that radiate spokewise toward all points of the compass. Post-Ozark differential uplift of the area is probably of small consequence in determining its altitudes.

Monadnocks.—This former divide of the Springfield peneplain carries almost no monadnocks or late mature remnants. It appears to have been reduced to base level more completely during the Springfield cycle than the east-west divide between St. Francois Mountains and the present scarp was during the later Ozark cycle. In Arkansas, however, that apparently anomalous upland of the Boston Mountains stands high above the Springfield peneplain although composed of no more resistant (Pennsylvanian) formations than the Mississippian rocks holding up the Springfield remnants in Missouri.

A monadnock of unusual character near Scholten in Barry County (Aurora Quadrangle) has a summit altitude of 1,540+ feet, 100 feet above the trace of the Springfield peneplain. It is a nearly north-south ridge, prominent in its southern portion but broadening and decreasing in vigor of expression northward toward Aurora. Road cuts and pastured slopes reveal a Pennsylvanian conglomerate of well-worn chert cobbles on the southern portion but only angular Burlington cherts on the summit and west slope a mile or two to the north. This Scholten monadnock is interpreted as an unusually pronounced pre-Pennsylvanian hill whose

residual cherts were worn and beaten by Pennsylvanian waves into a very local, beach cobble gravel. Hershey noted this hill as a monadnock composed of both Mississippian and Pennsylvanian rock.

Traced northward, the Scholten hill grades into the late mature topography of a Springfield divide, conspicuous about Aurora, Marionville, Logan, and Chesapeake State Park. This interfluve loops a mile or so over into extreme western Christian County (Halltown Quadrangle), there being a three-way divide separating headwater streams of the Osage, Spring, and James-White systems. Altitudes here are somewhat lower than well-developed Springfield peneplain remnants on the southern arm of this divide, apparently because of slight post-Springfield warping.

A sharply circumscribed monadnock on the eastern edge of the Bassville Quadrangle (Greene County) stands on the very brink of the Eureka Springs scarp (Fig. 37). The summit is 1,518 feet A.T., nearly 100 feet above closely adjacent Springfield peneplain flats and 250 feet above Bassville (1,260 feet A.T.) in the Pomme de Terre Valley a mile and a half to the north. Ozark peneplain remnants north of Bassville are 1,300 to 1,320 feet A.T. On the northern edge of this quadrangle is Fairgrove Mound (Fig. 38), an outlier of the retreating Eureka Springs escarpment still rising to the Springfield peneplain trace and surrounded by slopes left from dissection of the Ozark peneplain by the north-flowing Little Pomme de Terre.

The scarp brink running northwest from the Bassville monadnock is an interfluve separating the Little Pomme de Terre from the northwest-flowing Little Sac on the back slope of the cuesta. The monadnock (unnamed on the Bassville Quadrangle map) thus is a remnant of a pre-Springfield surface and, by the interpretation of this paper, is an attenuated residual, like the Scholten monad-

Fig. 37. Bassville monadnock. Foreground is a portion of the Springfield peneplain above which the mound rises 100 feet. R. Zangerl, photo.

Fig. 38. Fair Grove Mound. The summit records the Springfield peneplain trace. The foreground is an undissected Ozark peneplain remnant, a flat divide for two tributary creeks of the Little Pomme de Terre River. The mound rises 140 feet above the plain. R. Zangerl, photo.

nock, of a formerly existing Boston Mountains peneplain across the cuesta trace.

The existence of this Bassville Quadrangle hill, perched on the high edge of an erosion surface that overlooks a lower and younger one, raises again the question of peneplanation versus pedimentation (pediplanation). There are but two places on the hill where small out-running spurs provide any concavity in its slopes, any marked flattening of basal slope. Like all other monadnocks in the Ozark province, this hill lacks the cliffed free face and the lower detrital slope which the concept of pedimentation asks for in any pronounced retreating slope.

The Bassville hill has only one indentation that can be considered a product of concentrated water work. Apparently, it has suffered only slope wash erosion and transportation. Yet it certainly has been wasting away since dissection of the Springfield surface began. Though its slopes are only about half as steep as those on the escarpment face, they are several times as steep as those on adjacent Springfield interfluve summits. Granting that post-Springfield time has seen reduction of both height and area of the hill, the persisting steepness is a challenge. One suspects that the slopes of Ozark monadnocks have been retreating parallel to themselves without the free face and detrital slope ever existing. The gentling procedure of the Davis concept of slope wasting is not recorded, and a modified picture of pedimentation may be in order. To make the entirety of the Springfield surface by this

process, however, would seem to demand far more in the way of prominent residuals than the region possesses.

Relations with Central Lowlands province.—The northwestern boundary of the Springfield Plateau, as drawn by Fenneman (1938, pl. 6) follows no natural feature of topography or drainage. It is essentially an arbitrary line through Lamar (Barton County), Osceola (St. Clair County), and Sedalia (Pettis County) to the Missouri River about 10 miles upstream from Boonville (Cooper County). If any line is to be used, nothing better can be done because the Springfield subprovince of the Ozarks grades down almost imperceptibly into the Prairie Plains, Osage section of the Central Lowlands province. Consistency with the definition of the Springfield Plateau as "underlain by Mississippian rock", however, is shown in Fenneman's Figure 177 (1938) on which a long, narrow "structural plain" extends northward from the Osage to the Missouri to fit the pattern of Mississippian rock on the map. There is little in the topography to recommend this, but it does provide a transition zone between Ozark and Central Lowlands provinces.

Relations with Ozark peneplain on the western slope.—If one visualizes a restoration of the back slope of the Eureka Springs cuesta to its condition late in the Ozark cycle, he will in imagination fill all the later stream valleys draining that slope. He will also have to do considerable imaginary back-filling in such valleys as tap runoff from Springfield remnants, restoring them to the broad, shallow drainage grooves they were before the post-Ozark rejuvenation. But where a good spread of little altered Ozark peneplain lies downstream from a Springfield remnant, the broad grooves may remain almost as they were made in late Ozark time.

Only thus can one get a fair picture of the Springfield-Ozark relations on this southwestern slope of the dome. Development of the present topography has made precise separation of the two older surfaces almost impossible, and divergent geomorphic interpretations of this slope are understandable.

If the interpretation of this study in southwestern Missouri is correct, monadnocklike Springfield remnants should exist on major interfluves that carry the Ozark peneplain trace. Such remnants are well shown in Osage River drainage where some fairly steep margins and flattish summits are determined by a harder caprock, although both the Springfield remnants and the widespread Ozark surfaces are cut in Pennsylvanian strata.

Nearer to White River drainage and more critical for our purposes is the territory drained by Spring River, Shoal Creek, and Elk River, all flowing westward and joining Arkansas River in eastern Oklahoma. The drainage of these streams in Missouri is almost entirely on Mississippian rocks. The State Geologic Map shows scattered small patches of Pennsylvanian in their territory, but none has elevations above its surroundings. There are, however, such elevations in Mississippian rock. Unit hills of monadnock character are, as is to be expected, on major interfluve summits,

With the strongly marked separate hills may be grouped some larger and lower elevated tracts, late mature Ozark topography, which equally well testify to the former existence of a higher surface, partially reduced during the Ozark cycle.

One prominent unnamed monadnock in the Spring River drainage, two miles northwest of Miller, Lawrence County, is shown on Stotts City Quadrangle map as surrounded by Ozark surfaces above which it rises more than 100 feet (to 1,390 feet A.T.). Its summit is too narrow to carry an unquestioned Springfield flat, but its altitude falls in the Springfield trace on the Halltown Quadrangle immediately to the east. It is part of the Osage-Spring major divide.

Five miles to the north of this hill are Mound and Bryant Mound, (South Greenfield Quadrangle, Dade County), each 60 feet or so above surrounding plane surfaces. But their summit altitudes (1,150 feet) are the altitudes of Ozark traces of their latitudes (transverse to stream courses). These locally prominent hills are mentioned in order to classify them. They do not belong to the category under consideration.

The Shoal Creek-Spring River divide carries no marked monadnocks with summits surviving from a former Springfield peneplain, although late mature Ozark elevations occur on it. A definite residual of the Springfield lies west of Stark City on the Shoal Creek-Elk River divide. Here a broad, gently sloped elevation, Oliver's Prairie, (Ritchey Quadrangle, Newton County) rises 60 feet above the Ozark peneplain trace and clearly is a remnant of an earlier land surface that failed to be reduced to the Ozark level. Another is Pooles Prairie (Neosho Quadrangle, Newton County) and a northward continuation of it west of the city of Neosho, also about 60 feet higher than the Ozark peneplain trace.

Further evidence that the two peneplain surfaces are dependent in part on stratigraphy comes from tracing the Ozark strath southward up Kings River Valley on Shell Knob Quadrangle and thence across the Arkansas-Missouri state line on the Eureka Springs Quadrangle where the wide dissected strath becomes an upland surface; Mississippian rock having been stripped off margining interfluves, except for the Pilot Knob (Stone County) group of hills east of the river's course. Surviving summit altitudes for remnants of the Ozark surface are 1,140 to 1,160 feet (1,120 feet nearer White River), and the Pilot Knob hills constitute a monadnock group, residual from the Springfield; a group that rises to 1,400 feet A.T., 250 feet above the Ozark trace. Purdue and Miser's Osage anticline is continued a few miles north from Arkansas into Missouri as a fault (Lampe Quadrangle) on the east side of which the Springfield trace has the same altitude. Only four miles separate the two high tracts.

Breadtray Mountain (Lampe Quadrangle) is an isolated monadnock reaching 1,354 feet A.T., standing on and rising about 300 feet above the Ozark strath along White River.

Tipton type areas.—The summit of the Eureka Springs cuesta gradually becomes lower northwestward along the eastern side of the Springfield Plateau and is there segmented into separate hills. It is recognizable, however, as far as Fairplay and Cliquot Quadrangles, Polk County) where an irregular scattering of 1,200 to 1,260-foot hills records the Springfield peneplain.

The town of Walnut Grove, about midway between Bassville and Fairplay, is built on a broad flat upland with creeks radiating from it in every direction (Walnut Grove Quadrangle, Polk and Greene Counties). The altitudes range from 1,150 to 1,220 feet A.T. over several square miles above the stream heads, and the isolation and altitude mark it as a peneplaned residual. Like the Tipton tract (see p. 70), this Walnut Grove region apparently was a local, equidimensional interfluve of a peneplain and it so remains to this day, unviolated as yet by the encroaching valley heads. Unlike the Tipton tract, however, it is Springfield, not Ozark, in age. Several small patches of Pennsylvanian rock are shown on the State Geological Map as occurring on the Walnut Grove Quadrangle but they have no topographic expression on the 10-foot interval of the contour map.

Wheatland Prairie (Hemitage Quadrangle, Hickory County), 35 to 40 miles north of the Walnut Grove summit flat, is physiographically and geologically comparable but has a large area (nearly 20 sq. mi.) and falls into the Ozark peneplain trace. The range in altitude is between 1,000 and 1,060 feet A.T. The drainage is radially outward except where bounded on the east by the 200-foot deep Pomme de Terre Valley. The beautifully shown entrenched meanders of this river valley are descended from the shallow, low-gradient valley the stream possessed when the peneplain was consummated. They do not record meanders on a post-Ozark strath as do the great entrenched meanders of the Osage downstream from junction of the Pomme de Terre with the Osage. This is strikingly recorded by the largely unrejuvenated valley of an unnamed tributary heading at Liberty Cemetery two miles south of the town of Hermitage and, there, parallel to the Pomme de Terre less than a quarter of a mile away, flowing on its Ozark valley floor 140 feet above the river flood plain. The Pomme de Terre Valley here on the Ozark peneplain was about 100 feet deep.

Resurrected hills.—The Cliquot Quadrangle contains topography of unusual character for some of its hills are of Mississippian limestone while their separating valleys are in Pennsylvanian shale and sandstone. Obviously, a hilly topography on Mississippian rock was buried by Pennsylvanian sediments which, being weaker, are now being eroded away to bring the ancient hills to light again. The situation is reminiscent of the St. Francois subprovince. A relief of more than 150 feet in this buried topography is now revealed in the west-central part of the quadrangle near the station of Cliquot. The highest of these hilltops (southwest corner of quadrangle) were first discovered during the Springfield cycle and

became truncated so that they still carry appropriate altitudes for that peneplain in this region. The hill east of Cliquot station is a little lower but stands above the Ozark trace and should be interpreted as an Ozark monadnock. The Cliquot Quadrangle and several adjoining and neighboring quadrangles that include portions of the "structural plain" have numerous other hills and valleys determined by the pre-Pennsylvanian relief on Mississippian rock.

