GEOLOGY

of the

FIRE CLAY DISTRICTS

of

EAST CENTRAL MISSOURI

By

H. S. McQUEEN
Assistant State Geologist

With Chapters on
The Results of X-ray Analyses of the Clays
and
The Results of Firing Behavior Tests

By

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Vol. XXVIII, Second Series

1943

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MISSOURI GEOLOGICAL SURVEY
AND WATER RESOURCES

ROLLA, MISSOURI

MID-STATE PRINTING CO., JEFFERSON CITY, MO.

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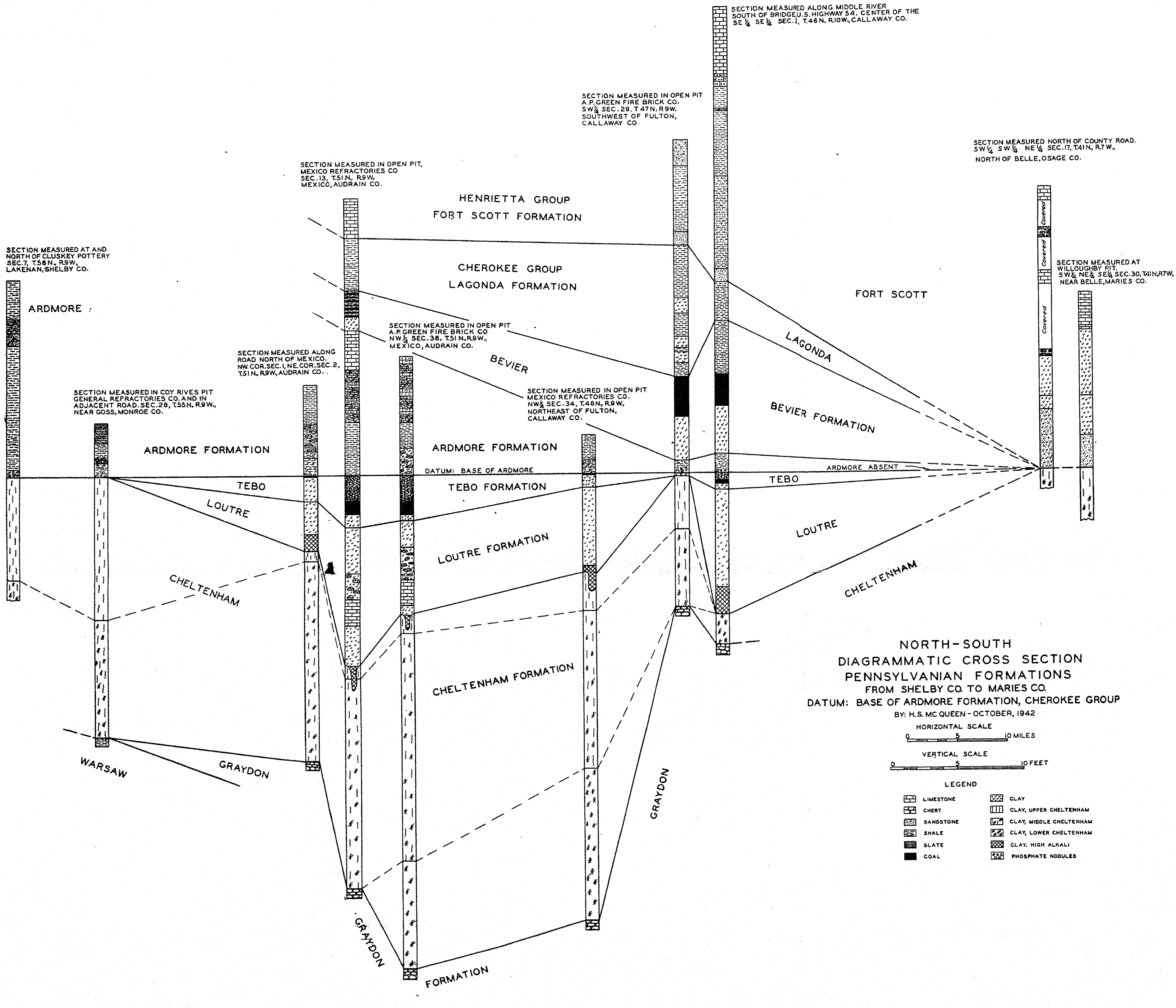
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BY: H. S. MC QUEEN - OCTOBER, 1942
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0 5 10 MILES
VERTICAL SCALE
0 5 10 FEET
LEGEND
LIMESTONE
CHERT
SANDSTONE
SHALE
SLATE
COAL
CLAY
CLAY, UPPER CHELTENHAM
CLAY, MIDDLE CHELTENHAM
CLAY, LOWER CHELTENHAM
CLAY, HIGH ALKALI
PHOSPHATE NODULES

LETTER OF TRANSMITTAL

Honorable Forrest C. Donnell
Governor of Missouri
Jefferson City, Missouri

Dear Governor Donnell:

I have the honor and pleasure to transmit herewith a report on the East Central Missouri Fire Clay Districts, by H. S. McQueen.

The publication of this report is very timely as the refractories industry is of paramount importance in the present war effort. The report should be a definite geologic guide to further development of the districts.

For the past ten years the clay industry has been a very important one in Missouri in the value of output, and the super refractories produced are not excelled in quality by any region in the United States.

The occurrence of high-grade refractory clays in this State may be grouped under three districts: (1) the northern district, including Audrain, Callaway, Montgomery and adjoining counties where the so-called plastic and semi-plastic fire clays occur in blanket-like deposits and constitute one of the most important reserves of fire clay in the United States; (2) the southern district lying south of the Missouri river centering in Gasconade, Maries, Osage and adjoining counties and comprising the so-called diaspore-flint clay district. This district is unique in that it is the only area in the country producing diaspore clay, a clay assaying over 70% alumina; and (3) the St. Louis district located in the city and county of St. Louis where the occurrence of the plastic clays in the Cheltenham formation were early recognized, and where the refractories industry of the state was first developed.

To have made this study complete the St. Louis district should have been included in the present report, but to have made a detailed study of the complicated geology of the area would have delayed the present report several months and would thus nullify its value in the present emergency. The St. Louis area, the productive portion of which has been outlined by past years of work, will later be made the subject of an additional report.

This report is the first published attempt to describe the complicated geology of the region from the standpoint of the occurrence and origin of the various types of clays. The geology is much more complicated than it was formerly thought to be, and Mr. McQueen has shown that several periods of deposition have been involved in the formation of the deposits and that the relative age of deposition, and the geologic structure, have had a vital influence on the character of the clays that are produced from the same pit and superficially appear to be derived from the same bed of clay.

The chapter on burning tests made by Prof. Paul G. Herold shows the refractory qualities of the various clays.

It is believed that this report is one of the most valuable issued by the Geological Survey.

Respectfully submitted,

H. A. BUEHLER, State Geologist.

GEOLOGY OF THE FIRE CLAY DISTRICTS OF EAST CENTRAL MISSOURI.

By H. S. McQUEEN

CHAPTER I.

INTRODUCTION.

PURPOSE OF REPORT.

Two of the most important fire clay districts in the world are located in east central Missouri (Fig. 1). These districts possess several features of great economic and industrial importance, and as a whole are making an important contribution to the war effort. Among the outstanding features are the presence of the only commercial deposits of the high alumina bearing, diaspore clay in the United States, extensive reserves of flint fire clay, and what are probably the largest reserves of plastic and semi-plastic fire clay in the United States.

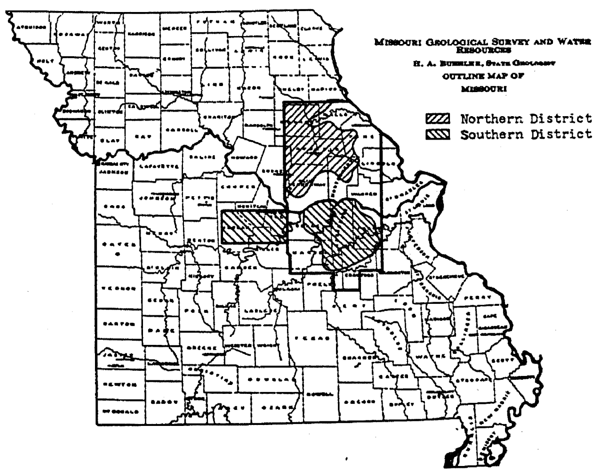

Fig. 1. Location of clay districts.

With the increased use of the fire clays from these districts in the manufacture of fire brick and super refractories, so vital at this time, there has been an ever increasing demand for information pertaining to the clays and to the possibilities of adding to the reserve supply now being drawn upon so heavily.

The present report has been prepared as a guide to the clays of the districts. It sets forth the geologic relations and modes of occurrence, the physical, chemical, and mineralogical properties, the gradations between the clays, the manner in which they have been produced, and the general stratigraphy and geologic structure of the area.

LOCATION OF DISTRICTS.

On the map (in pocket) accompanying this report the districts are outlined. The Missouri River forms a convenient and fairly definite line of separation. The northern district is underlain by the wide-spread blanket-like Cheltenham clay formation of the Cherokee group of the Pennsylvanian system. It contains plastic, semi-plastic, semi-flint, and flint fire clays.

In outlining the area in which the Cheltenham clays will be found, the clays or the rocks overlying them have been used, and the area of occurrence is indicated by the yellow color. The area designated totals over 2400 square miles. In the area marginal to the Cheltenham clay formation, there occur depressions filled with semi-flint and flint fire clay, which are remnants of that formation. Such deposits are also indicated on the map and their concentration is a guide to general areas for further prospecting.

The northern district is one of the most important fire brick and refractory manufacturing districts in the United States. The location and names of the various fire brick plants are shown, and the location of the deposits being worked within the area, are indicated also.

The southern district is outlined by a blue color and covers over 600 square miles. In delineating this area, the basal formation of the Cherokee group, the Graydon composed of chert conglomerate and sandstone, has been used. This formation caps and holds up the upland or plateau-like surface on which most, if not all, of the larger deposits occur.

The clays range from the hard non-plastic flint fire clay to the highly aluminous or diaspore clay, with an intermediate clay called burley clay being found also. These clays occur in a unique manner, in funnel-like sink-hole type deposits, hence prospecting for them where surface expressions are absent, is difficult. The individual deposits known to the writer have been indicated on the accompanying map and their concentration may again be a guide for further and more systematic prospecting. The map is designed as an aid and guide in such prospecting and many features have been shown, which it is believed will make the map useful.