POST-OZARK GEOMORPHIC RECORDS

The fifth theme of this study is that "uplift of the Ozark dome, after its third (Ozark) peneplanation, has been interrupted by two pauses which are recorded by strath terraces". This record is of course restricted to major valleys and, in all such which head in the province, is lacking along upper reaches.

If two sets of strath terraces on a valley's slopes require two pauses in uplift, then three separate uplift pulses are required, each causing a rejuvenation of streams, the last one producing the present valley bottoms. Record of this sequence has been found in favored places throughout most of the Ozark country but is lacking in parts of the west-central and southeastern sectors. It appears that in these almost diametrically opposite sectors, only the first of the three pulses affected the peripheral portions, and that their broad valley bottoms, therefore, still stand at the base level attained during the first pause.

The Osage stage in the west-central sector.—The west-central sector possesses the best field record from which this interpretation is drawn. That record is the consequence of dominant eastward flow of the headwater part of the Osage and of the full length of its tributaries, the Little Osage, South Grand, and Marmaton Rivers. This direction of flow leads the united stream water, the lower Osage, across the secondary bulge (already noted) on the dome's northern slope. Whether or not the peripheral part of the west-central sector was actually uplifted in the second and third movements, it remained lower than the bulge farther downstream.

This bulge or secondary dome has already been specified (p. 94) as the cause for the eastward rise in altitude of the Ozark peneplain trace across Benton, Morgan, Camden, and Miller Counties, and for the lack of any detectible gradient there in summit accordance in the Osage's "outer valley" remnants. Summits of those peninsular hills down in the outer valley, around and among which wind the river's incised meanders, constitute the much dissected strath terraces. Traced upstream (westward) for more than 100 miles, the present valley bottom gradient, now largely submerged under the artificial Lake of the Ozarks, rises until in the general region of Osceola, Monegaw Springs, and Taberville (St. Clair County) it is as high as the strath terrace profile which there disappears in the modern valley floor. This is the upstream limit of the rejuvenation which left the remnants of the outer valley floor.

Thus, the extremely wide floors of the upper Osage, the South Grand, the Little Osage, the Marmaton, etc. are essentially the floors they possessed before the time of that second uplift. The marked meandering of streams in this sector (Fig. 39) has broadened these valleys during all subsequent time, but never have they been trenched below the first post-Ozark base level.

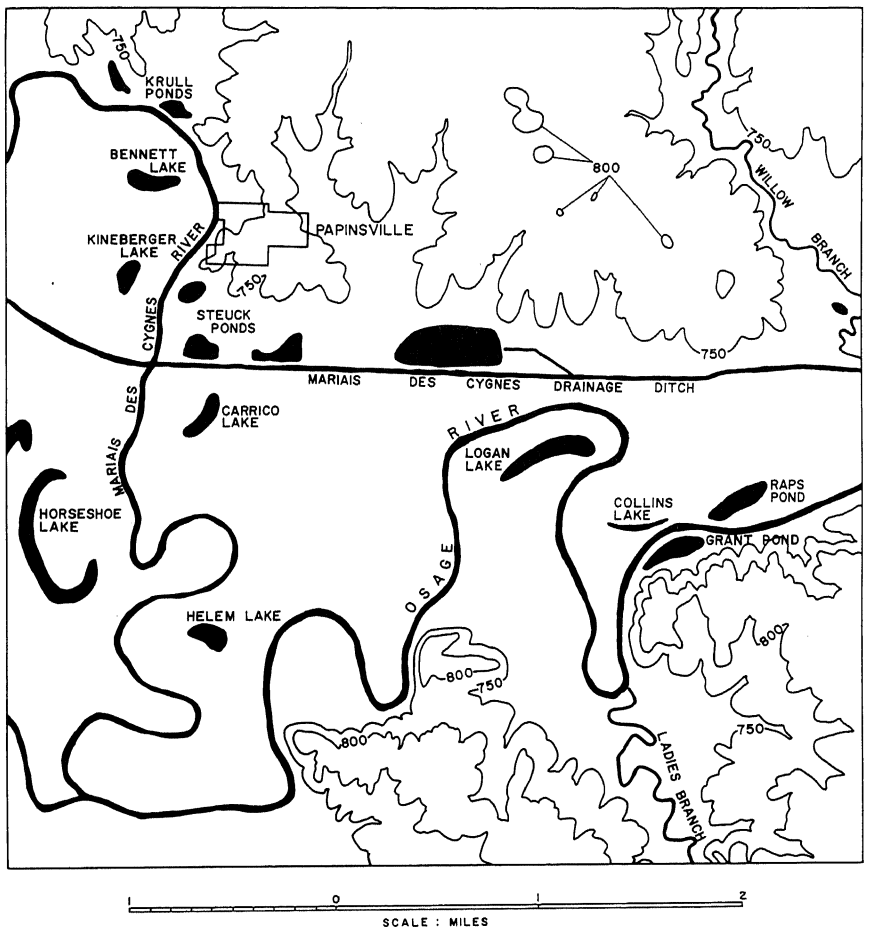

Fig. 39. Map of an unrejuvenated portion of the Osage River valley; Papinsville Quadrangle.

Actually, they probably have become somewhat shallowed by alluviation on their floodplains. Drainage of the Osage floodplain in Bates County (Worland, New Home, Butler, Rich Hill, and Papinsville Quadrangles) has required construction of a 20-mile ditch to eliminate meander detours aggregating 50 miles.

In harmony with this picture of river valley floors still at the first post-Ozark base level is the topography of their interfluve

summits and the drainage slopes descending thence to the valley bottoms. With a few exceptions, the uplands carry profiles of the Ozark peneplain, and this erosion surface, restored, rises eastward toward and into the minor dome bulge repeatedly noted (Benton, Camden, Hickory and parts of contiguous counties). This eastward rise in elevation of Ozark remnants appears to extend from the Kansas-Missouri line to the Lake of the Ozarks region.

Consistent with the picture also is the character of minor creek valleys. In the western counties (Vernon and Bates), the topographic maps (Worland, Hume, Richards, Deerfield, Moundville, Metz, Sprague, New Home) show almost no minor drainage ways deserving the name of ravines. The only exceptions are those very headwater courses descending the steeper slopes of scattered monadnock elevations above the Ozark peneplain trace. Vetters Hill and Vergil Mound on Deerfield Quadrangle and unnamed hills north of the town of Richards are examples of such monadnock residuals from a former Springfield peneplain across the region. Their flattish tops, however, are probably structurally determined, not survivals of the Springfield plain. Traced farther east across the contour maps covering Henry and St. Clair Counties, such minor valleys gradually assume ravine characters as the Ozark trace rises, and the valley floors descend in that direction.

Much of the gently sloped post-Ozark drainage area of the Marmaton, Little Osage, and South Grand rivers may be considered as old land topography made since the first post-Ozark uplift occurred. Only little more reduction of these slopes would justify their description as a "near peneplain". Indeed, the erosion which has produced these gentle slopes has been going on ever since the first post-Ozark rejuvenation. It was only the major valley's deepening that ceased with attainment of the higher strath profile (the outer valley) along the lower Osage farther east. Lowering of uplands has continued.

We shall drop the awkard term "first post-Ozark" and name this incomplete cycle of erosion the Osage Stage. We shall keep in mind that the Osage Stage has never been interrupted in this west-central region, that detritus is still being brought off its gentle slopes to the Osage base level, but we must also remember that post-Osage differential uplift farther downstream has made a wholly different record. We shall date the attainment of the base level from the high, dissected strath along the lower Osage and Missouri Rivers and there shall find record of later events that have never occurred in the upper Osage River drainage.

Study of bedrock topography in Illinois is far more difficult than in the Missouri Ozarks because of a nearly complete cover of glacial drift. Nevertheless, by use of thousands of well and drill hole logs, Horberg (1950) has been able to identify a widespread buried erosion surface which truncates structure, is lower than the established Lancaster (Ozark) peneplain, and is developed largely on weak Pennsylvanian rock: this he named the Central Illinois peneplain.

Had the low country of the Osage, Little Osage, South Grand, and Marmaton drainages been invaded by a northern ice sheet and become buried under glacial drift, it would now have, from drill hole data, a close simulation of Horberg's third erosional surface. This would include its relief, the weak character of its buried Pennsylvanian bedrock topography, and its position immediately lower than the Ozark peneplain. The correlation here proposed is that the Osage and Central Illinois erosional stages were contemporaneous and were consequences of a stillstand following the first uplift of the Ozark-Lancaster peneplain. This correlation is strengthened by the existence both in Illinois and Missouri of a still younger, lower and more limited erosion surface along major valleys; one which Horberg named the Havana strath and which we are calling simply the post-Osage strath. Following uplift of this system of broad valley bottoms came a "deep valley" stage known also in some major valleys in both states.

Large portions of Horberg's Central Illinois peneplain have no record of the later Havana strath. This is comparable to Missouri's lack of a post-Osage record in the upper drainage of the Osage River system.

Missouri Valley straths.—The trans-state Missouri River was a much smaller stream in preglacial time than it is today. Pleistocene ice sheets that advanced southward across the state to this valley greatly modified the drainage of the northern territory invaded, adding most of Montana and the Dakotas to the preglacial Missouri drainage area (Todd, 1914), more than doubling it and probably increasing the volume to correspond. Previous to this major shift of what had been Arctic Ocean drainage over to that of the Gulf of Mexico, the trans-state valley entering at Kansas City carried only the Kansas River. A third of the way across Missouri this river was joined by another from the northwest, the preglacial Platte. Grand River (North) now follows much the same route, although surface expression of the old Platte valley is largely obliterated by glacial drift. There was then no river valley from St. Joseph to Leavenworth, (Greene and Trowbridge, 1935), and the Gulf-Arctic divide stood somewhere not far north of Omaha, Nebraska.

With contributions from Gasconade and Osage systems, this preglacial Kansas-Platte River followed the course of the present Missouri Valley eastward across the state during the entire sequence of geomorphic events thus far considered. Later development of a second, lower strath was also during preglacial time. This trans-state valley and its larger tributaries contain the best record in the Ozarks of both the Osage and post-Osage strath levels.

The Osage strath.—The first announcement that remnants of an older, outer, higher valley bottom are identifiable along the Missouri River in this state was made by O. H. Hershey in 1895. His observations were in the vicinity of Jefferson City and his term

was "duplex valley". His presentation was unsupported by photographs, sketches, or maps. Indeed, there were no topographic maps of this almost diagrammatically displayed, double valley for nearly 40 years afterward. Yet Hershey could hardly have come upon a better place to demonstrate his thesis, and the region about Jefferson City will serve equally well as a text for the present study.

Uplands both north and south of this stretch of the Missouri Valley have flattish summits of 800+ feet only a few miles back from the valley walls and of 900 feet or more in a few places less than 10 miles back. Such uplands record the Ozark peneplain on the Centertown, Jefferson City, Mokane, Columbia, Millersburg, Morrison, and Hermann Quadrangles (Moniteau, Cole, Osage, Callaway, Gasconade, Boone, and Cooper Counties). The record is imperfect because the major valley walls have been gashed by myriads of ravines, and a thick smear of glacial drift on the north side has produced a misleading upland flatness. Proper view points are necessary if one is to avoid confusion from such details.

There are two good viewpoints from which the dissected floor of the outer valley, (the Osage strath), can be seen, both from Ozark peneplain altitudes on spurs along the north side of the Missouri Valley on the Jefferson City Quadrangle. One is along U. S. Highway 63 near Clayville School, about eight miles from the State Capitol. The other is along the old route of U. S. Highway 54 a little north of Holts Summit, about six miles from the Capitol. Both viewpoints are approximately 850 feet A.T. or 300 feet above the river floodplain. The summit accordance of these residuals of the Osage strath is even better seen along the descent from Holts Summit where one at altitudes of 700 to 750 feet is in the projected plane of the old valley bottom.

The surviving record hardly suggests a former flood plain, for most spur tops carrying the profile range through 50 feet of altitude. Unequal reduction of summits may be part of the reason for this, and gentle lower slopes on the sides of the wide, old river valley may also be part.

The advanced degree of dissection renders measurement of the strath's gradient along the Missouri nearly impossible. A generalized picture, from study of the topographic maps, seems to be that there is no lowering of the average ridge summits from Jefferson City downstream as far as New Haven (Washington Quadrangle), a distance of more than 50 miles. A definite lowering is recognizable thence downstream, but again no precision of measurement is possible. In the 50 mile stretch, the river approaches and crosses the Hermann upwarp of the Ozark peneplain, and presumably some of this uplift is post-Osage, like that described along the lower Osage River.

On the south side of the Missouri Valley near Jefferson City, the Osage strath is strikingly shown in the lower reaches of Moreau River valley, a tributary entering just below Jefferson City. The tortuous twistings of this stream's entrenched meanders (Jefferson City Quadrangle) clearly are inherited from a former baseleveled

flood plain now on record in summits of the peninsular projections inside the river loops. The Moreau which had a deferred junction with the Missouri when the post-Osage rejuvenation was initiated, may actually have joined the Osage itself just above that river's own junction with the Missouri. Subsequent widening of the Missouri Valley here has permitted a domestic piracy by trimming away the north side of the peninsula which the rejuvenation had made of the deferred junction (Fig. 40). This piracy appears to have occurred quite recently in geomorphic history for the floor of

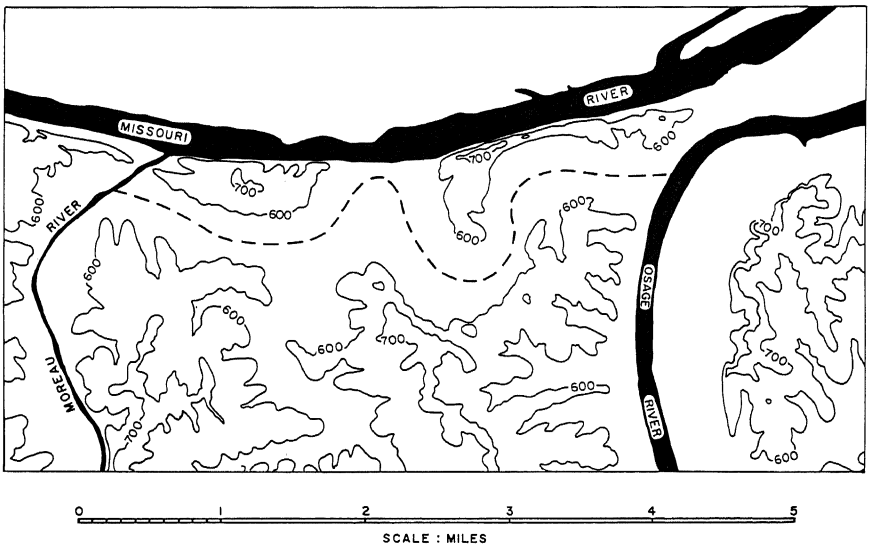

Fig. 40. Map of abandoned part of Moreau River valley; Jefferson City Quadrangle. The dashed line indicates former course of Moreau River along abandoned lower portion of its valley.

the lower four miles of the Moreau's course (Fig. 41) lies not more than 40 feet higher than the Missouri floodplain and is 100 to 130 feet lower than the Osage strath here.

The new short cut of the Moreau is a narrow gorge through the western base of the peninsula. Probably the tributary river discovered a subterranean short cut whose roof rock has since collapsed to open the new route to the sky. No actual breaching of the peninsular partition by the Missouri from lateral erosion has occurred here as it obviously did a mile or so farther east where Rising Creek crosses the abandoned valley to enter the Missouri. Thus two piracies have occurred here.

Upstream from Jefferson City, on northeastern Centertown and southern Columbia Quadrangles, Ozark peneplain remnants run out valleyward on spur tops on both sides of the valley, their tips reaching within three or four miles of each other. There is little record here of an Osage stage valley floor. The valley slopes in

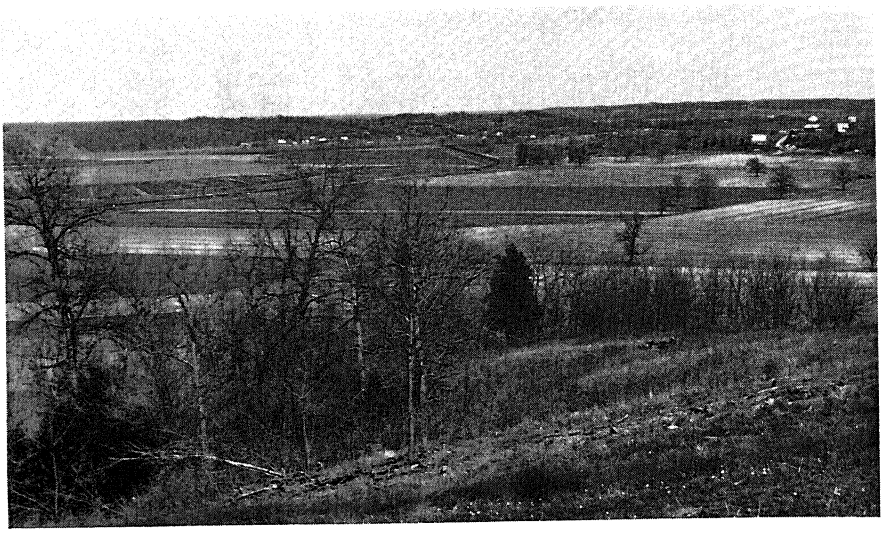

Fig. 41. Abandoned valley of the Moreau River. The distant northern bluffs of the Missouri River valley can be seen through the ancient river mouth on right side of the photograph. R. Zangerl, photo.

this stretch are largely of Devonian and Ordovician rocks as they also are downstream from Jefferson City for the next 100 miles.

In the northern half of the Missouri's course across the Columbia 15-minute Quadrangle, Mississippian rocks constitute the full height of the bluffs, and Ozark peneplain remnants seem rather abruptly to disappear, the summits of the valleyward-projecting upland spurs standing too low to coincide with the Ozark profile upstream from Jefferson City. Altitudes come closer to what the Osage stage records should have. One explanation could be that the Osage strath in this valley stretch is much wider than elsewhere, and its development has destroyed the Ozark record. The uplands of the city of Columbia, nearly 10 miles back from the Missouri Valley, range from 740 to 780 feet A.T.

It is doubtful, however, that this lower upland tract should be interpreted as a broadening of the Osage strath or that its existence is conditioned by contrast in erodibility of Mississippian rock with that of Devonian and Ordovician. The regional slope from Columbia rises gradually eastward for six or seven miles nearly to 900 feet A.T. and six miles farther east, broad upland flats (albeit drift-covered) stand about 900 feet. The underlying rocks are Mississippian and even Pennsylvanian in this highland. On the Millersburg Quadrangle, immediately east of Columbia, drainage is southward, semiparallel to the Missouri and not far from right angles to the drainage at Columbia. Cedar Creek (boundary between Callaway and Boone Counties) flows essentially along the strike of this regional slope and takes several more miles to reach the Missouri than does a course along the dip like

that of Hinkson Creek. Furthermore, the general slope also rises westward from the city's environs, upstream with reference to the Missouri, to reach 820 feet in 10 miles.

The preferred interpretation, therefore, is that the lower upland of the northern part of the Columbia Quadrangle is relatively less uplifted Ozark peneplain in which the Osage baselevel record is too weakly developed to be identifiable.

An extraordinary contrast exists between the valley of the Missouri and those of its major tributaries entering between Brunswick (Chariton County) and Washington (Franklin County). The Missouri Valley is a flat-bottomed trench with approximately parallel bluffs aligned on very slightly curved courses. It has no peninsular spurs inside the river's own meandering curves and little evidence of meander scars, past or present, in its straight bluff lines. In contrast, the tributary valleys possess very crooked entrenched courses with some peninsular necks in imminent danger of incision and a few with the feat accomplished, leaving a "lost hill" out in the valley (Fig. 42). The tributary

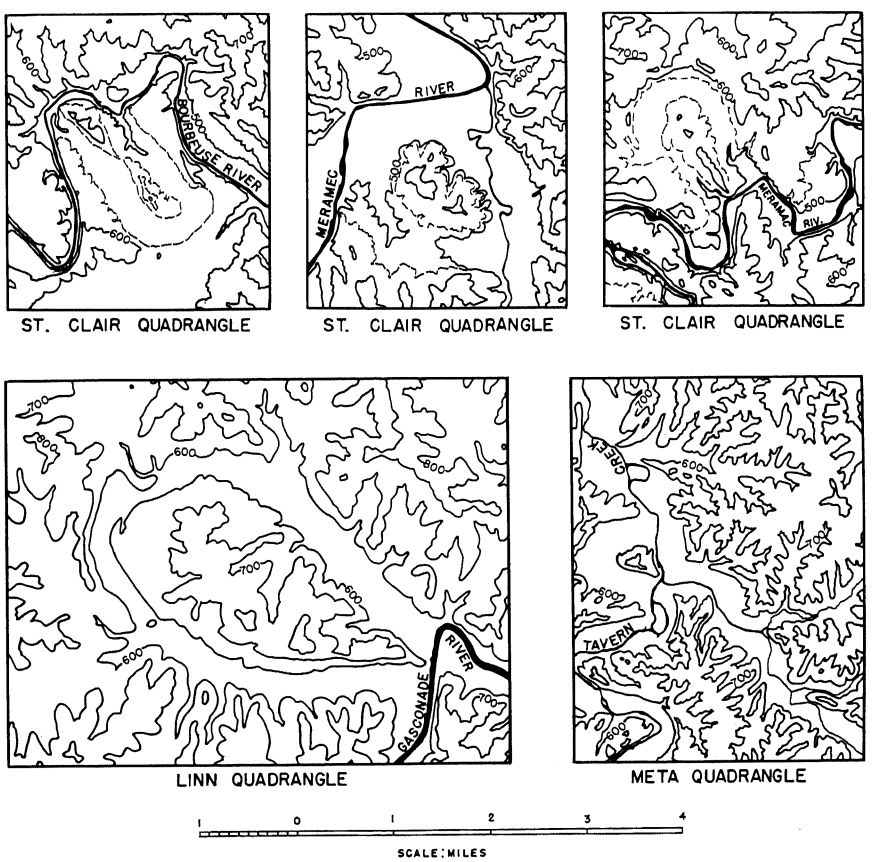

Fig. 42. Maps of "lost hills" in cut-off entrenched meanders.

streams from the south (Blackwater, Lamine, Moreau, Osage, Gasconade) show more of these contrasts than those from the north (Grand, Mancas, Hinkson, Cedar). The conspicuous cliffed, trenchlike character of the Missouri bluffs seems imputable to trimming by the greatly enlarged volume of the river after the doubling of its drainage area, especially when carrying the melt-water discharge from the wastage of a northern ice sheet. Such a Pleistocene river could make essentially a bankfull channel of the two-mile width of the valley bottom and presumably could cut off all peninsular projections that may have existed.

However, the most unusual feature of these contrasts is that the entrenched meander belts of some of the Missouri tributaries are *wider* than the *trench* of the master valley, within whose walls the present cramped and imperfect Missouri River meanders are necessarily confined. When the Osage, Gasconade, and other meanders, now entrenched, were initiated, the preglacial Platte-North Grand, now the Missouri, certainly had a proportionately wider belt at nearly the same altitudes, and the Osage strath is its record.

The trench character must be a later deepening below both Osage and post-Osage traces, and any lingering record of either must be only fragmentary.

Figure 43 shows the limits back from the trench walls of any possible Osage stage valley floor. Altitudes outside the dashed line are too high. The dotted line is a smoothed-out approximation of outlines of surviving Ozark peneplain upland. The area between these two lines carried the slope of the Osage stage's main valley. Of valley slopes surviving from the Ozark cycle, there appears to be no record comparable to that in the lower Osage Valley, discussed on preceding pages.

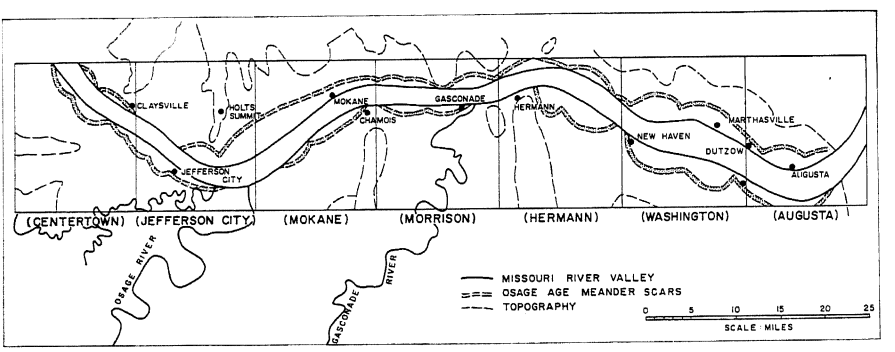

Fig. 43. Reconstruction of Osage age meanders along the Missouri River.