Of particular interest to the refractories industry and to ceramists in general is the chapter describing the results of firing behavior tests of the types of fire clays described in the report. The results have been obtained and described by Professor Paul Herold, Chairman, Department of Ceramic Engineering, Missouri School of Mines and Metallurgy, from samples collected by the writer from the different clays of the districts. The ceramic data are an important contribution to this report. Dr. Herold has also contributed a chapter describing the results of X-ray studies of the clays.

The report and map are offered with the hope they will be of assistance in the further development of the district and particularly in establishing substantial reserves of these important clays, which are so basic and so vitally important to the successful prosecution of the war.

CLAYS OF THE DISTRICTS.

Several types of clays are found in east central Missouri. Each is described in detail in later chapters of this report. As a matter of convenience they may be summarily described at this time as follows:

(1) Plastic to semi-plastic or semi-flint fire clay, varies from soft to fairly hard, varies also in color and texture; grades imperceptibly into, (2) flint fire clay, a hard, compact non-plastic fire clay. Flint fire clay is characterized by a conchoidal fracture and sharp splintery edges, and grades into (3) burley clay, so called because of the presence of "burls" or shot-like particles (oolites) or small nodules (pisolites), which usually are highly aluminous in character. As the number and aluminous content of particles increase this clay grades into (4) diaspore clay, which is usually a rough textured, compact clay of varying color and hardness, and distinguished by a high alumina content. Diaspore clay is the

designation used in the districts for clay containing a minimum of 70 per cent alumina (Al_2O_3). There are many variations between the types of clay above described, and they will be discussed in detail in later pages of this report.

USES OF THE CLAYS.

The clays of the northern district are used in the manufacture of high grade fire brick and other refractories. Those made of flint fire clay and diaspore clay have no equal, and the high standard of manufacture maintained by the fire brick and refractories companies operating in the State has given Missouri fire clays and Missouri fire brick an international reputation.

The recognition of Missouri clays and Missouri refractories and the important part they are playing in the war effort was expressed on November 10, 1942 by the United States Maritime Commission in the award of the Maritime "M" Pennant and Victory Fleet Flag to the A. P. Green Fire Brick Company, and the Maritime Labor Merit Badges to all of its employees for the production of fire brick and fire clay specialties for use in Liberty Ships and other cargo vessels.

Missouri fire clays, and the products manufactured therefrom, are probably playing a more varied and important part in the war effort than any other domestic mineral resource. Although specific uses of the fire brick are mentioned in chapter V, which describes the results of firing behavior tests, it is proper to mention briefly at this time a few of the many basic industries in which these products are vital to successful operation. In fact, it could well be said that wherever there is fire, there is Missouri fire brick.

Important industries are the manufacture of iron and steel, the smelting and refining of metals, the refining of petroleum, the manufacture of cement and lime, the manufacture of glass, the railroad and maritime shipping, and the generation of electric power through the consumption of fuel. In addition to the manufacture of high alumina refractories, the diaspore clay, particularly a high iron variety, has been used in the manufacture of certain types of cements, and a similar variety was used at one time in the manufacture of abrasives.

Uses other than for the manufacture of fire brick, annually consume a considerable tonnage of flint fire clay. The hard, very white, fine grained type is used as a filler in the rubber industry, and this type, as well as other flint clay types, is used also in the chemical industry. Stoneware has been made from the plastic clays of the upper and middle members of the Cheltenham formation in a plant located near Lakenan, Shelby County and also in plants that were operated at one time in the vicinity of Clapper, Monroe County.

The utilization of the various clays in the production of aluminum has been considered. In this connection it would be well to consider briefly the various types of clay and certain factors affecting them.

The high alumina diaspore clay occurs in local sink-hole type deposits. The alumina content of this clay is variable and the size and shape of the deposits and mode of occurrence are factors that preclude large scale operations. While the actual tonnage of unmined diaspore clay is not known, it is apparent to any casual observer that the tonnage being mined for use in the fire brick industry at the present time vastly exceeds the present rate of discovery. Although additional deposits will be discovered with modern methods of systematic prospecting, it is not believed that the tonnage of diaspore and associated burley clay will ever reach a comparatively large figure.

The foregoing statements are also applicable to the pocket like or sink-hole type deposits of flint fire clay and the semi-flint fire clay of the northern district.

The plastic and semi-plastic clays to be described in subsequent pages of this report as occurring in the middle and upper members of the Cheltenham formation are more extensive and occur as blanket-like or bedded deposits over a wide area. One or both will occur under many square miles of the northern district described in this report. The clays could be utilized for this purpose, but under present economic conditions, the silica content of from 50 to 55 percent is probably too high and the alumina content of 25 to 30 percent is probably too low to compete with clays of higher alumina content available elsewhere. Of the above general composition, however, it is believed that the tonnage of plastic and semi-plastic clay in the middle and upper members of the Cheltenham formation in the northern district is sufficiently large to support both the requirements of the fire brick industry and an aluminum industry as well for many years to come.

ACKNOWLEDGMENTS.

The present report is a summary of field investigations of the fire clays of east central Missouri by the Geological Survey over a period of many years. It is also a testimony to the whole-hearted cooperation extended, without exception, by the fire clay and fire brick industries of Missouri. Without that splendid cooperation, without the unfailing willingness to help at all times, to show new and interesting features, and to provide discussions, often of closely held information, this report would not have been possible.

There has never been an occasion when the present writer has been denied access to a pit, a large mine or a plant. On many occasions persons with operating responsibilities have taken time from their duties to guide the way to a deposit exhibiting some unusual or new feature, or to search for some record that was considered to be pertinent to this report.

For this unselfish and genuine interest the writer expresses his deep appreciation. In the preparation of this report, he has not been unmindful of this splendid cooperation and genuine hospitality, nor forgetful of the many worthwhile ideas, obtained by others as the result of years of experience in the districts, which were given freely and generously. Many of these ideas are incorporated in this report.

With the foregoing in mind the writer has endeavored to repay his indebtedness by the preparation of a report that will serve as a practical guide to the geology of the district, a classification of the clays, a definition of their mode of occurrence, and finally and most important, the offering of suggestions that may result in the discovery of new deposits and thus add additional tonnages of high grade clays to the reserve supply of Missouri.

To cite specifically and to acknowledge the help of those who have contributed to this report would be to call the roll of the personnel roster of every clay mining and fire brick company operating in east central Missouri. Particular assistance has been rendered, however, by Ben K. Miller, Mining Superintendent, A. P. Green Fire Brick Company, Mexico; Edward Sassman, Mining Superintendent, Owensville, and Harry C. Stulting, Mining Engineer, Huntington, West Virginia, both of the General Refractories Company, and Clyde Evans, Mining Superintendent, Harbison-Walker Refractories Company, Vandalia, Missouri.

Professor Walter D. Keller, Chairman, Department of Geology, University of Missouri, generously contributed much information pertaining to the clays, particularly the occurrence and mineralogy. Professor Victor T. Allen, Department of Geology, St. Louis University, also contributed to the discussion of the mineralogy and made several determinations. Two previous papers, by Allen, describing the mineralogy of the clays of east central Missouri have been freely quoted in this report.

The writer also desires to acknowledge the assistance of associates in the Missouri Geological Survey.

The investigation was undertaken at the direction of Dr. H. A. Buehler, State Geologist, whose advice and counsel have been freely given regarding many problems connected with the field work and the preparation of this report.

The help of Garland B. Gott is gratefully acknowledged. He revised the original clay map of east central Missouri, prepared by the writer, and prepared also the geologic cross sections appearing in this report. He also prepared at the direction of the writer the interesting map showing the alignment or direction of the axes of several pits in the southern district. (Pl. XXIV.) He also accompanied the writer on one short field trip.

Frank C. Greene discussed with the writer many problems pertaining to the stratigraphy of the Pennsylvanian in connection with the preparation of this report. He also assisted materially in regard to earlier definitions and stratigraphic nomenclature. This help is gratefully acknowledged.

John G. Grohskopf contributed data pertaining to the pre-Pennsylvanian formations and also prepared, from sample studies, certain well logs that were used by the writer in the interpretation of the geologic structure. That assistance is acknowledged with thanks.

Kenneth Aid mapped in detail, by stadia traverse, the Goss locality in Monroe County (Pl. XIV), and also prepared the map of the Kruegers Ford anticline, Gasconade County (Pl. XXXII). He also made other structural reconnaissance studies in the southern district from which the writer obtained valuable information. This splendid help is gratefully acknowledged.

R. T. Rolufs made many chemical analyses during the latter part of 1942. Previous analyses were made by Herbert W. Mundt. W. E. Davis prepared the illustrations and L. J. Grimm drafted the accompanying map of East Central Missouri. Davis also assisted in compiling certain statistics of production and expertly aided in the preparation of the formal text. Miss Mary Houston faithfully and efficiently performed the arduous stenographic work necessary to the preparation of the text, and compiled some of the statistics of production.

The section describing the occurrence of the unusual uranium-bearing mineral, metatorbernite, in flint fire clay was prepared by Dr. O. R. Grawe. The writer appreciates the courtesy of permitting the inclusion of this section in the present report.

Chapters V and VI describing the results of X-ray studies and the firing behavior of the clays, were prepared by Professor Paul G. Herold, Chairman, Department of Ceramic Engineering, Missouri School of Mines and Metallurgy. These contributions to the constitution and physical properties of the clays form a very valuable part of this report.

DEVELOPMENT AND PREVIOUS SURVEYS OF THE DISTRICTS.

The fire clay industry of east central Missouri began according to Wheeler[1] in 1883 when the first fire brick plant was started near Vandalia, Audrain County, in the northern district. Production of flint fire clay in the southern district was begun, according to him,[2] about the same time. The first report specifically describing the fire clays of east central Missouri was prepared by Wheeler.[3] That report is a classic and is today a reference work for the entire area.