In summary of what may be called the Ordovician-enclosed 100-mile stretch of the trans-state Missouri Valley, we noted: 1) that the river through all the erosional sequences which preceded Pleistocene glaciation had probably no more than half its present volume; 2) that the broad shallow valley of the Ozark cycle's

culmination has been essentially destroyed because of later rejuvenation caused by further uplift of this flank of the dome; 3) that a considerable pause in post-Ozark uplift is recorded by the Osage strath and that some approximation of the width and depth of the valley developed during this pause can be determined from surviving portions of that strath as at Jefferson City; 4) that a second post-Ozark uplift caused a post-Osage rejuvenation; 5) that a following pause allowed the making of the post-Osage strath; 6) that the third and latest uplift introduced the "deep valley stage" which is recorded in the rock floors buried beneath alluvial deposits up to 100 feet thick that are encountered in construction of bridge foundations; 7) that approximate doubling of the river's volume, plus unknown but undoubtedly great additions to that doubled volume during relatively brief occasions (icesheet wastage), have resulted in marked trimming back and steepening of all bluffs (Fig. 44). Some of these bluffs descend almost from the Ozark peneplain level to the flood-plain. The obviously cramped condition of Missouri meanders of today seems clearly a consequence of the river's great volume from ice-sheet derangement of the preglacial drainage. Widening of the overly narrow valley bottom by meander undercutting has hardly begun.

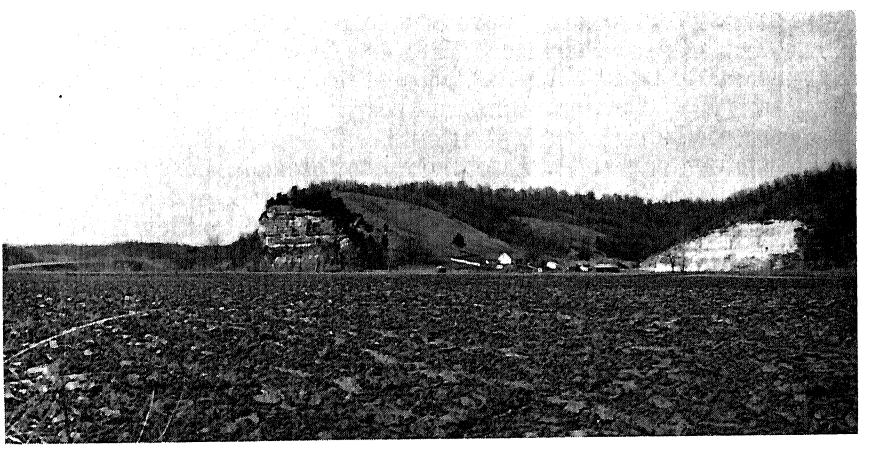

Fig. 44. Trimmed and steepened bluff, Missouri River valley north of Jefferson City. R. Zangerl, photo.

The post-Osage strath.—As already noted, post-Ozark history has not been a simple unit affair. It has involved a second pause in uplift and stream rejuvenation; a post-Osage stage of widening of major valleys to leave a second, lower strath in favored places. It was briefer, of course, than the Osage pause, else that strath would have been destroyed. Its terrace has suffered much from Pleistocene widening along the Missouri Valley, and the pause is unequivocally recorded along the Ordovician-bounded valley stretch only on Mokane, Morrison, and Augusta Quadrangles. The north

side of the river carries a dissected terrace at 630 to 650 feet A.T. for the full 15 miles across the Mokane Quadrangle. Farther down the valley are other terracelike surfaces at approximately lower altitudes which are dubiously correlatable because a heavy cover of loess near the river conceals the bedrock surfaces.

The earlier noted saddle in the Missouri-Meramec divide at Gray Summit (St. Clair Quadrangle, Franklin County) has no such cover and can not be so criticized. Its altitude of 650 feet A.T. is about 100 feet below the projected trace of the Ozark peneplain. If we ignore our own warning about a thick loessial cover, the Augusta Quadrangle (Franklin and Warren Counties) provides a fine example of what looks like an elongated, flat-topped, north-pointing Missouri Valley spur west of Labadie, two to three miles north of the Gray Summit saddle and close to 640 feet in altitude throughout its one and three-fourths mile length. Thickness of loess on this spur is not known. An attractive idea is that this saddle records a former river course of the post-Osage stage, and the 640-foot spur is part of the old channel floor. Altitudes of post-Osage terraces on Mokane Quadrangle (Osage and Callaway Counties), 620 to 640 feet, are a little low for this correlation since Mokane Quadrangle is four quadrangles west, upstream, from Augusta Quadrangle.

Leverett (1924) suggested a Pleistocene detour of the Missouri across the saddle. Robertson (1938) has described lacustrine sediments containing erratics in terrace remnants along the lower Missouri Valley, the ponding which they record having been caused by a dam of glacial ice at and below the Missouri-Mississippi junction. Although probably correct, no record of such a river across the saddle or down the Meramec has yet been found, and a low place must have existed previously to invite any such spillover.

Still considering the hypothesis of a river crossing at Gray Summit, we might speculate that the Meramec originally used this saddle and joined the Missouri near Labadie, and that its present course across St. Louis and Jefferson Counties has resulted from piracy by a Big River tributary late in post-Osage time. The speculation runs against a stone wall, however, when a crossing of the Crystal escarpment below the site of the piracy is considered. Any crossing must have occurred during the Springfield cycle before the escarpment had been etched out. It never could have occurred later.

Probably the most satisfactory disposition of the Gray Summit problem is to consider the saddle as a low post-Osage interfluve that may have been further lowered by a brief discharge of the Missouri across it at some time during the Pleistocene.

This interpretation seems to be supported by features of the asymmetrical Bourbeuse-Missouri divide and some of its minor interfluves which descend the long northward slope into the Missouri Valley. Ozark peneplain remnants, followed closely by Rock Island Railroad and U. S. Highway 50, are almost continuous and readily identifiable on the divide summit eastward from Owensville

(Bland Quadrangle) nearly to Union (Union Quadrangle). The gradient, nearly four feet per mile (950 feet at Owensville, 850 feet near Union) lies along a tangent to the Ozark dome and, therefore, probably is very close to the original slope.

Between the vicinity of Union and the Crystal escarpment overlooking Gray Summit, the divide (Bourbeuse and Meramec Rivers on the south, Missouri Valley on the north) has but one small tract as high as 800 feet (The Diamonds, St. Clair Quadrangle) and in general ranges between 740 and 780 feet across the 12 miles involved. The Ozark peneplain trace projected eastward across the Gray Summit saddle is close to 100 feet above this part of the divide crest. Thus, the low hilltops of the northern half of the St. Clair Quadrangle are judged to record the Osage partial peneplain, much dissected after a post-Osage uplift to make the Gray Summit saddle.

More of this post-Osage topography appears in the aberrant Brush Creek valley south of Gray Summit (Fig. 21) and also in the wide stretch of low hills bordering adjacent Meramec Valley. Brush Creek's broadly open, flat-bottomed valley south of Gray Summit is 100 feet higher than Meramec River half a mile distant, yet the creek flows semiparallel to the river for five miles farther east before joining it.

The minor interfluve best showing comparable erosion levels on the Missouri Valley slope of the Bourbeuse-Meramec divide is followed in large part by Franklin County's Supplementary Road C which runs northward from a junction with U. S. Highway 50 three miles northeast of Gerald to New Haven on Missouri River. For half of the 14 miles involved, the road is on a surviving Ozark surface which descends about 14 feet per mile. Near Kiel (Washington Quadrangle) the altitude of the interfluve summit drops approximately 100 feet in one mile and, thence, northward for a mile more holds fairly closely to summit altitudes of about 730 to 740 feet. This lower stretch with neighboring interfluves of comparable altitudes is taken as an Osage stage record.

Several square miles of lower country, bounded by New Haven, Dundee, and Campbellton (Washington Quadrangle) and now occupied by the tortuous meanders of Boeuf Creek, represent the dissected floor of a Missouri meander scar of post-Osage (and perhaps also Osage) age.

The trimming back and steepening of Missouri Valley bluffs, imputed to repeated Pleistocene floods, is recorded also in a "betrunking" of minor ravine systems. In these little dendritic systems, the lower lateral branches may converge toward a basal trunk that no longer exists and, thus, have their own mouthings in the bluff line or may share an abnormally wide mouth. A dozen cases of this maltreatment of obviously once longer trunks can be found on topographic maps along the Missouri from the Columbia to the Augusta Quadrangle. Well shown examples are a mile northwest of Clayville (Centertown Quadrangle), a mile southwest of Mokane (Mokane Quadrangle), at Case (Hermann Quadrangle),

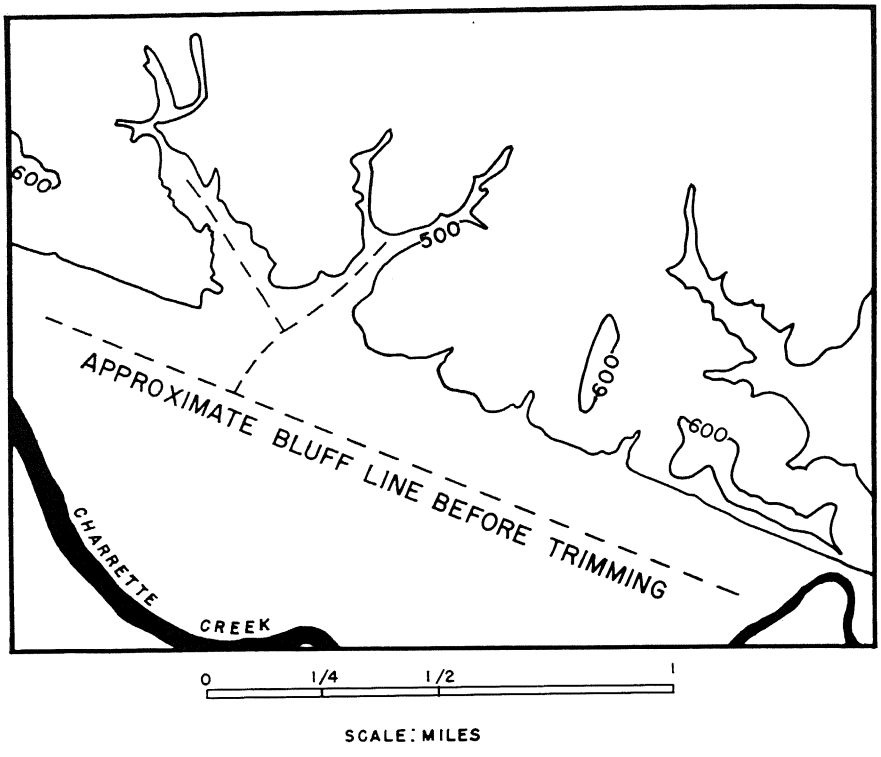

Fig. 45. Map of a betrunked ravine system; Washington Quadrangle.

and at Marthasville (Washington Quadrangle) (Fig. 45). The Mississippi River trench has even more examples of this betrunking on both the Missouri and Illinois sides.

Gradients of these betrunked ravines, projected out into the Missouri Valley, go below the present alluvial bottom. This indicates that, after the post-Osage stage, the master valley was eroded to a greater depth than at present and has since received an alluvial partial refilling. This "deep valley stage" occurred before the trimming back of the bluffs, i.e. before Pleistocene time.

The Osage stage on the southeastern slope.—On the southeastern margin of the Salem province, between the St. Francois Mountains and the Embayment, the southeastward-draining valleys of Whitewater River, Hurricane Creek, Crooked Creek, and Little Black River, and the stretches of St. Francis and Castor Rivers across the district all lack straths recording the Osage pause in uplift of the dome. Their valleys appear to record but one rejuvenation since the peneplain stage. In contrast, valleys draining both east and southwest from the St. Francois Mountains subprovince carry a clear record of two uplifts with a sufficiently long intervening pause to leave double valley profiles.

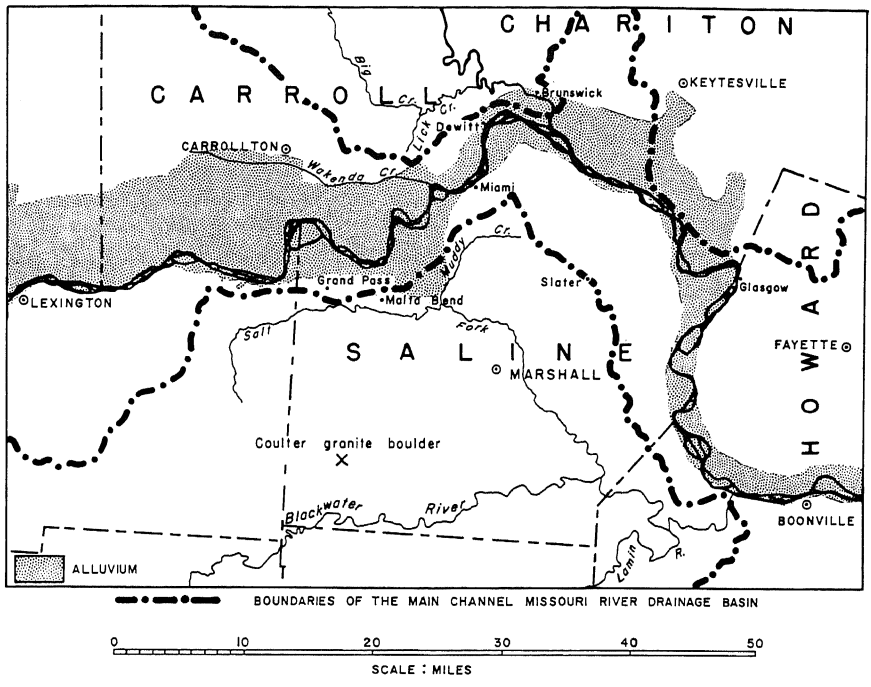

Fig. 46. Map of Saline County Big Bend of the Missouri River and environs. Lower Wakenda Creek has a deferred junction because of natural levees along the Missouri River.

If this absence of an Osage record means that this district (Higdon, Perryville, Coldwater, Marquand, Marble Hill, Piedmont, Greenville, Zalma, Grandin, Williamsville, Poplar Bluff, Doniphan, and Naylor Quadrangles) did not undergo the second uplift, peneplain traces on the interfluves which separate these streams should also record that fact.

The interfluve altitudes of peneplain remnants range from 800 feet A.T. near the mountains to 500 feet in the Embayment bluff summit. When these altitudes are connected by contours extrapolated across the intervening valleys, a definite sag in the peneplain trace appears on the map. It constitutes an identation in the generalized outline of the dome that amounts to as much as 100 feet vertically and 10 to 15 miles horizontally and is just what should exist if this limited flank of the dome never experienced a second uplift of adequate character. Valley bottoms of the streams, therefore, may be considered as still in the Osage stage of erosion.

The Saline County Big Bend.—Another area along the transstate Missouri Valley where interpretations are uncertain is the environs of the great bend which bounds Saline County on the north and east (Fig. 46). If this bend is pictured as half a circle, then Salt Fork and lower Blackwater River describe a diameter. South-

east-flowing Salt Fork's tributary drainage heads in a low sag in the south wall of the Missouri Valley not more than 50 feet, at the upstream end, above the river's floodplain. The upland thus enclosed (Slater upland) contains half of Saline County, and much of it is 200 feet and more above the Missouri floodplain. From the headwaters of Salt Fork's tributary drainage, one can see the Missouri only a mile distant. Thus the pass at the head of the "sag" is extraordinarily low. Yet this drainage flows *away* from the master stream and, although several miles shorter than the main stream, does not enter it for another 35 miles downstream.

Summit flats of the Ozark peneplain on the Slater hill land range from 800 to 840+ feet (Marshall and Glasgow Quadrangles). West of the Salt Fork Valley, comparable uplands are nearly as high (Shackleford Quadrangle), and east of the half circle course occupied by Missouri River similar flattish interfluve summits (Glasgow 15-minute Quadrangle) do not rise above 850 feet A.T. for four or five miles back from the main valley. Altitudes of other remnants to the north of Missouri Valley (Miami Station Quadrangle) confirm the interpretation of this district as an upwarped portion of the Ozark peneplain into which the valleys of both river and fork have been eroded.

Yet at the 800-foot contour, Salt Fork Valley is twice as wide as Missouri Valley, and its slopes are much gentler. Indeed, the river's trenchlike course around the curve is essentially walled in by 100-foot cliffs, as obviously trimmed back as those from Boonville to Washington.

These contrasts between the two valleys do not seem referable to differences in underlying rock. It may be suggested that the low pass and the broad valley of Salt Fork can be explained if the earliest valley-making in this district was during the pre-Pennsylvanian erosion interval already noted and was limited here to the Salt Fork route. The weaker Pennsylvanian sediments filling that valley can be conceived to have readily wasted away in subseqent time to "resurrect" the old valley. But no convincing evidence supports this suggestion, and the greater width and gentler slopes of that route may all be of post-Ozark age. The explanation for these features is believed to be found in the occurrence of different events along each of the two routes.

The Missouri Valley alluvial plain in this district has some notable variations in width which are vital elements in the problem. At the low pass at the head of Salt Fork's tributary drainage the Missouri Valley floor is a bit more than 10 miles wide, but in five miles farther downstream (White Rock, Miami Station, Miami) it narrows to less than a fourth of that width, and broad, flattish Ozark peneplain summits at 800 to 820 feet come to the brink of the 150-foot bluffs. This narrows continues downstream as far as DeWitt (Brunswick West Quadrangle), another five miles, where the alluvial plain receives Grand River and doubles in width at Brunswick.

This Miami-Dewitt narrows appears explicable only if the present Missouri has been superposed on a northwest-elongated broad spur of the Slater upland which lies between Salt Fork and Missouri valleys; a spur which earlier was a divide separating the preglacial Kansas and Grand (Platte) Rivers. Todd (1896) first suggested this idea. The Kansas, by this view, followed Salt Fork Valley, and the two then joined a little above Boonville.

During continental glaciation, ice certainly crossed the present course of the Missouri, covered the Slater upland, and followed down Salt Fork Valley nearly or quite to its junction with Blackwater River (Todd, 1896, and verified in the present study). This occurred as early as the Kansan glaciation of northern Missouri and may have been during the Nebraskan invasion (Holmes, 1942). The narrows could well be considered a glacial derangement if the edge of the ice sheet could be plausibly reconstructed to blockade early valley ways and produce the new course between Miami and Brunswick.

Such an attempt must take account of two valley fillings in the complex. Gravel with pebbles of igneous rock has been reported (well logs in files of Missouri Geological Survey) at a depth of 125 feet near Marshall, approximately 12 miles down along the Salt Fork valleyway and somewhat lower than the Missouri floodplain. It is interpreted as glacial gravel, evidence for a river deposit made late in the history of that valley.

The other valley fill is in Low Gap (NW¼ sec. 6, T. 53 N., R. 21 W.) in north-central Miami Station Quadrangle, directly across the Missouri Valley from the low pass at the head of Salt Fork's tributary drainage. Here the Missouri Valley's northern walls break down at the apex of a right-angled re-entrant in the bluffs. Altitudes in the gap are below 700 feet, and drainage is to north-flowing Lick Creek. This is directly *away* from the master valley, like Salt Fork drainage, but is in the opposite direction. Four miles north from this gap in the bluffs, Lick Creek joins Big Creek, a tributary of Grand River, and its drainage, like that of Salt Fork, joins the master stream only after following a roundabout route.

Another and more significant similarity with Salt Fork is that the Low Gap route is on a valley fill. Wells in the area find water in a bed of gravel overlain by quicksand which in turn is beneath blue clay with boulders, probably a till. Top of the gravel is 30 feet or more below the Missouri floodplain level. No other numerical data were obtainable.

Thus, in this district two partly filled minor valleys appear to branch off from the Missouri Valley on each side and both surely are older than the Miami-Dewitt narrows. To this must be added the fact that glacial till is exposed in quarry walls on the White Rock salient two miles downstream from Low Gap and is known in roadcuts on the summit of Slater upland and far south in the Salt Fork Valley. This till can be no younger than Kansan. If the buried Low Gap gravel is Pleistocene in age, it could be pro-Kansan o Aftonian or Nebraskan. It could also be preglacial in age. Its exis

ence below till does prove that valleys even deeper than those of the present had been eroded here before invasion of the Nebraskan or Kansan ice sheets. Presently known facts are inadequate for a satisfactory hypothesis for the complete succession of drainage changes in this part of the trans-state Missouri Valley. Particularly difficult is any conceivable glacial blockading for initiation of the Miami-DeWitt narrows.

Erratic boulders have long been known in lower courses of tributary valleys downstream from Saline County and on the south side of the Missouri. They are adequate evidence for drifting bergs on a ponded or greatly flooded glacial river. They suggest the possibility of properly placed, proportioned, and durable jams of floated icebergs as the cause for the initiation of the Miami-Dewitt route. But only in the broadly open Salt Fork Valley could such an ice jam cause the Missouri Valley detour around Saline County, and there is no shred of field evidence yet known for its former existence. Another difficulty with this idea is the avoidance of ice jams in the growing narrows of such time and other blockades in narrow places along the trans-state valley. When specifically applied, the hypothesis meets insuperable difficulties.

Significant in elucidating late events in Missouri Valley's history in the Saline County region is the great terrace in the northwestern part of the county, largely within the northern half of Malta Bend Quadrangle. The town of Malta Bend stands on this terrace, the Teteseau or "Teeshaw" flats—both words are reported to be corruptions of "Petite Osage"—(Fig. 47). Although confined within the Missouri Valley depression, it does not qualify as a terrace belonging to the master valley for its drainage all goes to Salt Fork,

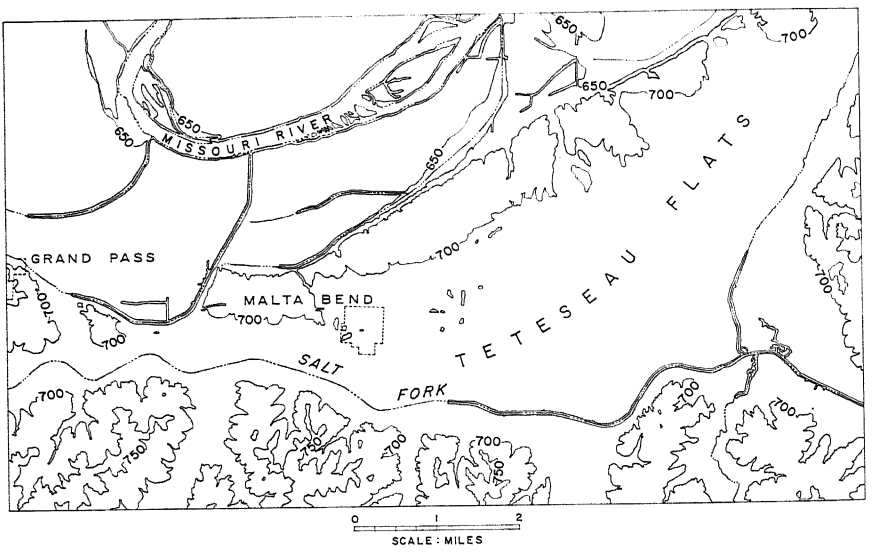

Fig. 47. Map of Teteseau Flats; Grand Pass and Malta Bend Quadrangles.

away from the main valley even though, as noted, the Missouri river channel of today comes within a mile of the terrace scarp.

The northwest-facing scarp of the Teteseau terrace is 50 to 60 feet high, and is sharply outlined by Missouri River undercutting. The terrace surface slopes very gently southeast, carries shallowly entrenched tributaries of Salt Fork, and undoubtedly was constructed by Missouri Valley water flowing down Salt Fork either before the Dewitt-Miami narrows existed or when they were blocked by glacial ice. The undissected surface suggests the latter date.

The high northwestern edge of the Teteseau terrace is 700 to 720 feet A.T., and the unmodified surface gradient is approximately 10 feet per mile southeastward. But the terrace form disappears in that direction, the contours closing in on the Salt Fork Valley in eastern Malta Bend Quadrangle and becoming the outlines of a narrow inner valley at Marshall (Marshall Quadrangle). Indeed, the constriction and the barbed orientation of some tributaries there strongly suggest that a pre-terrace divide existed at Marshall and that the meltwater river which made the Teteseau terrace was forced to cross this low divide (approximately 750 feet) and erode the present Salt Fork Valley.

Any glacial blockade of the Missouri Valley around Saline County's Big Bend was no later than Kansan. The Teteseau terrace, therefore, is no younger than Kansan, despite its lack of surface erosion. If the gravel at 125 feet depth near Marshall is glacial, it should be of Nebraskan age, and any suggested former divide at Marshall should be the consequence of Aftonian erosion of the earlier fill. But it is puzzling that a Kansan meltwater Missouri River did no more in crossing this divide. A heavy loess cover and a paucity of sections make reconstructions rather tentative.

However, the ice-drifted, erratic boulders reported by various observers in the lower reaches of Missouri tributaries from the south lie as much as 75 feet above the Missouri or about 625 feet A.T. Their existence requires a ponded lower Missouri and such ponding could provide the slack gradient which seems recorded by the Teteseau terrace and a Salt Fork detour route of the Missouri.