The occurrence of diaspore clay was not known at the time of Wheeler's investigation. In fact for many years the rough, ashy, porous, sometimes oolitic material found with the flint fire clays in the sink-hole type deposits in the Ozark region, and known as "sand rock" or "waste clay", was discarded in mining operations. From a review of the available records it would appear that the first knowledge of the alumi-

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[1]Wheeler, H. A., Clay Deposits, Mo. Geol. Survey, 1st Ser., Vol. XII, p. 294, 1896.
[2]Idem. p. 228.
[3]Idem.

nous character of this waste material was known in 1908 according to Crawford,[4] who also reports that the the first refractories from this clay were made in 1914. The first published recognition of the presence of the mineral diaspore in the clays was made by Wherry.[5]

Field studies were made by Ries in the southern or diaspore district in the summer of 1918 and the results were published.[6] Studies of the chemical composition of the clay were being made by the Missouri Bureau of Geology and Mines (now called the Missouri Geological Survey) about this time, and the term diaspore was first applied. The results of this work presented by Buehler[7] attracted the attention of producers, and commercial shipments were made as early as 1918 by the late W. S. Cox of Cuba, Missouri. The analytical work by the Missouri Geological Survey attracted the attention of other operators and users and the market for the clay was gradually developed and expanded.

Field work was undertaken by the Missouri Geological Survey during the first World War, and much information pertaining to the flint fire clay and burley and diaspore clay was gathered by C. R. Schroyer. During the period 1922 to 1923 field work was carried on by Roy H. Hall. In 1925 the work was continued by the author[8] and additional data collected by him were incorporated with the existing and previously collected information and published as a map of the district.

The work was continued at intervals in both the field and laboratory of the State Geological Survey. In the latter, some notable results were obtained by H. W. Mundt regarding the chemical composition of the clays, particularly the diaspore clay and the component fractions thereof, and some of the results were released.[9]

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[4]Crawford, J. L., High Alumina Refractories, Jour. Amer. Ceram. Soc., Vol. 6, No. 1, p. 291, 1923.

[5]Wherry, E. T., Diasporite in Missouri, Amer. Mineralogist, Vol. II, No. 12, p. 144, 1917.

[6]Ries, H., and others, High grade clays of the Eastern United States, U. S. Geol. Survey, Bull. 708, pp. 135-147, 1922.

[7]Buehler, H. A., Mo. Bur. Geol. and Mines, Biennial Report, State Geologist, 50th General Assembly, pp. 17-20, 1919.

[8]McQueen, H. S., Map of East-Central Missouri Fire Clay Districts, Mo. Bur. of Geol. and Mines, 1926.

[9]Press Notice, Mo. Bur. Geol. and Mines, May 30, 1925.

Subsequent work by the author resulted in the preparation of two short reports, one[10] pertaining to the geology and the other in collaboration with C. R. Forbes[11] describing the occurrence and methods of mining and prospecting in the southern district.

In the period 1934 to 1936, V. T. Allen[12] made for the Missouri Geological Survey the first detailed study of the mineralogical composition of the clays and two excellent reports were issued. One described the flint and diaspore clays of the southern district and the other,[13] the Cheltenham clay of the northern district.

In the latter part of 1941, and the early part of 1942, Garland B. Gott undertook the revision of the original clay map of the districts, by adding the deposits opened since its publication. This map was completed in June, 1942 and it is believed to represent a distinct improvement in every detail.

In September, 1942, a short time before Gott's resignation from the Geological Survey he and the writer made a brief trip through the district. Additional short field trips have been made by the writer on several occasions, and the information obtained, added to that collected in earlier surveys has been brought together in this report.

CHAPTER II.

THE NORTHERN DISTRICT.

Geography. The area of the east central Missouri fire clay districts as considered in the present report is outlined on the accompanying map (in pocket), and the relation of the area to the State as a whole is shown in Figure 1. Geographically, geologically, and from the standpoint of clay types, the district may be divided into two distinct portions or sub-districts, and that plan will be followed in this report. These sub-

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[10]McQueen, H. S., Geologic relations of the diaspore and flint fire clays of Missouri, Jour. Amer. Ceramic Soc., Vol. 12, pp. 687-697, 1929.

[11]McQueen, H. S., and Forbes, C. R., Mining of diaspore and flint fire clays in Missouri, Mining and Metallurgy, Vol. 9, pp. 271-275, 1928.

[12]Allen, V. T., Mineral Composition and Origin of Missouri flint and diaspore clays, Mo. Geol. Survey, 58th Biennial Report, State Geologist, App. IV, 1935.

[13]Allen, V. T., The Cheltenham Clay of Missouri, Mo. Geol. Survey, 59th Biennial Report, State Geologist, App. V, 1937.

districts are described in this report as the northern district and the southern district.

The northern district lies north of the Missouri River and in the fertile upland or prairie region characteristic of most of the northern portion of Missouri. The manufacture of fire brick and the mining of clay are the most important mineral industries; in fact the area makes the largest contribution to the total output and value of fire brick and other refractories manufactured in Missouri, an industry in which the State ranks second among the States of the union.

It is further distinguished by what is considered to be the largest reserve tonnage of plastic and semi-plastic clays in the world. The available tonnage of flint clay, lying as masses or lenses in depressions at the base of the continuous and widespread Cheltenham formation or as outlying sink-hole deposits in the area marginal to the formation, is also considered to constitute one of the largest reserves in the United States available to the fire brick industry.

The following companies operate plants:

Audrain County:

1. A. P. Green Fire Brick Company, Mexico.
2. Botfield Refractories Company, Mexico.
3. Harbison-Walker Refractories Company, Vandalia.
4. Mexico Refractories Company, Mexico.
5. North American Refractories Company, Farber.
6. Walsh Refractories Corporation, Vandalia.
7. Western Stove Lining Works, Mexico.

Callaway County:

1. Harbison-Walker Refractories Company, Fulton.

Montgomery County:

1. New Florence Fire Brick Company, New Florence.
2. Wellsville Fire Brick Company, Wellsville.

In addition to the foregoing plants, two companies operating fire brick plants in the St. Louis area, are also operating large scale mines in east-central Missouri. They are as follows:

1. The General Refractories Company, Gregg Station, Clayton, St. Louis County, operating a large mine south of Wellsville, Montgomery County.
2. Laclede Christy Clay Products Company, operating a large open pit mine, south of Wellsville, Montgomery County.

In addition, other companies buy clay on the open market in this district.

The district is served by an excellent system of Federal and State Highways and county roads, the principal ones being shown on the accompanying map. The flat topography characteristic of most of the area has permitted the construction of an intricate network of roads, which makes almost every locality accessible, and also permits economical trucking of clay over considerable distances.

Five railroads serve the district. The central and most highly developed portion is served by the Wabash Railroad, the Alton Railroad, and the Chicago Burlington and Quincy Railroad, the three furnishing adequate and direct transportation facilities to Kansas City, St. Louis, Chicago, and Detroit.

The Wabash Railroad and the Chicago Burlington and Quincy Railroad also traverse the northern limits of the district as defined in this report. The northeastern portion, and one undeveloped to date is served by the St. Louis and Hannibal Railroad, which extends from Hannibal to Perry. The southern margin of the northern district is traversed by the Missouri-Kansas-Texas Lines.

The northern district is separated from the southern district by the Missouri River. It is further separated by the mode of occurrence and the types of clays. Here the high-grade clay occurs as a bedded deposit in the Cheltenham formation of the Cherokee group. It ranges in thickness from a few to a maximum of 65 feet, and in character from plastic through semi-plastic and finally into hard non-plastic flint fire clay. Around the margin of the area underlain by the bedded deposit of Cheltenham clay are pocket-like deposits of hard flint fire clay and locally similar pocket-like deposits of plastic clay.

The occurrence of the high alumina diaspore clay in the northern district is rare. High grade burley with possibly a small amount of No. 1 diaspore has been found near Whiteside, Lincoln County, and south of Warrenton, and Wright City, Warren County, at least two other isolated deposits are known. In the above two specific instances the sink-hole type structure to be described as common to the southern district is present.

The main producing counties of the northern district are as follows: Audrain, Callaway, Montgomery and Warren Counties. A small but important separate area of production is also found in Lincoln County and recently a deposit of semi-plastic clay of some promise has been opened to production near Goss, Monroe County in the northern portion of this district. Additional deposits of a similar nature may be reasonably expected elsewhere in the district. Deposits of clays varying from plastic through semi-plastic and into flint fire clay have been previously described as occurring near Perry, Ralls County.[1]

In addition to the foregoing, deposits of semi-plastic and flint fire clays are known to occur in Boone County, and deposits are also reported as occurring in the area underlain by the Cherokee group in St. Charles County, which may well be the connecting link between the northern district and the Cheltenham district of the St. Louis area. The western and northern limits of the northern sub-district have not been defined. It seems likely that the blanket deposit of the Cheltenham formation will extend, particularly in a northwesterly direction, for some distance and probably into Randolph, Macon, and Linn Counties. It becomes increasingly deeper with respect to the surface, however, in that direction and there is a possibility that the refractoriness of the clay will be decreased because of the geologic relations, which will be discussed later.

Topography. The northern district lies in the southern portion of the glaciated area of northern Missouri, with the exception of the extreme southern portion, or that area immediately adjacent to the Missouri River where there is exhibited a rough, maturely dissected type of topography.

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[1]McQueen, H. S., The Clay and Coal Resources of the Perry Area, Mo. Bureau of Geol. and Mines, 55th Biennial Rept., State Geol., pp. 102-112, 1929.

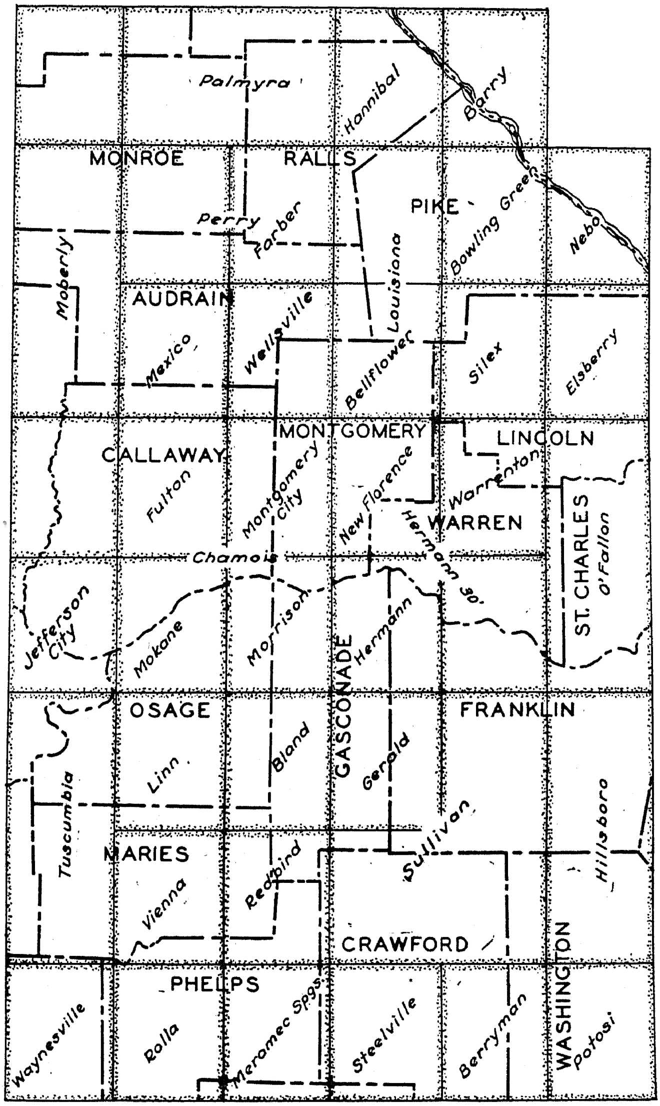
The topography of the major portion of the district is that of a gently rolling upland surface. Within such areas the local relief is not great, being less than 100 feet in the vicinity of Mexico, Audrain County, which is considered to be a typical locality (Pl. XVI).