A previously unrecorded, ice-floated, erratic boulder has a higher altitude than any others known and, therefore, is evidence of more extensive ponding. The boulder is a granite two feet in diameter which was found in a tributary valley of Blackwater River 40 miles up-valley from junction of Lamine River with the Missouri and some miles upstream from the Salt Fork detour route. The altitude was 670 feet A.T. and the site was in Section 26, T. 49 N., R. 23 W.* A ponding for its flotation, therefore, appears to have been adequate to have held the glacial Salt Fork detour to a gradient sufficiently low to explain the aggradation of the Teteseau terrace and the lack of marked trenching at Marshall. By this view, the

*The boulder has been moved by John Coulter to his farm, now owned by Ledru Buie, in Section 2 of the next township north.

terrace is a local outwash plain adjusted to the level of ponding farther down the Missouri River. If the dam for this ponding existed near the confluence of Mississippi and Missouri valleys, the Gray Summit pass (altitude 650 feet A.T.) could well be invoked as the outlet of this presumed lake. In such case, however, one must assume that the head of the Teteseau terrace was somewhat out in the width of the present Missouri alluvial flat and was some tens of feet higher than its existing scarped head.

If and when this lake existed, no valley train could have been built downstream from the Saline County region. A detailed study of the trans-state Pleistocene Missouri River is yet to be made, but no one has ever announced the existence of gravel terraces that would suggest the former presence of such a valley train. Instead, Robertson (1938) believed that the dissected Boeuf silt terrace, at altitude 570 feet and with numerous embedded erratics, (Washington Quadrangle, Franklin County) is a lake deposit of Kansan (or possibly Nebraskan) age, that Kansan ice crossed the Missouri Valley at St. Charles, and that Kansan till underlies Illinoian till in St. Louis. Obviously this would provide the dam for the ponding.* A widely accepted interpretation for loess deposits which margin major valley units of the Mississippi system is that the sources were valley trains windswept during deglaciation. Loess of at least two different ages occurs along the trans-state Missouri. There are also silt terraces of two ages, the older Boeuf terrace and the younger Bonfils terrace, both interpreted by Robertson (1938) as lake deposits. Furthermore, the Missouri State Highway Commission found only clay and silt for the first 24 to 60 feet of borings at Boonville, Jefferson City, and St. Charles. If our suggestion that this master valley below Saline County never has had a valley train alluviation is correct, the dust for the loess deposits would theoretically have to come from valley bottom lake silts which the surviving terraces record.

If diversion of upper Missouri drainage from the Arctic to the Gulf of Mexico was initiated by the Kansan ice sheet (Howard, 1958), that part of the Missouri Valley between St. Joseph and Leavenworth must be entirely a Kansan and post-Kansan affair. Yet, as shown on topographic maps, its widths and the straightness of its bluffs are similar to those of the trans-state Missouri Valley. The inference follows that valley wall trimming, throughout the total length being considered, is the cumulative product of Kansan, Illinoian, and Wisconsin glacial floods. For this reason, no terraces dating back to Kansan experiences can be expected in the trans-state length unless they lie back in the mouths of tributary valleys, as does the Boeuf terrace of Robertson.

A "deep valley stage" (see Horberg, 1950) of late Pliocene or perhaps early Pleistocene age has been identified from well logs, bridge foundation data, and other penetrations of the alluvial fill

*This presumed Kansan lake is not to be confused with Rubey's Lake Brussels (1952) which had an Illinoian ice dam at St. Louis and an outlet 150 feet lower than the Gray Summit col.

in the Mississippi Valley and in many major valleys east of it. This deep stage seems clearly to have occurred later than the Havana strath stage of Horberg, with which the Missouri post-Osage stage is here correlated. Similar excavations in the trans-state Missouri Valley have found comparable depths of fill (Todd, 1896), and a contemporaneous deep valley stage should be established when a detailed study is made. But if the valley between St. Joseph and Leavenworth is no older than Kansan, no deep valley stage record will be found in that stretch unless that great river of Pleistocene age scoured deeply into bedrock. Nor will the Osage or post-Osage strath terraces exist there.

Blackwater River's drainage is eastward, semiparallel to the course of the Missouri for 70 miles. The separating interfluve carries Ozark peneplain remnants almost as far east as the junction of Salt Fork. The interfluve bounding the Blackwater on the south records the Ozark peneplain equally far east. The valley gradient is low, and the stream has been ditched for miles on the Knobnoster Quadrangle where a broad flood plain 100 feet or so below the Ozark surface strongly suggests the Osage base level. This plain narrows notably eastward on the adjacent Sweet Springs Quadrangle where it is higher above the stream and has steeper and more intricately ravined bounding slopes. But the approximate altitude of the Knobnoster Quadrangle's flood plain is carried on the Sweet Springs areas by flattish spurs. Thus, Sweet Springs Quadrangle appears to show a post-Osage rejuvenation, its base level here at altitudes of 630 to 640 feet A.T.

The Coulter granite boulder (altitude 670) originally lay on the lower slopes of Salt Pond Creek valley which joins the Blackwater at the town of Sweet Springs. The boulder was introduced during the Nebraskan or Kansan glaciation, and if it was floated back up Blackwater Valley, the post-Osage partial cycle was an earlier experience in Ozark geomorphic history.

There remains the remote possibility, however, that the ice sheet, Nebraskan or Kansan, may have crossed the Blackwater-Missouri divide from the north and brought the boulder at some earlier date than post-Osage. But in all the region it necessarily would have traversed, no evidence for glacial ice is known beyond the southern margin of the Missouri Valley itself, and the limit of glacial ice shown on the State Geological Map is based on only tentative depictions in early studies. Thus, the post-Osage stage of valley development appears to have occurred in pre-Pleistocene or very early Pleistocene time.

The Perry County sinkhole plain.—Because Perry County lies on the relatively steep eastern structural limb of the Ozark dome, the State Geological Map shows a series of linear formational bands parallel to the Mississippi trench along its eastern border. Except for a narrow strip of faulted country close to the river valley, the county's bedrock is limited to Ordovician formations; Gasconade dolomite on the far west and Upper Ordovician formations on the

east except where faulting has dropped Devonian and Mississippian rocks against them.

All these formations are truncated by erosion planes. The complete stratigraphic and topographic picture requires consideration of the geology of Illinois immediately east of the trench. Here the uplands carry the highest of these erosion planes, the Ozark, on Caseyville Pennsylvanian strata at altitudes of 750± feet, only 50 to 100 feet lower than on Gasconade dolomite 30 miles to the west. This very low gradient of the peneplain trace is a restoration of the Ozark surface from the St. Francois Mountains eastward into the Shawneetown spur of southern Illinois (see p. 62).

This correlation of summit uplands is supported by Springfield residuals (or Ozark monadnocks) on the Higdon Quadrangle west of Perry County (see p. 56), on eastern Cape Girardeau (Missouri) and Jonesboro (Illinois) Quadrangles and on Alto Pass (Illinois) Quadrangle where Bald Knob rises nearly 200 feet above the Ozark peneplain trace.

Between these uplands, the sinkhole plain in the eastern half of Perry County, some 20 miles wide, lies 200 to 300 feet below the projected Ozark profile. This is far too low to record the bottom of the Ozark cycle's Mississippi Valley on the peneplain. One thinks at once of a strath of Osage age along the master stream. But if it is that, it represents a huge and closely appressed meander loop that left the present valley route near Station Seventy-six and returned near Wittenburg. This tight curve is demanded by the hills both north and south of the suggested loop, hills that rise almost to the projected Ozark trace.

The best at present but not wholly satisfactory interpretation of the Perry County sinkhole plain's geomorphic history seems to be that the Joachim limestone which so largely underlies the sink areas was uncovered during post-Ozark erosion and yielded more readily than other formations, thus attaining a local base level before the Osage cycle was interrupted. Ground water attack probably was part of this reduction but the present population of sinks must be post-Osage.

The Grand Tower narrows.—The Mississippi River along the eastern boundary of Perry County has a flood plain from four and a half to six miles wide. For 40 miles, this valley maintains a southeastward course, then at Cape Cinque Hommes it abruptly swings directly south at the site of the most spectacular feature the Mississippi Valley possesses in all its 135 mile course along the Salem Plateau's eastern margin. At the Cape and on the inside of this curve, the river leaves the flatbottomed alluvial valley, here six miles wide, and enters the Grand Tower narrows whose maximum width is only a mile. In four more miles of length, the river again joins the broad valley. The hill thus isolated, Fountain Bluff, (Fig. 48) is nearly two miles wide and stands 400 feet above both the river on the west and the alluvial flat of the abandoned valley on the

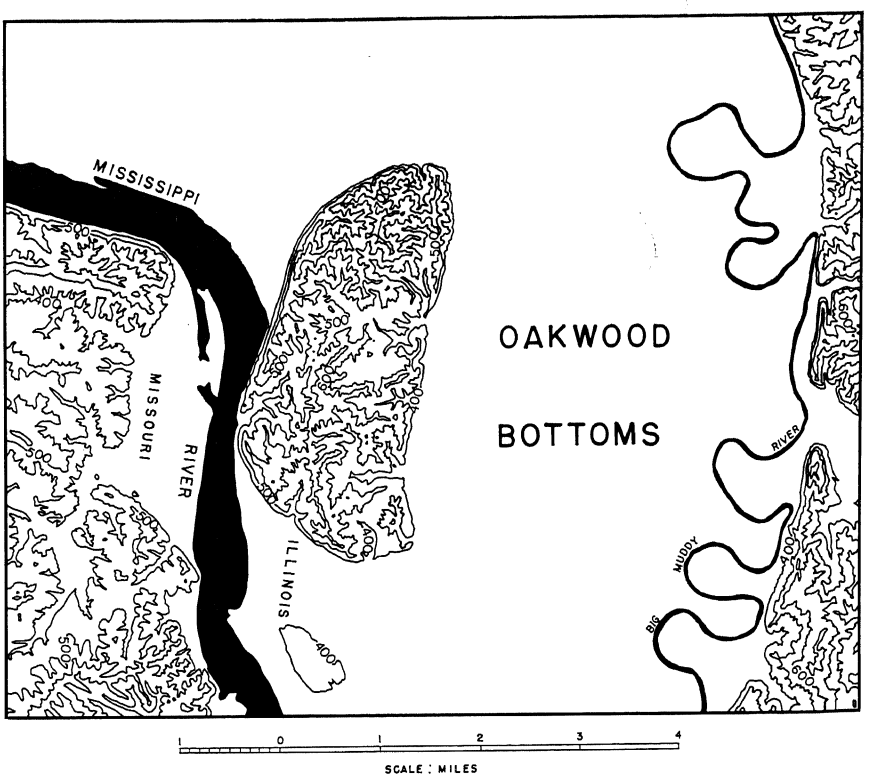

Fig. 48. Map of Fountain Bluff and environs; Altenburg Quadrangle, Missouri, and Alto Pass Quadrangle, Illinois.

east, Oakwood Bottoms, now used by the last few miles of Big Muddy River.

The prominent Rattlesnake fault crosses the mouth of the narrows but has not been a factor in determining the short detour that has given Illinois what otherwise would have been an extreme eastern salient of Perry County, Missouri.

The cause of this detour was undoubtedly the Illinoian ice sheet. Glacially deposited material has recently been reported from Fountain Bluff*, and it is an inescapable conclusion that the ice crossed the pre-Illinoian Mississippi trench at the 45 degree angle above noted to rest on the north end of Fountain Bluff long enough for the glacially detoured Mississippi to make the Grand Tower bypass in bedrock. This was deep enough to carry the river after retreat of the ice occurred. Leighton and Brophy (1961) hold the same interpretation.

However, this is not the complete story. The Mississippi has been back in the Oakwood Bottoms section of the valley in later than Illinoian time. The southern end of Fountain Bluff carries a

*Stanley Harris, personal communication.

gravel terrace of Wisconsinan age, presumably Tazewell, that tells of an outwash aggradation 40 feet higher than the present valley bottom on either side of the bluff. This valley train has been removed from both sides of both valley floors by still later river occupation of each. In the present day situation, high Mississippi floods have sent some discharge down the old valley to make the bluff a water-girt island for their duration (Leverett, 1921).

The setup at Fountain Bluff is reminiscent of that at the Saline County Big Bend of the Missouri (see p. 119) where glacial ice must have crossed a pre-existing major valley. But the only possible bypass known there, Salt Fork Valley, falls short of resembling the Grand Tower (Cinque Hommes-Wittenburg) narrows on the Mississippi. It seems most probable that the Missouri was back-ponded sufficiently at the Saline County Big Bend to deny the escaping water along Salt Fork the gradient necessary for any comparable erosion.