In the upland portions the streams have been developed in the glacial drift or in the underlying rocks of the Cherokee and Henrietta groups of the Pennsylvanian system. As the rocks are in the main comparatively soft the streams meander, at times in an intricate manner. In the upland portion the streams do not cut down to any great depth, hence the relief is not great. The maximum relief, however, as measured in the area adjacent to the Missouri River would approach 400 feet. Here the upland area is intricately dissected and only remnants of the upland plateau remain, and the topography would be characterized as rough and similar and related to the topography of the southern district which lies in the north central Ozark region.

The northern portion of the area is drained by Salt River and the tributaries thereof; and the eastern portion by Cuivre River and its tributaries. Both drainage systems are tributary to the Mississippi River, which flows east of the district.

The southern portion of the district lies in the Missouri River drainage basin and the important streams from east to west are Loutre River, Auxvasse Creek, and Cedar Creek. Minor streams are Charette, Lost, and Little Auxvasse Creeks, and Middle River.

During the past few years the Missouri Geological Survey, in an effort to aid in the development of the fire clay districts, has carried on in cooperation with the United States Geological Survey a program of topographic mapping. A considerable portion of the entire fire clay district has now been covered by topographic maps having a scale of not less than one inch to one mile and a contour interval of not over 20 feet. The maps completed to date and available for purchase from either agency are shown on Plate I. These quadrangles cover approximately 225 square miles each and as a matter of convenience, are designated by some geographic name, and in every instance in this area by the name of a town. These



Index map showing quadrangles of which topographic maps are available.

maps show accurately the upland areas, and hence the areas in which fire clays may be expected in both the northern and southern districts. They show also the "breaks" in the topography or the edges of the uplands, in which many clay pits have been found. The maps show also the roads, buildings, and many other features and are invaluable aids in any systematic program of prospecting and development.

Statistics of Production. The State of Missouri ranks second among the States of the union in the production of fire brick and other refractories, being exceeded at the present time only by Pennsylvania. Of the state's production the largest volume and value are obtained in the northern district of east central Missouri.

The tonnage of clay produced is also large and the State has ranked at or next to the top for many years in the production of raw fire clay, a material part of which came from the northern district.

Figures covering the value and production of fire clay in the northern district appear to have been obtained first in 1910. Whether or not the figures completely reveal in the earlier years the total production and value of clays is a matter of conjecture. They probably do not, as it is believed that the clay reported was only that mined and sold, and did not include that produced by and processed by a fire brick company. In recent years, however, the figures are considered to be more nearly complete.

In reporting the production of clay, the types have not been always differentiated into plastic fire clay or flint fire clay. Therefore the figures given in the table to follow indicate the total tonnage of all clays mined. During the years 1940 and 1941, statistics were available covering both plastic and flint fire clay.

PRODUCTION AND VALUE OF CLAYS, NORTHERN DISTRICT, 1910-1941.

Year	*Fire clay* Short tons	Value
1910	31,393	$ 37,431
1911	17,961	22,373
1912	19,274	25,226
1913	40,211	48,507
1914	12,877	19,416
1915	8,123	14,848
1916	23,271	37,603
1917	30,600	62,077
1918	9,018	20,591
1919	14,277	32,144
1920	22,392	108,090
1921	11,330	57,249
1922	16,187	60,166
1923	17,247	75,425
1924	47,612	151,959
1925	26,319	104,599
1926	36,773	139,509
1927	42,915	199,500
1928	84,877	146,539
1929	81,350	273,379
1930	81,255	228,384
1931	41,987	102,961
1932	33,559	90,271
1933	46,928	139,026
1934	50,972	199,219
1935	103,986	238,737
1936	271,019	472,532
1937	301,383	572,458
1938	127,302	255,063
1939	221,899	400,677
1940	281,245	464,878
1941	437,331	797,172

	Plastic fire clay Short tons	Value	*Flint fire clay* Short tons	Value
1940	107,033	$219,638	174,212	$245,240
1941	183,772	346,718	253,559	450,454

GEOLOGY OF THE NORTHERN DISTRICT.

STRATIGRAPHY.

In any geological consideration of the fire clays of the district, it becomes apparent that a complete discussion of the relation of the various clay zones to each other, to related strata, and a review of the periods of history in which they were deposited, removed by erosion, or altered into various states, are pertinent to this report.

It also became apparent that considerable revision was desirable in the present report in order to interpret properly the stratigraphy, particularly as it is related to the mode of occurrence of the clays and more particularly as it is concerned with the relations of the formations to each other. The foregoing are highly important in connection with any systematic and intelligent prospecting and the various formations of Pennsylvanian age are therefore considered in detail.

In addition to the Pennsylvanian formations, in which the fire clays occur, it is also proper to describe the associated formations in order to provide the proper geologic setting for a discussion of the clays.

Pre-Pennsylvanian Formations. The formations underlying the basal Pennsylvanian formation, the Graydon conglomerate, reflect, by the wide range in age the magnitude of the unconformity at the base of the Pennsylvanian and the overlap of the Pennsylvanian rocks upon the older formations. Within the northern district, or that area lying north of the Missouri River, the formations underlying the Pennsylvanian range in age from Canadian to Mississippian, the regional distribution being with the former to the south and the latter to the north.

The section in ascending order is as follows:

- Canadian System:
  - Jefferson City formation
  - Cotter formation
- Ordovician System:
  - St. Peter sandstone
  - Joachim dolomite
  - Plattin limestone

Decorah formation
Kimmswick limestone
Maquoketa shale

Devonian System:
Mineola limestone
Callaway limestone
Snyder Creek shale

Mississippian System:
Kinderhook shale
Chouteau limestone
Sedalia formation
Burlington formation
Keokuk formation
Warsaw formation
Spergen formation
St. Louis formation
Ste. Genevieve formation

The arrangement or sequence of formations is indicated by the accompanying cross sections, Plates II, III, and IV, accompanying this report. The distribution of the formations is shown, either singly or in groups on the State Geological Map,[2] which will be found to be a valuable guide in any geological investigations of the area. Several reports have been published which describe the pre-Pennsylvanian[3 4 5 6 7] rocks of the Ozark region and as many of the formations described are found in this district these reports should be referred to for more detailed descriptions.

Canadian System. The formations of the Canadian system outcrop mainly in the southern portion of the northern district in the bluffs bordering the Missouri River, and in the larger stream valleys tributary thereto. The Jefferson City

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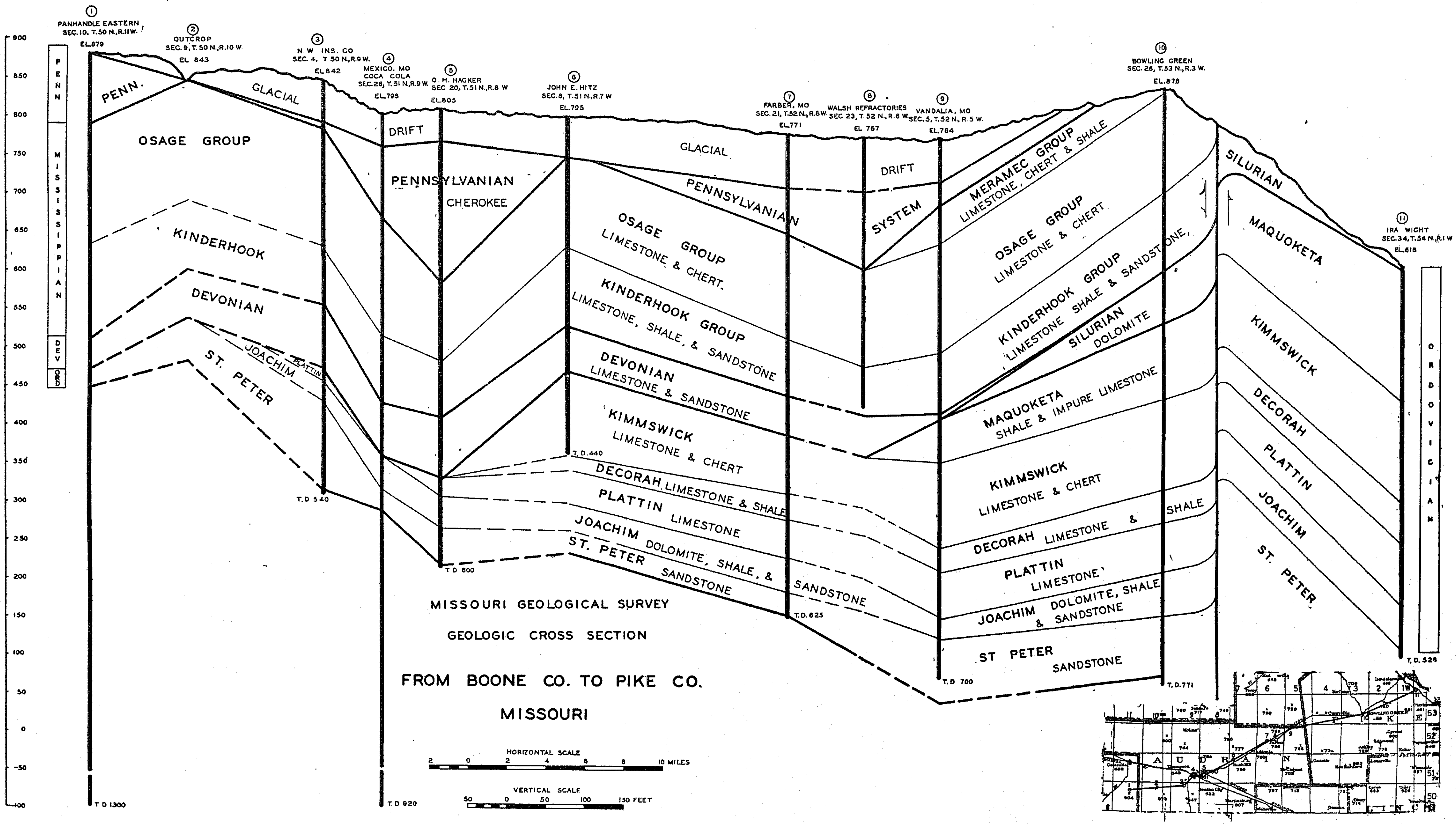
[2]State Geological Map, Mo. Geol. Survey, 1939.
[3]Dake, C. L., Sand and gravel deposits, Mo. Bur. Geol. and Mines, Vol. XV, 2nd Ser., 1918.
[4]Wilson, M. E., Oil and Gas resources of Missouri, Mo. Bur. Geol. and Mines, Vol. XV, 2nd Ser., 1922.
[5]Branson, E. B., The Devonian of Missouri, Mo. Bur. Geol. and Mines, Vol. XV, 2nd Ser., 1922.
[6]Krey, Frank, Structural reconnaissance of the upper Mississippi valley area, Mo. Bur. Geol. and Mines, Vol. XVIII, 2nd Ser., 1924.
[7]Moore, R. C., Early Mississippi formations in Missouri, Mo. Bur. Geol. and Mines, Vol. XXI, 2nd Ser., 1928.


MISSOURI GEOLOGICAL SURVEY
GEOLOGIC CROSS SECTION
FROM BOONE CO. TO PIKE CO.
MISSOURI
① PANHANDLE EASTERN SEC. 10, T. 50 N., R. 11 W. EL. 879
② OUTCROP SEC. 9, T. 50 N., R. 10 W. EL 843
③ N W INS. CO SEC. 4, T 50 N., R. 9 W. EL. 842
④ MEXICO, MO COCA COLA SEC. 26, T. 51 N., R. 9 W. EL. 798
⑤ O. H. HACKER SEC 20, T. 51 N., R. 8 W EL. 805
⑥ JOHN E. HITZ SEC. 8, T. 51 N., R. 7 W EL. 795
⑦ FARBER, MO SEC. 21, T. 52 N., R. 6 W. EL. 771
⑧ WALSH REFRACTORIES SEC 23, T 52 N., R. 6 W. EL 767
⑨ VANDALIA, MO SEC. 5, T. 52 N., R. 5 W. EL. 784
⑩ BOWLING GREEN SEC. 26, T. 53 N., R. 3 W. EL. 878
⑪ IRA WIGHT SEC. 34, T. 54 N., R. 1 W EL. 618
PENN.
GLACIAL
DRIFT
OSAGE GROUP
KINDERHOOK
DEVONIAN
JOACHIM
PLATTIN
ST. PETER
PENNSYLVANIAN
CHEROKEE
GLACIAL DRIFT
PENNSYLVANIAN SYSTEM
MERAMEC GROUP LIMESTONE, CHERT & SHALE
OSAGE GROUP LIMESTONE & CHERT
KINDERHOOK GROUP LIMESTONE, SHALE, & SANDSTONE
SILURIAN DOLOMITE
DEVONIAN LIMESTONE & SANDSTONE
MAQUOKETA SHALE & IMPURE LIMESTONE
KIMMSWICK LIMESTONE & CHERT
DECORAH LIMESTONE & SHALE
PLATTIN LIMESTONE
JOACHIM DOLOMITE, SHALE, & SANDSTONE
ST. PETER SANDSTONE
SILURIAN
MAQUOKETA
KIMMSWICK
DECORAH
PLATTIN
JOACHIM
ST. PETER
PENN
MISSISSIPPIAN
DEV
ORD
ORDOVICIAN
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
-100
T.D 1300
T.D 540
T.D. 920
T.D 600
T.D. 440
T.D. 625
T.D 700
T.D. 771
T.D. 525
HORIZONTAL SCALE
2 0 2 4 6 8 10 MILES
VERTICAL SCALE
50 0 50 100 150 FEET
A U D R A I N
P I K E
L I N C

formation is the oldest one exposed. It consists of dolomite and magnesian limestone. Chert is also an important constituent and green shale and sandstone are also present. The formation has been penetrated by many deep wells in the northern district and appears to have a thickness of 225 feet.

The overlying Cotter formation has much the same lithologic make up. It also is composed dominantly of dolomite and magnesian limestone, and in this respect it is sometimes difficult to differentiate it from the Jefferson City. The cherts of the two formations are sufficiently different to separate them however, and the fossils contained also may be used for the same purpose. Sandstone is not uncommon to the Cotter, and green shale is locally present. The thickness of the Cotter formation as revealed by the logs of deep wells is 250 feet.

Ordovician System. In southeastern and southern Missouri and northern Arkansas, Canadian formations younger than the Cotter occur. All of them were probably not deposited in this area, but in any event in the long period of erosion which followed the deposition of the Canadian rocks, the formations present were reduced in thickness or probably wholly removed prior to the deposition of the overlying St. Peter sandstone.

The St. Peter consists of fine to medium grained sandstone. On fresh exposures it is white in color and usually massive bedded. The grains are fine to medium in size, and generally well rounded. An excellent exposure of the St. Peter may be observed on U. S. Highway 40, just east of the village of Mineola, Montgomery County where the sandstone has a thickness of about 50 feet. The thickness varies however, and a deep well record at Mexico indicates a maximum of 188 feet. The minimum thickness occurs in the southwestern portion of the northern district, where it is absent and completely overlapped by formations of Devonian, and in some instances of Mississippian age.

The overlying Joachim formation consists of buff, yellow, argillaceous dolomite, and in this respect resembles the formations of the Canadian system. The Joachim, however, is marked by an absence of chert which is a criterion in its identification. Green shale and sandstones occur interbedded with the dolomite in the basal part of the formation. The Joachim is overlapped by younger formations, hence varies from nothing to about 50 feet in thickness. The problems involved in the overlap have been described by Branson.[8]

The Plattin formation overlies the Joachim. It is composed of dark gray, fine-grained, fossiliferous limestone, with beds of magnesian limestone at the base. This formation also varies in thickness from nothing to 60 feet.

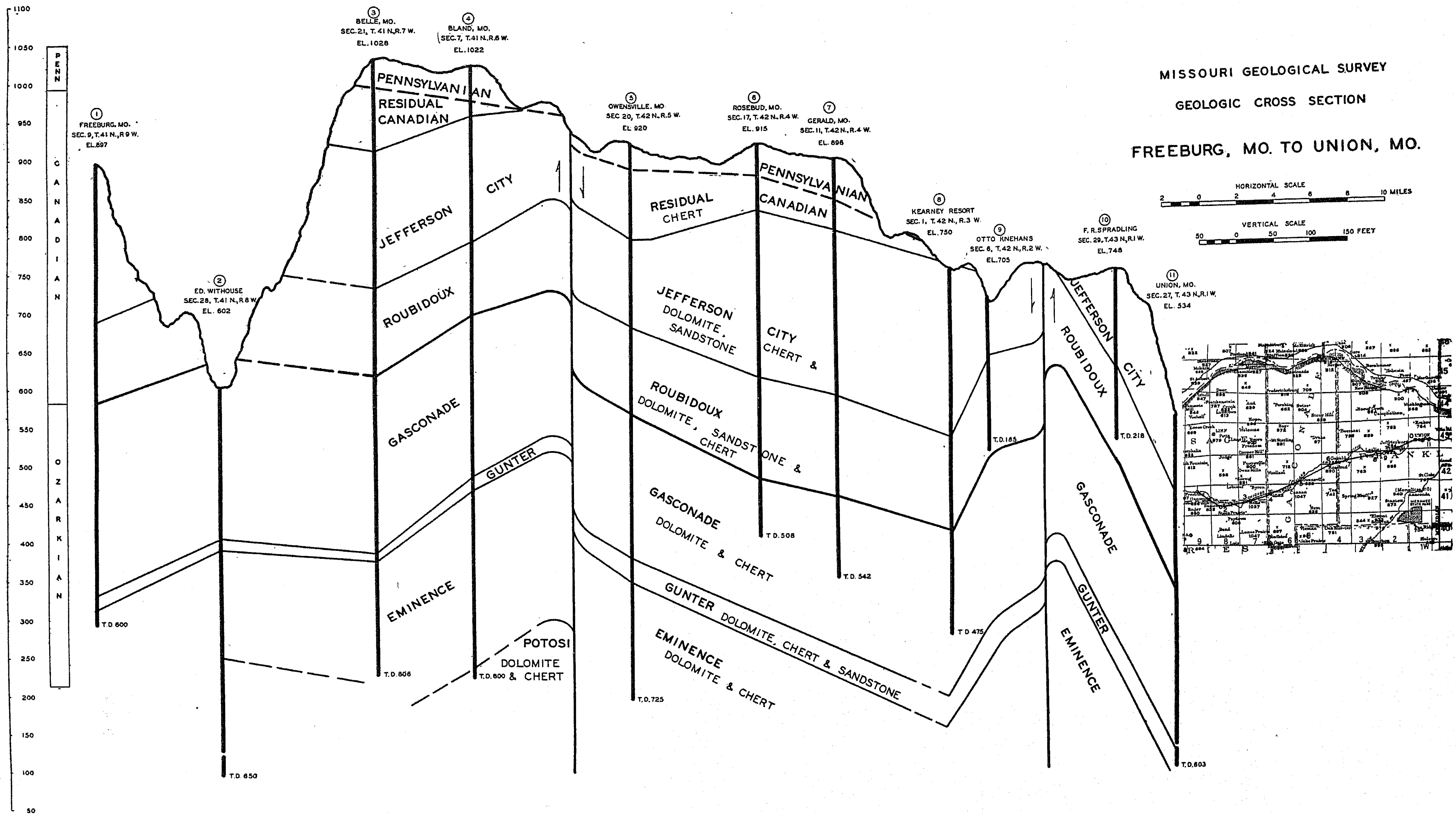
Over a considerable portion of the area, the Decorah formation overlies the Plattin, although locally it may be absent. The Decorah is composed of limestone, usually gray or brown in color, very fine-grained and usually highly fossiliferous. Beds of green and reddish brown shale are common. Tripolitic chert is often found in the top of the formation. The thickness varies from nothing to 60 feet.