The Osage strath in White River valley.—It is not to be expected that later uplifts of the Ozark dome precisely followed earlier domal patterns. Already noted are departures from a uniform warping in the extreme northwest and southeast sectors of the dome, recorded there by the lack of straths of Osage and post-Osage ages. The White River drainage in Missouri, (portrayed on the Shell Knob Quadrangle and on the 7½-minute quadrangles that replace the old 30-minute Forsyth Quadrangle), has a different record of departure from uniform later doming movements. As already stated, the Ozark peneplain itself is traceable up White River drainage as only a wide, much dissected strath. In its general appearance, the Ozark strath of southwestern Missouri resembles the Osage strath in midlength of the trans-state Missouri Valley.

But Hershey's duplex White River valley is now known to be triplex, i.e. there are *two* inner valleys, one within the other. The lower is here correlated with the Osage strath because the upper and conspicuous strath so clearly records the Ozark base level, and the uplands back from the valley can only be Springfield remnants. Fenneman followed Hershey and Marbut in reading a post-Ozark (post-Salem) age for the outer valley floor, but none of them knew that the inner valley was itself double. Fenneman (1938, p. 654), however, had a saving comment that farther up the White River system in Arkansas, a width as much as 25 miles "is here denuded of its Mississippian rocks and reduced to a surface of moderate relief. As this surface is underlain by Ordovician rocks the geologic map may suggest an extension of the Salem Ozark upland. Most of it, however, is to be correlated with the bottom of the old broad valley ....." He also commented that the "older valley of the White River is more than a mere trench between bluffs. It is a strath or incipient peneplain ....." (Fenneman, 1938, p. 661). He pointed to the existence of a local upwarp, the Kings River or Osage anticline (see p. 104) as the cause of the Arkansas widening. He did not, however, consider what we believe from a

reconnaissance in Arkansas to be the correct interpretation; that both the old broad valley and the 25-mile width in Arkansas are Ozark baseleveled records.

The Kings River or Osage anticline bounds this 25-mile widening on the east and determines a row of prominent monadnocks. East of it is a much wider expanse of the Ozark peneplain about Harrison, Arkansas, not noted by Fenneman.

Showings of the dissected Osage terrace or strath are provided by the Lampe, Table Rock Dam, Branson, Forsyth, and Mincy 7½-minute Quadrangles. On Lampe Quadrangle, farthest upstream, the terrace is close to 1,000 feet A.T. On the Table Rock Dam Quadrangle, next down-stream, flat-topped minor interfluves at 960 to 980 feet are accepted as Osage valley bottom remnants. The dam's southern abutment rests against the steep valleyward slope of one such terrace whose highest marked altitude is 968 feet A.T. and whose length transverse to the valley is about a mile. Traced farther downstream, such terrace remnants on the Branson Quadrangle are approximately 940 to 980 feet A.T. Old river gravel at Branson is reported 250 feet above Lake Taneycomo. On the summit of the slip-off peninsula southwest of the town of Forsyth, there is more river gravel at close to 920 feet A.T., 260 feet above the river just beyond the lake's dam and less than a mile away. On Forsyth Quadrangle, 920- to 940-foot flattish interfluve summits record the same old valley floor, and on Mincy Quadrangle their altitudes have dropped to 920 to 900 feet. The total river length considered is 76 miles, and the present gradient of the Osage terrace remnants is a little more than a foot to the mile. The river, before dam construction here, had a gradient of a little less than one and a half feet to the mile. An original uniform descending gradient for the Osage terrace is obvious and seems impossible to explain as structurally determined when all the tortuous twistings and turnings are considered. Every point of the compass is involved in these meander courses.

Furthermore, detailed stratigraphic studies on these quadrangles have found the Mississippian-Ordovician contact consistently well above the level of the Ozark strath itself, thus disposing of the possibility that sapping at this contact has been responsible for either Ozark or Osage straths.

An asymmetry of the meander-bounded peninsulas of the Gasconade River has been noted (see p. 89) as indicating a down-valley shifting of its entrenched meanders during and since Osage time. Evidence for this same behavior along White River is shown on the five quadrangle maps. The crest lines of the peninsulas enclosed by the more strongly appressed meanders are considerably closer to their upstream margins, and the slopes down to the river there are largely cliffed and unravined. In contrast, the slopes on the downstream sides are relatively gentle and have ravines, some of which may head in notches in the crest line. Downstream shifting of a meander course, thus recorded, may be almost as great as its enlargement at the tip of its slip-off slope. In fact, the slip-off slop

includes much of the downstream side of the peninsula. Cliffs on the outside of meander curves may continue downstream to become the upstream cliffed margin of the peninsula belonging to the next meander. These relations can become graphic by imagining the river as reversed around the meanders shown on Figure 33. The pattern then becomes absurd.

Insofar as James River is included on the Reeds Spring topographic map, its meanders show a similar downstream migration. James River Valley carries a much dissected strath that rises upstream from junction with the White at altitudes appropriate for the Ozark strath. In a complicated entrenched meander less than five miles from this junction (see Shell Knob and Reeds Spring Quadrangle maps), the James flows northward for two miles and a half before resuming its southward course. Most of the irregular peninsula, thus enclosed, rises no higher than 1,000 to 1,020 feet A.T. and clearly is old valley bottom level, now expanded at lower altitudes because of later enlargement of these meander loops. Other terrace-topped, meander-enclosed peninsulas farther up the James appear to carry this same profile. The town of Galena (Galena Quadrangle) covers one such remnant of the old valley bottom without being enclosed by a meander.

Only this stretch of White River valley's length is sufficiently well mapped for our study. But these five quadrangles with 20-foot contour intervals and a scale of 1:24,000 show no lower benches. The Osage strath's altitude is about 200 feet above the present stream throughout the 76-mile stretch and thus there is ample vertical space for development of a post-Osage strath.

The fact that one does not exist appears to mean that on this southwest flank of the Ozark dome only one uplift has occurred since the Osage strath was made and the White and its tributaries have cut their valleys from the Osage level without recorded pause down to that of the present.

However much one may question the actuality of cliff sapping as a prime factor in shaping Ozark topography, he must admit its complete dominance in producing the lowland of White Rock Prairie (Noel Quadrangle) along Little Sugar Creek, a tributary to Elk River in McDonald County. The creek's valley bottom for five miles above junction with Big Sugar Creek has steep walls and a uniform width of about a quarter of a mile. But in the next four miles upstream, these walls recede and, with several minor creeks, the valley broadens for that stretch to be about as wide as long. White Rock Prairie is similarly bluff-enclosed, but its floor, shared by the half dozen converging creeks, has a relief of 150 feet or more. On this floor stand five isolated knobs 100 to 200 feet high, their summits reaching approximately to the Ozark peneplain level. Traced up the tributary creeks, the broadened character vanishes in normally proportioned stream valleys.

Three stream piracies are recognizable among these creeks and another is imminent. The ensemble is the consequence of sapping of Mississippian rock underlain at stream levels by Devonian black

shales. The geomorphic puzzle here is the absence of comparable sapping along the lower five miles of narrow valley where black shale outcrops at the base of the bluffs are obvious.

One safe generalization regarding the Ozark peneplain appears to be that it does not transect Mississippian formations anywhere in southwest Missouri east of the Eureka Springs escarpment, although it is extensively developed on Mississippian rock west of this feature. Stated in another way, the only Springfield remnants are found in the rugged country along the line of the scarp and in monadnocks east of that scarp. West of it, scarping as a marker between Springfield and Ozark surfaces did not develop because the Ordovician formations are not exposed in the uplands.

If the Springfield and Ozark erosion surfaces on the southwestern slope of the dome were the product of pedimentation instead of peneplanation, there should be remains of scarps interrupting the interfluve gradients without benefit of stratigraphy or structure. But the only steepened slopes on the western side of the Eureka Springs cuesta are stream valley bluffs.

If these two summit erosion surfaces were actually only coincidences of altitudes in a ridge- and ravine-product of noncyclic "dynamic equilibrium" that has operated continuously since the beginnings of Ozark uplift, then only contrasts in rock resistance could explain their vertical separation, their valley straths with entrenched meanders, their monadnocks, and their stream crossings of a prominent escarpment. This theory provides no logical reason for high-level stream gravels and none for broad, smooth, summit truncation of diverse formations and of faults and folds. It assumes an incredible effectiveness of rainwash and rivulets in eroding many hundreds of feet of rock from interfluve summits while their run-off concentrates, the rivers, are given credit for only a small additional fraction of the total vertical denudation. Indeed, the above listed disharmonies between theory and fact are found throughout the entire Ozark province.

CONCLUSIONS

Throughout this report, one encounters descriptions of topographic situations for which only doubtful interpretations can yet be made. For them, alternatives have been examined in the light of present knowledge and the author's choice indicated. More prominent are those larger interpretations which may be challenged by proponents of a different scheme of geomorphic evolution but which are held herein to be sound inferences. Adverse opinions are not likely to seek supporting data beyond the pages of this book because adequate field examination and detailed study of the more than 500 topographic maps would be infeasible. Such adverse interpretations have been anticipated and rebutted, yet a critic may suspect an unconscious loyalty in the author to concepts current during his schooldays. It may be argued by them that meandering of rivers does not necessarily record old age, that river gravel on

upland flats proves only that a stream once flowed there, that lone hills are not of necessity monadnocks, that clay deposits in caves may not record a former peneplain above them, that upland peneplain remnants or strath terraces may be found by a selective ignoring of some altitudes and forms, that cuesta development may be the consequence of retreat of pediment scarps, that contrasts in resistance to erosion or differential erosional attack may account for land forms herein attributed to the cycle of stream erosion, that the identification of "late mature Ozark cycle topography" is a confession that the Ozark peneplain is a purely subjective interpretation, et cetera.

Many of the ideas herewith advocated run counter to the two newer schemes of geomorphic evolution: pedimentation and dynamic equilibrium, and the author has been at pains to outline his conviction that neither scheme can explain the situations those ideas cover (Bretz, 1962).

If adequate coverage and study of the Ozarks has been made and the reasoning has been sound, the geomorphic history of the province begins with the destruction of a wide spread of Pennsylvanian sediments across the subsequently upwarped region; sediments that still cover much of the surrounding territory. In nearby Arkansas, the Boston Mountains constitute the highest remnants of this cover and earlier workers have held that, even in the absence of flat-topped interfluves, the truncation of the Pennsylvanian rocks and structures of the Bostons indicates a former base leveling. This idea can never be substantiated from field evidence and must remain only a probability, weighted by each student according to his preferences. The Ozark province itself does not tell whether its former Pennsylvanian cover was ever peneplaned, nor how much Pennsylvanian rock remained on the slopes of the dome when the first uplift definitely recorded in land forms occurred.

But the positive area, which is the Ozark dome, was uplifted enough to initiate a cycle of erosion (the Springfield) which is now definitely recorded in more than a dozen places and which ran on into old age and eventual peneplanation. The Springfield peneplain's profile, reconstructed from its surviving remnants, transsects Pennsylvanian, Mississippian, and Ordovician formations of the dome. So far as we know, it was a more nearly complete peneplanation than the later Ozark cycle produced, but it has been so largely destroyed that this is only speculation. However, the location of Springfield remnants as monadnocks on the dome's major interfluves indicates that the Ozark cycle's rivers followed the pattern of the Springfield cycle's rivers.

The long interval of diastrophic quiet which allowed the Springfield cycle to run on to its penultimate end was terminated by another domal uplifting whereby the Ozark erosion cycle was initiated. Except in the St. Francois Mountain subprovince of Precambrian rocks, almost every wide horizontal view in southern Mis-

souri contains elements bequeathed from the peneplain that was left at the end of that cycle. Even this mountainous section possesses the record, though there it is limited to the valleys floors of Paleozoic rock. All cuesta back slopes in the entire province are Ozark surfaces, and their scarped fronts had considerable relief on that peneplain, for the Ozark end product was not a featureless plain of denudation. Though its river valleys were wide, gently sloped and low in gradient, they were up to 100 feet deep. The nearly baseleveled land surfaces at the end of this cycle rose from the riverways to involve most interfluve summits and to make extensive erosional plains of them, now the site of a large fraction of all Ozark towns and farms. Conditioned by smaller stream patterns throughout the region, some interfluves lost, or never developed, a strict parallelism to radii of the dome. Thus we find places where a local radial drainage of creeks, that never were rivers, flow from a local portion of the peneplain whose production is clearly the work of those creeks alone. We have called these Tipton type areas.