The overlying Kimmswick formation consists of limestone. It differs from the underlying limestone in that it is lighter in color, white not being uncommon. It is also more crystalline, in places being coarsely so. Fossils are common to the limestone. Exposures of the limestone are present in Warren, Montgomery, and Lincoln Counties, and particularly in the latter where exposures are present in the vicinity of the clay deposits at Whiteside. The thickness of the formation again varies because of the overlap of younger formations upon it. It is completely absent in some localities, but reaches a maximum of 120 feet in others.

The youngest formation of the Ordovician system is the Maquoketa shale. Exposures are limited to the eastern counties of the northern district. The formation consists of green and gray shale, with interbedded limestone and dolomite. The thickness ranges from nothing to 100 feet.

Silurian System. Although rocks of Silurian age outcrop throughout Lincoln and Pike Counties they do not appear to be exposed in the immediate vicinity of the clay producing area, nor do they appear to occur in the subsurface sections of the district, with the possible exception of the extreme eastern portion. The Silurian is composed chiefly of dolomite, with some minor beds of limestone. The total thickness is ap-

[8]Branson, E. B., Paleozoic formation margins in Missouri, Am. Jour. Science, 5th Ser., Vol. 8, pp. 317-322, Oct. 1924.


MISSOURI GEOLOGICAL SURVEY
GEOLOGIC CROSS SECTION
FREEBURG, MO. TO UNION, MO.
HORIZONTAL SCALE
10 MILES
VERTICAL SCALE
150 FEET
PENN
CANADIAN
OZARKIAN
FREEBURG, MO.
SEC. 9, T.41 N., R.9 W.
EL.897
ED. WITHOUSE
SEC.28, T.41 N., R.8 W.
EL. 602
BELLE, MO.
SEC.21, T.41 N., R.7 W.
EL.1028
BLAND, MO.
SEC.7, T.41 N., R.6 W.
EL.1022
OWENSVILLE, MO
SEC 20, T.42 N., R.5 W.
EL 920
ROSEBUD, MO.
SEC.17, T.42 N., R.4 W.
EL. 915
GERALD, MO.
SEC.11, T.42 N., R.4 W.
EL. 898
KEARNEY RESORT
SEC. 1, T.42 N., R.3 W.
EL.750
OTTO KNEHANS
SEC. 6, T.42 N., R.2 W.
EL.705
F. R. SPRADLING
SEC. 29, T.43 N., R.1 W.
EL.748
UNION, MO.
SEC.27, T.43 N., R.1 W.
EL. 534
PENNSYLVANIAN
RESIDUAL CANADIAN
JEFFERSON CITY
ROUBIDOUX
GASCONADE
GUNTER
EMINENCE
POTOSI DOLOMITE & CHERT
RESIDUAL CHERT
JEFFERSON DOLOMITE, SANDSTONE
CITY CHERT &
ROUBIDOUX DOLOMITE, SANDSTONE & CHERT
GASCONADE DOLOMITE & CHERT
GUNTER DOLOMITE, CHERT & SANDSTONE
EMINENCE DOLOMITE & CHERT
T.D. 600
T.D. 650
T.D. 806
T.D. 800
T.D. 725
T.D. 508
T.D. 542
T.D. 475
T.D. 185
T.D. 218
T.D. 603

proximately 65 feet. A complete discussion of the Silurian formations has been published elsewhere.[9] [10]

Devonian System. As defined by Branson[11] three formations comprise the Devonian of the northern district. They are the Mineola and Callaway limestones and the Snyder Creek shale.

Subsurface studies carried on in the laboratory of the Missouri Geological Survey for a number of years have indicated the very close relationship of the first two mentioned. The Devonian limestones vary in texture from very crystalline to fine-grained and dense. Locally they are quite sandy and beds of sandstone are present, in fact, sandstone may be the dominant rock of the Devonian sections in some localities. Chert and shale are not common. Fossils usually occur in great abundance. The Devonian rocks range in thickness from nothing to about 100 feet. Locally, in the southern portion of the northern district the clay bearing Pennsylvanian formations are in contact with the Devonian limestones.

The Snyder Creek shale is reported by Branson[12] to have a thickness ranging from 0 to 63 feet, and to consist of dark blue and drab shale, and shaly limestone. Outcrops of the formation appear to be limited to Callaway and possibly Montgomery counties. The determination of the formation in well samples is difficult as the shale washes out of the samples and the limestone of the formation closely resembles some of the limestone of the Callaway formation.

Mississippian System. The formations of the Mississippian are of more importance because they underlie the main portion of the clay bearing area of the northern district. This is particularly true of the Burlington, and possibly the associated Keokuk formation and the Warsaw formation. The character of these formations may well have played an important part in determining the composition of the Cheltenham clays.

The oldest formation of Mississippian age is the Kinderhook, which in the eastern portion consists of black to gray

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[9]Krey, Frank, Structural reconnaissance upper Mississippi valley, Mo. Bur. Geol. and Mines, Vol. XVIII, 2nd Ser., pp. 24-28, 1924.

[10]Rowley, R. R., The geology of Pike county, Mo. Bur. Geol. and Mines, Vol. VIII, 2nd Ser., 1908.

[11]Branson, E. B., The Devonian of Missouri, Mo. Bur. Geol. and Mines, Vol. XVII, 2nd Ser., 1922.

[12]Op. cit., pp. 34-39.

and green shales. Locally it may be represented by a thin sandstone. This is true in the extreme western part of the district. The upper portion of the Kinderhook in the western and southern portion of the district is composed of the Chouteau formation. It consists chiefly of fine-grained to dense, and in some places argillaceous and cherty fossiliferous limestone. Thin beds of shale are common to the formation. The Chouteau varies in thickness and in east-west direction ranges from nothing to 100 feet.

The Chouteau is overlain by the Sedalia formation which is composed of very argillaceous, fine-grained, magnesian limestone. The formation ranges from nothing to 20 feet.

The Burlington-Keokuk formations overlie the Sedalia. They underlie the Pennsylvanian rocks in which the clays occur over a wide area and therefore are of more than passing interest. It has not been possible to attempt any separation of the two formations, however, during the field work connected with this report.

The combined formations, assuming that both are present in the northern district, show a similarity in lithology in surface exposures and in deep well samples. Limestone is the dominant rock. It is usually light to dark gray, crystalline, and highly fossiliferous; in fact locally the rock is a soft mass of shells. Chert is common to this section. It is white to gray in color. In the upper part of the section the chert is fine-grained, smooth, but with a faint speckled appearance. Occassionally irregular inclusions of crystalline quartz are contained in it. In the lower part of this section, the chert appears to have a rougher texture, and tripolitic or finely porous types are very common. The chert of the lower portion appears to be more fossiliferous than that of the upper. The chert derived from these formations during the long period of weathering prior to the deposition of the Pennsylvanian was later reworked and became the dominant material of the basal Pennsylvanian formation, the Graydon chert conglomerate. This formation separates the clay bearing Cheltenham formation from the underlying cherty limestones of the Burlington-Keokuk formations.

In the long period of erosion that intervened between the deposition of the youngest formation of Mississippian age and the Graydon formation of Pennsylvanian age, the surface of the former was truncated. As a result the component formations of the Mississippian show variations in thickness. The Burlington-Keokuk are no exceptions. Also the thickness varies considerably in local areas due to folding and subsequent bevelling by erosion of the folds. Over the larger anticlinal folds the formations are thinner, but in the synclinal areas they are thicker. The combined thickness is best determined from numerous records of wells drilled in the district, for which samples of cuttings have been submitted to the Geological Survey for examination. These records show that the thickness ranges from possibly 100 to 175 feet.

In the area of outcrop, caves and caverns are not uncommon to these formations, and attest to the relative solubility of the limestone. The collapse of these features and the subsidence of the Pennsylvanian rocks, including the clays, was an important chapter in the alteration of the clays to their present state. The collapsed underground caverns, the surface expressions of which were sink-holes, thus afforded "leaching pots" and into them the soluble salts of the clays were carried by percolating ground water. More than one period of sink formation is recorded by the presence of certain Pennsylvanian formations. This subject is discussed more fully in that chapter devoted to the stratigraphy of the Pennsylvanian formations.

The formation overlying the Burlington-Keokuk formations is the Warsaw, which likewise is an important one, as it possibly affects the character of the Cheltenham clay. Also because of its composition, knowledge of it is necessary for intelligent prospecting in certain localities. As developed in the northeastern part of Missouri, the Warsaw consists of at least two portions. The lower is dark gray, often bluish gray to brown, crystalline fossiliferous limestone. Glauconite is not uncommon to the basal beds. Chert is an important constituent of the basal portion. It is bluish gray in color, although a mottled light and dark variety is often characteristic. The chert contrasts sharply from that of the underlying Keokuk-Burlington. The lower portion of the formation is probably about 25 feet in thickness.

The succeeding portion of the Warsaw and the one most readily identifiable is composed of shale and very argillaceous limestone. The shales are light buff, brown or green in color.

On weathered exposures they are very plastic. The shales are thin bedded and the bedding planes appear to persist even after prolonged weathering. The total thickness of the shale member may reach 50 feet.

The associated limestone beds are usually thin. They have a high clay content, are fine-grained and fossiliferous. They range in color from buff to brown. Geodes or nodular concretions with hollow interiors lined with quartz crystals are common and serve as a means of identifying the Warsaw formation.

The following section shows the relation of the Cheltenham clay formation of Pennsylvanian age to the Warsaw formation of Mississippian age. It was measured along a road, formerly State Highway No. 10 but now abandoned to traffic, in the NW¼ NE¼ sec. 28, T. 55 N., R. 9 W., 2 miles east of Goss, Monroe County. The section is just east of the Rives clay deposit.

Measured Section in the NW¼ NE¼ Sec. 28, T. 55 N., R. 9 W., Monroe County

Number	*Lithology*	*Thickness Feet*	*Inches*
Pleistocene Series:			
1.	Glacial clay, red, plastic, with fine sand and pebbles up to one inch in diameter of igneous rock, pebbles ovoid in shape, and smooth.		
Pennsylvanian System:			
Moberly sandstone:			
2.	Sandstone, rusty brown to deep buff, thin bedded, soft, very micaceous, very cross bedded, contains some fine particles of green shale, which also overlies as a very thin bed	5	
3.	Shale, light buff, clayey, no great defined break with No. 2.......	4	
4.	Sandstone, similar to No. 2	10	
Cheltenham formation:			
5.	Clay, light and dark gray, semi-plastic type, angular fracture, fairly hard	21	
Graydon formation:			
6.	Sandstone, quartzitic to sugary	0	6
7.	Hematite, brown to red, slabby, impossible to determine thickness accurately	0	7
Mississippian System:			
Warsaw formation:			
8.	Limestone, buff to brown colored, fine grained to finely crystalline, very argillaceous, slightly fossiliferous	3	0
9.	Shale, green, fine-grained, micaceous, sandy, contains bryozoa.....	2	6
10.	Limestone, dense, argillaceous, cotton rock type, lower six inches finely crystalline and fossiliferous	3	0
11.	Shale, buff	2	6
12.	Limestone, similar to lower part No. 10	1	0
13.	Shale, green, calcareous, sandy	2	0
14.	Limestone, similar to upper part No. 10	1	0
15.	Shale, light buff	3	0
16.	Limestone, similar to upper part No. 10	1	0
17.	Covered to valley level	15	0

The presence of Warsaw shale, and the absence of the Graydon chert conglomerate plus the greater depth of the Keokuk-Burlington formations in the northern portion of the area may have some bearing on the character of the Cheltenham clay. If the theory of leaching by meteoric water is tenable, then such leaching would be retarded, if not prevented by the Warsaw shale. Also, the Graydon chert conglomerate because of its composition might also present a zone of fairly easy circulation, and its absence would possibly further retard the alteration of the clay.

In the extreme northern portion of the district being described, the Spergen (upper Warsaw?), St. Louis, and Ste. Genevieve formations, chiefly composed of limestone, may underlie the Pennsylvanian. The possibilities of the occurrence of these formations would be greater in synclinal areas. As no actual exposures have been observed, the relations and effect of these formations are not known. Their presence, however, would mean a greater depth to the comparatively more soluble, hence cavernous Keokuk-Burlington formations, and a different relation to the regional ground water table. Hence, sink holes and attendant leaching of the clays might reasonably be absent, and the clays therefore be less refractory under such geologic relations.

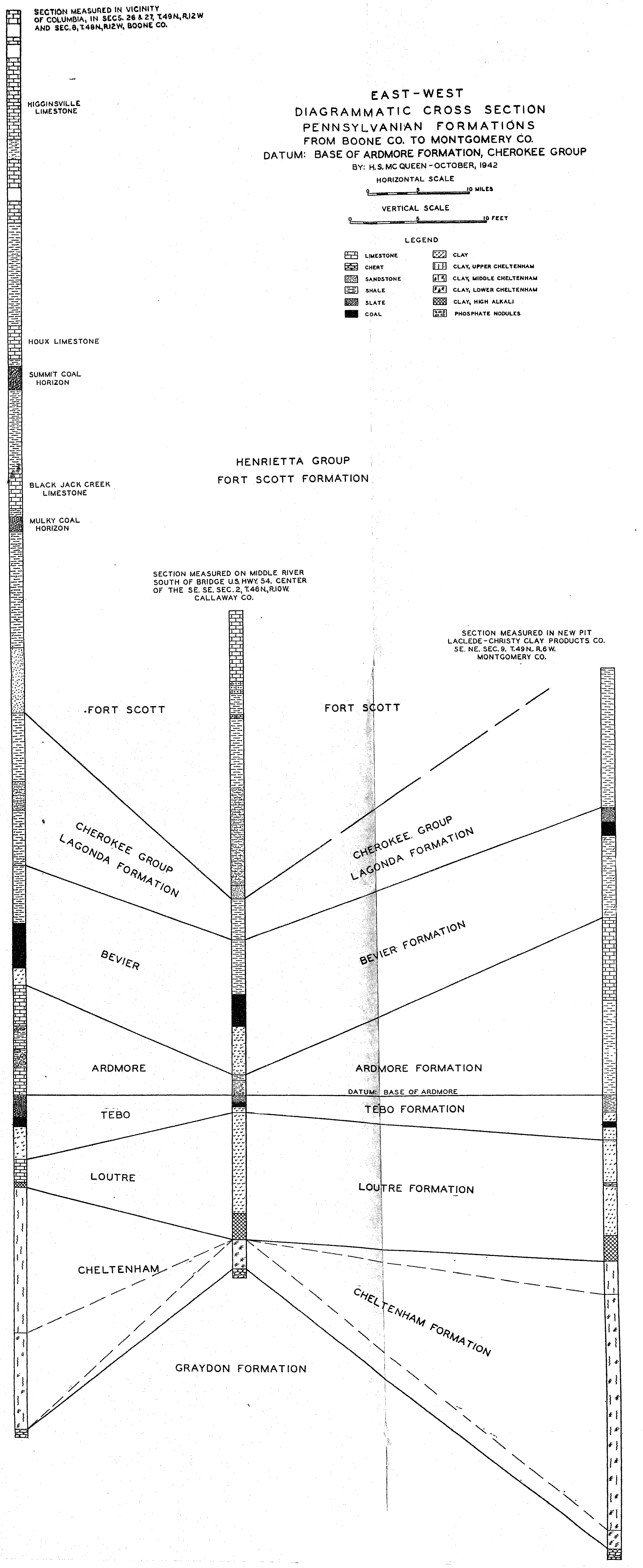
PENNSYLVANIAN SYSTEM.

INTRODUCTION.

In the preparation of this report it soon became apparent that a revision of the stratigraphy of the Pennsylvanian system, in which the fire clays occur as a formation, was necessary in order to describe properly the geologic setting, the mode of occurrence, and the events which marked their history in east central Missouri. No intensive stratigraphic work had been undertaken by the Geological Survey in the northern district since the publication of two reports, one dealing with the coal deposits,[13] and the other with the stratigraphy of the Pennsylvanian system.[14]

[13]Hinds, Henry, the coal deposits of Missouri, Mo. Bur. of Geol. and Mines, Vol. XI, 2nd Ser., 1912.

[14]Hinds, Henry and Greene, F. C., The stratigraphy of the Pennsylvanian series in Missouri, Mo. Bur. of Geol. and Mines, Vol. XIII, 2nd Ser., 1915.


EAST-WEST
DIAGRAMMATIC CROSS SECTION
PENNSYLVANIAN FORMATIONS
FROM BOONE CO. TO MONTGOMERY CO.
DATUM: BASE OF ARDMORE FORMATION, CHEROKEE GROUP
BY: H. S. MC QUEEN - OCTOBER, 1942
HORIZONTAL SCALE
0 5 10 MILES
VERTICAL SCALE
0 5 10 FEET
LEGEND
LIMESTONE
CHERT
SANDSTONE
SHALE
SLATE
COAL
CLAY
CLAY, UPPER CHELTENHAM
CLAY, MIDDLE CHELTENHAM
CLAY, LOWER CHELTENHAM
CLAY, HIGH ALKALI
PHOSPHATE NODULES
SECTION MEASURED IN VICINITY OF COLUMBIA, IN SECS. 26 & 27, T.49N., R.12W AND SEC. 8, T.48N., R.12W., BOONE CO.
HIGGINSVILLE LIMESTONE
HOUX LIMESTONE
SUMMIT COAL HORIZON
BLACK JACK CREEK LIMESTONE
MULKY COAL HORIZON
HENRIETTA GROUP
FORT SCOTT FORMATION
SECTION MEASURED ON MIDDLE RIVER SOUTH OF BRIDGE U.S. HWY. 54. CENTER OF THE SE. SE. SEC. 2, T.46N., R.10W. CALLAWAY CO.
SECTION MEASURED IN NEW PIT LACLEDE-CHRISTY CLAY PRODUCTS CO. SE. NE. SEC. 9. T.49N. R.6W. MONTGOMERY CO.
FORT SCOTT
FORT SCOTT
CHEROKEE GROUP
LAGONDA FORMATION
CHEROKEE GROUP
LAGONDA FORMATION
BEVIER
BEVIER FORMATION
ARDMORE
ARDMORE FORMATION
DATUM: BASE OF ARDMORE
TEBO
TEBO FORMATION
LOUTRE
LOUTRE FORMATION
CHELTENHAM
CHELTENHAM FORMATION
GRAYDON FORMATION

As the sections exposed in the clay pits, and in surface exposures, and those revealed by shafts and prospect drilling were studied, it was soon evident that many units, some of which were of limited thickness, were in every respect of formational rank, and they are thus considered in this report.

CHEROKEE GROUP

Nomenclature. The Pennsylvanian rocks described in this report, include two groups as now recognized by the Missouri Geological Survey, the Cherokee and the Henrietta. The remaining higher groups do not outcrop in the area of this report and will not be considered further with the exception of the Moberly channel sandstone, which will be described. The Cherokee is the equivalent of the "Lower Coal Measures" of the older reports of the Missouri Geological Survey with the exception that the Mulky coal and its roof shale and underclay, were placed at the base of the "Middle Coal Measures". The latter term was applied essentially to beds now grouped as Henrietta and Pleasanton with the exception noted above.

Hinds and Greene[15] in 1915 reviewed the literature pertaining to the Cherokee and Henrietta and included subdivisions. The following is quoted:

"The name Cherokee was first given to this formation, the lowest of the Des Moines group, by Haworth and Kirk.[16] Since then practically every publication dealing with the formation has used the name, which has become firmly established in the literature of Kansas and Missouri, and it has therefore been adopted by the United States Geological Survey, the previous application of the term Cherokee to rocks in North Carolina and to a Mississippian limestone in the Ozark region being considered obsolete."

The Cherokee group as defined in this report is composed of several new formations. The names of certain well known coal beds have been used in order to reduce to a minimum the introduction of new names, as well as to retain those names of long standing and common usage.

The succession of formations is indicated on Plates V and VI. In addition a number of measured sections with the

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[15]Op. cit.

[16]Haworth, E., and Kirk, M. Z., The Neosho River section: Kansas Univ. Quart., Vol. 2, p. 105, 1894.

formations properly designated are appended to this chapter, and may prove to be helpful in field work in the district.