Curiously, the St. Francois Mountains themselves possess no recognizable benchings left by the Springfield peneplanation which is sparingly recorded to the north, south, east, and west on the surrounding country of Paleozoic rocks. Nor is there any good record of widening of St. Francois valleys during the Ozark cycle.

Again uplift occurred and the Ozark streams were given steepened gradients. They promptly attacked the elevated peneplain and initiated a new erosion cycle, one that is operating today in an early stage of maturity. During this cycle, thus far, there are on record three pulses of uplift. The first one was the greatest, and the pause between it and the next one was the longest of the two interruptions in that series. During that pause, the larger Ozark rivers attained an approximation of base level and devoted their energies to widening their valleys. This they accomplished undoubtedly by meander undercutting of their still steeply sloped valley margins. So successful was this attack that no peninsular headlands have been left inside any of the meanders on their temporarily baseleveled flood plains. From this widening came the surfaces of the Osage straths. It was only when the second pulse of uplift came that the remarkable entrenched meanders of the Gasconade, Osage, and other large rivers were made on the northern slope of the dome. As existing today, there has been but little change in the meander pattern which was inherited from the very last of the Osage episodes.

An often made comment on an erosional history such as outlined for the Ozark province is that the sequence of events required not alone a series of diastrophic uplifts separated by long pauses but a *decreasing* series in both the amount of movement and in the duration of the intervening pauses. Otherwise, earlier records would be destroyed by later, greater movements and later, longer pauses for the streams to catch up in performance of their duty of reduction of land to base level.

In that is the answer to the challenge. For a region with but one peneplanation on record may have had several briefer epi-

sodes because of less marked uplift and shorter consequent and incomplete cycles of erosion. Only where the succession of the contrasting events of uplift and erosion did decrease with time can there exist any record. If perchance the post-Springfield uplift was pulsatory, Ozark peneplanation has destroyed any possibility of knowing the fact. Only a series diminishing in magnitude of uplift and of duration of the intervals of quiescence can tell us of their occurrence.

Many questions raised in this report have been left unanswered because of insufficient information or imperfect understanding. Future geomorphic studies will answer them but undoubtedly will discover more questions. Complete agreement, in such studies, with all interpretations of this report can hardly be expected. But a closer approximation to a correct geomorphic history of the Ozarks will surely result as students of the future obtain more data and a better understanding of fundamental principles. No report like this can be final.

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INDEX OF GEOGRAPHIC AND GEOMORPHIC FEATURES

A

Page

Allenton 68
Alton 79
Antire Creek 63
Arcadia 29
Arkansas River 97
Atwood Ridge 74
Auburn 69
Ava 84
Avon escarpment 57, 61, 62

B

Back Creek 61
Bald Knob 126
Baraboo 67
Barry County 97, 98, 100
Barton County 97, 103
Bassville monadnock 101
Bates County 107, 108
Beachler Ridge 86
Bear Creek, Jefferson County 63
Bear Creek, Taney County 86
Beaver Creek, Taney County 84, 86
Belew Creek 60
Belle 38, 40
Benton County 48, 49, 107
Benton Hills 74
Bethany escarpment 52
Betrunking 117
Big Creek, Carroll County 121
Big Creek, Cass and Henry Counties 51
Big Muddy River 88, 127
Big Piney River 44, 91, 99
Big River 22, 25, 29, 56, 60, 62, 64
Big Sugar Creek 130
Black Mountain 29
Black River 22, 31, 72, 76
Blackwater River 48, 51, 52, 114, 119, 125
Blue River 52
Boeuf Creek 117
Bollinger County 56, 72
Boone County 110
Boonville 103, 124
Boston Mountains, definition 12
Bourbeuse River 40, 43, 92
Bowling Green 69
Branson 85, 86, 129

Page
Breadtray Mountain 104
Brunswick 113
Brush Creek, Franklin County 117
Bryant Mound 104
Bull Creek, Taney County 85
Burlington escarpment, definition 56
Butler County 75

C

Cabool 35, 80
Callaway County 56, 100
Camden County 45, 48, 92, 93
Campbellton 117
Canaan 38, 40
Cap au Gres fault 69
Cape Cinque Hommes 126
Gape Girardeau County 56, 72
Carter County 75, 76
Case 117
Castor River 56, 58, 72, 118
Cass County 52, 54
Caves 12, 87
Cedar Creek, Boone and Callaway Counties 112, 114
Central Illinoisan Stage, definition 109
Chariton County 113
Chesapeake fault 98
Chesapeake State Park 101
Chestnut Ridge, Christian County 86
Christian County 101
Clay County 55
Clayville 94, 110, 117
Clinton County 55
Coldwater 58
Cole Camp 89
Cole County 49, 110
Columbia 112
Compton Ridge, Stone County 85
Continental ice sheet 21
Cooper County 48, 103
Crawford County 43, 68, 92
Crooked Creek, Bollinger County 58, 118
Crystal escarpment, definition 62
Cuivre River 69
Current River 75

D

Dade County 104
Deep Valley Stage, definition 118, 124
Dent County 32, 38
Dewey Bald 85
Dewitt 120
Diamonds 117

Page
Dickens 84, 86
Dixon 45, 91
Dodgeville peneplain, definition 22
Doniphan 76
Douglas County 100
Dove Mountain 35
Dundee 117
Dutchtown 73

E

Eldon 49
Eleven Point River 31, 79
Elk River 100, 103, 130
Ellsinore 75, 76
Elsberry 69
Embayment escarpment, definition 72
Eugene 49
Eureka Springs escarpment, definition 14

F

Fairgrove Mound 101
Fanning Fault 40
Farmington Plain, definition 59
Filled sinks 40, 79
Flat Creek, Barry County 97
Fort Leonard Wood 44
Fountain Bluff 126
Franklin County 42, 44, 62, 64, 92, 113, 116, 124

G

Gainesville 80
Galena 130
Gasconade 69
Gasconade County 38, 91, 92
Gasconade River 31, 44, 46, 89, 114
Glasgow 120
Glen Allen 58
Gospel Ridge 44, 45
Grandin 75
Grand River, North 114, 121
Grand River, South 52
Grand Tower 126
Gray Summit 42, 64, 67, 116, 124
Greenbriar 57
Greene County 101, 105
Grover 66

H

Halltown 101, 104
Harrisonville 53

Page
Havana strath, definition 109
Helm 45, 91
Henry County 108
Herculaneum 63
Hermitage 105
Hickory County 56, 105
Higdon 29, 56, 119, 126
High Ridge 63
Hilltop 76
Hinkson Creek 113
Holts Summit 94, 110
Hope 84
Horse Creek 98
House Spring 63
Howell County 79
Hugo 92
Hunter 75
Hurricane Creek 118

I

Iconium 93
Independence 54
Indian Ridge 86
Ironton 25, 30

J

Jacks Fork 77
Jackson County 54
James River 46, 130
Jefferson City 110
Jefferson County 56, 60, 62, 66, 68
Joachim-St. Peters escarpment, definition 62
Johnson County 52
Jonca Plain 29
Jonesboro 126

K

Kansas City 55, 109
Kansas River 109
Karst, definition 12
Kiel 117
Killarney, lake 27
Kimmswick 55
Kings River 105
Kings River anticline 129
Knob Creek 26, 30
Knobnoster 53, 125

L

Labadie 116
Laclede County 45, 92

Page
Lafayette County 52, 54
Lake of the Ozarks 48, 94
Lake of the Ozarks State Park 93
Lamar 97, 103
Lamine River 48, 51, 114, 123
Lancaster peneplain, definition 22
Lanes Prairie 37, 43, 45
Lawrence County 164
Leasburg fault 43
Leavenworth 109, 125
Lebanon 45, 48
Lick Creek 121
Licking 35, 49, 59, 77
Lincoln County 55, 69
Lincoln fold 69
Lincoln Hills 55, 68, 75
Linn 45
Little Antire Creek 63
Little Black River 118
Little Blue River 52
Little Dry Fork 43
Little Maries River 45
Little North Fork 84
Little Osage River 106, 108, 109
Little Pomme de Terre River 101
Little St. Francis River 57, 61
Little Sugar Creek 130
Logan 100
Lodi 58

M

Madison County 51
Malta Bend 122
Mancas Creek 114
Mansfield 46
Maries County 37, 45
Maries River 45
Marionville 101
Marlow-Black Narrows 29
Marmaton River 107, 109
Marshall 123
Marshfield 46
Marthasville 118
McDonald County 130
McDowell 97
Meramec River 31, 43, 60, 65, 92
Middlebrook Creek 26
Miller 164
Miller Chapel ..... 5[illegible]
Miller County ..... 45, 48, 1[illegible]
Mokane ..... 1[illegible]
Monegaw Spring ..... [illegible]

Page
Monett 97
Moniteau County 48
Moreau Creek 49
Moreau River 71, 110, 114
Morgan County 48, 92, 107
Mound 104
Muddy Fork Creek 97

N

Naylor 76, 119
Neosho 104
New Haven 117
New Offenburg 62
Newton County 98, 104
Niangua River 46
Noel 172
North Fork River 31
Northview Hill 46

O

Oakwoods Bottoms 127
Old Alexandria 69
Olivers Prairie 98, 104
Osage anticline 129
Osage County 45, 91
Osage River 31, 48, 49, 92, 94
Osage Stage, definition 108
Osceola 103, 107
Owensville 38, 40, 43, 67, 117
Ozark County 82
Ozark peneplain, definition 10
Ozark Plateau, definition 11

P

Perry County 56, 125
Petite Saline River 71
Pettis County 51, 103
Pevely 62
Phelps County 33, 38, 43
Phillipsburg 46
Pike County 55, 69
Pilot Knob, Iron County 29
Pilot Knob, Phelps County 38
Pilot Knob, Stone County 104
Platte County 55
Platte River 114
Polk County 105
Pomme de Terre River 31, 46, 101, 105
Pond 68
Pooles Prairie 104
Post-Osage Stage, definition 115

Page
Precambrian peneplain, definition 13
Proctor Lookout 49
Protem 82, 84
Pulaski County 44, 91

R

Rattlesnake fault 127
Ray County 55
Raymondville 49, 59, 77
Red Bank 84
Reeds Spring 85
Resurrected Hills 105
Richards 108
Richwoods 60
Ripley County 75, 76
Rising Creek 111
Roark Creek 85
Roby Lookout 44
Rolla 43
Rosati 68
Roy 84

S

Salem Creek, St. Francis and Ste. Genevieve Counties 60
Salem Plateau, definition 11
Saline County 119, 122
Saline Creek, Iron County 25
Saline Creek, Jefferson County 63
Saline Creek, Madison and Perry Counties 56
Salt Fork 119
Salt Pond Creek 125
Sand Ridge 63
Scholten 101
Scott County 73
Sedalia 103
Shannon County 76
Shawneetown Ridge, definition 11
Shell Knob 97, 104, 128
Shepherd Mountain 27, 29
Shoal Creek 96, 98, 100, 103
Shut-in, definition 13
Slater 120, 121
Sniabar Creek 52
South Dry Sac 98
South Greenfield 104
Springfield Plateau, definition 12
Springfield peneplain, definition 21
Spring River 96, 97, 100, 104
Sprott 62
St. Charles 55, 124
St. Clair 67

Page
St. Clair County 93
St. Francis County 56
St. Francis River 22, 31, 56, 62, 72, 118
St. Francois Mountains, definition 11
Ste. Genevieve County 56
St. Joseph 109, 125
St. Louis County 55, 66, 68, 92
Station Seventysix 126
Steelville 68, 92
Sterling 80
Stoddard County 74
Stone County 104
Stoutland 45
Stouts Creek 26, 61
Stutts 85
Sugar Creek 63
Sullivan 44, 60
Summersville 77
Swan Creek 84
Sweet Springs 125

T

Taberville 107
Table Rock Dam 129
Taneyville 84
Taum Sauk Mountain 23
Terre Bleu Creek 60
Teteseau Flats 122
Texas County 33, 44, 76
Tipton 70, 105
Troy 69
Turnbo Creek 46
Turtle 36
Twelve Mile Creek 58

U

Union 67, 117

V

Valhalla 94
Vergil Mound 108
Vernon County 108
Vetters Hill 108
Vichy 37
Vienna 89

W

Wachita Mountains 61
Walnut Grove 105
Warren County 62

Page

Washington 113
Washington County 60
Wayne County 58
Webster County 46, 102
Weingarten 62
Wheatland Prairie 105
White River 31
Whitewater River 56, 72, 118
Wildhorse Creek 66
Williams Creek 64
Williamsville 76, 119
Whittenburg 126
Womack 29, 56
Wright County 100

Y

Yancy Mills 38

Z

Zalma 119