The formations of the Cherokee group may be enumerated in ascending order as follows:

1. Unnamed sandstone and shale of local occurrence.
2. Graydon formation, chert conglomerate and sandstone, usually occurs at the base; of wide-spread distribution.
3. Cheltenham formation, the chief producer of fire clay, composed of three clay members of varying degrees of refractoriness, and aggregating as much as 65 feet in thickness, locally.
4. Loutre formation, containing a basal green high alkali clay grading upward into clay, a thin nodular limestone and gray clayey shale.
5. Tebo formation.
6. Ardmore formation.
7. Bevier formation.
8. Lagonda formation.

UNNAMED SANDSTONE AND SHALE FORMATION.

Upon the slightly irregular, and somewhat cavernous surface of the Mississippian, chiefly the Burlington and locally the Warsaw formations, there was deposited a series consisting of fine-grained carbonaceous sandstone and dark-colored, usually black fissile shale, which form the initial or basal member of the Cherokee group.

Only remnants of these early Cherokee deposits now remain and but little is known about the details of their character and thickness. One of the few exposures known to the writer, where the relation to the Cheltenham clay may be observed also, occurs west of the northern district in SW¼ SW¼ sec. 12, T. 48 N., R. 19 W., in a deep cut on U. S. Highway No. 40, one-half mile west of Lamine River, and approximately 14 miles west of Boonville, Cooper County. Here both the earlier Cherokee sediments, the Graydon chert conglomerate (?) and the succeeding Cheltenham clay occur filling a series of caverns, chimneys, caves, or sink holes of irregular size and shape. The relations are particularly well known in the cavern on the south side of and near the east end of the cut (Fig. 2), where the following section is exposed:

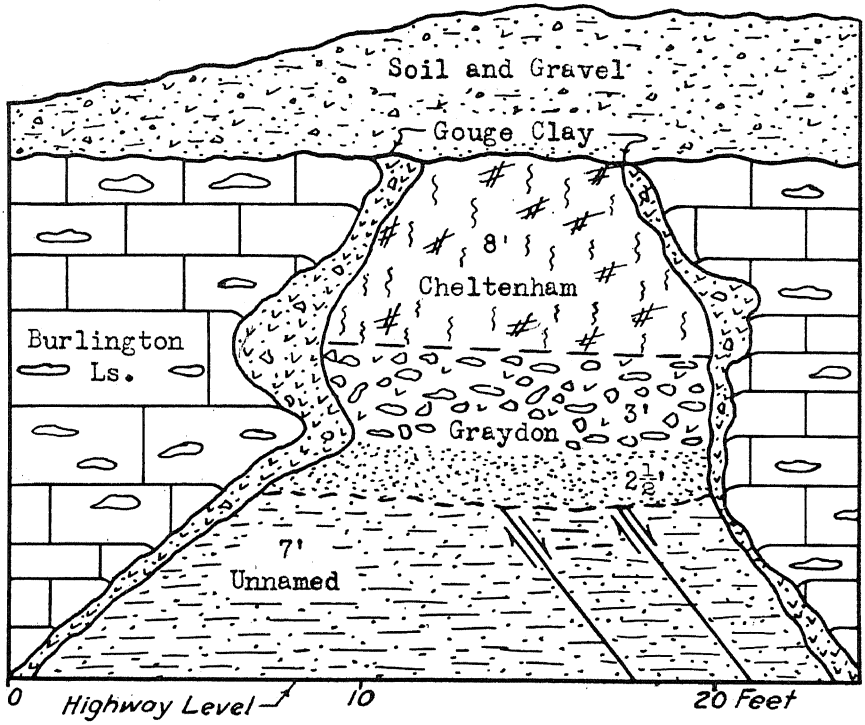


Fig. 2. Sketch showing a cave in Mississippian limestone filled with Pennsylvanian formations, section 12, T.48N., R.19W., Cooper County.

Measured Section in the SW¼ Sec. 12, T. 48 N., R. 9 W., Cooper County

Number	*Lithology*	*Thickness Feet*	*Inches*
1.	Surface, chert gravel and soil up to	12	
Cherokee Group:			
Cheltenham formation:			
2.	Clay, or clayey shale, light gray, fairly soft, has characteristic conchoidal fracture and lumpy appearance, thickness about..	7	
Graydon formation (?)			
3.	Similar to 2, with much mineral charcoal, balls of green shale weathered from No. 5, and fairly large boulders of Burlington chert	3	
4.	Sandstone, white, hard, fine-grained, separated from No. 5 by an angular unconformity	2	6
Unnamed formation:			
5.	Sandstone, hard, gray, fine-grained, marked by coaly material and mineral charcoal, with thin interbedded black platy shale seams, grades upward and in upper portion of exposure contains green and black plastic shale, with thin intercalated sandstone beds. Individual beds dip gently to southeast and are truncated by overlying sandstone, exposed	7	

A number of interesting features may be noted in this exposure. Among them are the small scale normal faults which cut bed No. 5, but do not appear to affect bed No. 4.

Also the beds of No. 5 dip gently to the east, and appear to have been bevelled prior to the deposition of the overlying sandstone, bed No. 4. This would suggest a period of movement and erosion. The latter is certainly suggested by the presence in the Graydon (?) (No. 3) of fairly well rounded balls of green and black clay which obviously have been derived from No. 5 of the measured section. These features indicate movement and erosion between Graydon-Cheltenham time and the unnamed unit below.

The cave was formed in dark bluish gray, very cherty Burlington limestone of Mississippian age. Between the limestone walls and the section above described, there occurs a clay gouge, or clayey material derived from the beds of the sections and squeezed into this position in the subsidence of the mass into the cave. Whether or not there was more than one period of movement at this locality is a matter of conjecture. It would appear, however, that the earlier deposits had settled at least slightly into a depression and the exposed surface had been eroded before the Graydon-Cheltenham formations were deposited upon its truncated surface.

What may possibly be a remnant of the pre-Graydon beds was found in drilling a water well on the Robert S. Green property, NW¼ NE¼ SE¼ sec. 35, T. 51 N., R. 9 W., south of Mexico, Audrain County. In this well the normal Cherokee section appears to have been encountered, with the Graydon chert conglomerate at the base. The line between the Graydon and the cherty Burlington limestone is not easy to fix precisely but the contact was not far from a depth of 110 feet. At a depth of 180-190 feet, however, or 70 feet below the top of the Burlington, a cave filled with the following described material was encountered.

Depth in feet	*Material*
180-185	Clay, hard, very dark bluish gray, very fine grained.
185-190	Clay, light gray or light green, hard but softer than above.

The clay was followed by cherty Burlington limestone to a depth of 265 feet. This clay is believed to be of Pennsylvanian age, and is thought to represent the older or pre-Graydon deposits, although there is also a possibility that it represents the lower or basal zone of the Cheltenham clay formation. There is certainly no material of similar lithology of regular occurrence within the Burlington or any other formation of Mississippian age in central Missouri, whereas almost if not identical clay is known to the Cherokee group. Also the clay appears to be below the normal chert conglomerate (Graydon) hence would appear to be older.

The clay, in this instance, is believed to be material deposited in a cave, which had an opening extending to the surface at the time of deposition, and hence was filled by the fine-grained clay sediment, or else the clay slumped into a chimney-like sink in a period of erosion following deposition. A similar case is known at Bland, Gasconade County, in the southern district, as will be discussed in the section of this report devoted to that district.

The unnamed formation under discussion is well developed in the Forest City basin area of northwestern Missouri, where it reaches a maximum thickness of 300 feet, and is represented by black fissile shale, and hard fine-grained sandstone, the latter being often characterized by thin streaks of coal or carbonaceous matter. Similar shale and sandstone occur in the Dederick,[17] "a uniform, widely-present member" of the Cherokee group in Vernon, Bates, and adjoining counties, and the material under discussion may well be the correlative of it. Whether or not such a correlation is tenable, it is evident that a long period of erosion followed the deposition of the sediments above described and reduced them in thickness until they now range from zero to 300 feet. In the northern and structurally higher area of this report, this member was completely removed except for occasional remnants, two of which have been described in preceding pages.

GRAYDON FORMATION.

Name. The basal formation of the Cherokee group over practically the entire area is a chert conglomerate and sandstone. It consists in the main of chert boulders varying in size from a few inches to those measuring two feet or more in diameter. The boulders are often rounded and show evidence of having been transported and concentrated at least locally by streams. To a similarly developed chert conglomerate and sandstone, the name Graydon Springs sandstone and conglomerate was first suggested by W. P. Jenney and afterward used by

[17] Greene, F. C., and Pond, W. F., The geology of Vernon County, Mo. Bur. Geol. and Mines, Vol. XIX, 2nd Ser., p. 40, 1926.

Winslow,[18] to apply to Pennsylvanian deposits in Lawrence, Greene, and Dade Counties that occupy depressions in Mississippian rocks. The name was shortened to Graydon sandstone by Shepard[19] and was extended by him[20] and by other writers to coarse deposits filling channels and depressions in the pre-Pennsylvanian land surface from Callaway County to southwest Missouri.

More recently the name Graydon has been applied to the splendid exposure of the conglomerate at Fulton, Callaway County, by Branson.[21] The term appears to be an appropriate one and is applied to the basal chert conglomerate and sandstone in both the northern and southern districts of this report.

Occurrence and Thickness. The Graydon formation occurs as an irregular yet widespread blanket-like deposit. It represents an initial deposit of an advancing sea over a highly weathered surface, and one capped probably by a thick mantle of residual material, which developed as a result of a long period of erosion. Irregularities in thickness occur and there is a suggestion that locally the conglomerate and sandstone fill sink holes or pre-existing caves, or fill on the other hand much larger features such as stream valleys.

The thickness of the Graydon formation appears to be highly variable and ranges from zero to at least 50 feet.

Areal Distribution. The Graydon is one of the most wide-spread formations of the Cherokee group in east central Missouri and the only Pennsylvanian formation of any continuity in both the northern and southern districts. In the former it is found almost continuously, except in the Goss locality, T. 55 N., R. 9 W., and the Holliday locality, T. 55 N., R. 11 W., Monroe County, where it is absent and the normally overlying Cheltenham formation is in direct contact with the Warsaw formation, of Mississippian age.

Topography. The Graydon formation in the northern district affects the topography only locally. Where the maximum

[18]Winslow, Arthur, Lead and zinc deposits: Missouri Geol. Survey, Vol. 7, pp. 422-425, 1894.

[19]Shepard, E. M., Geology of Greene County: Missouri Geol. Survey, Vol. 12, p. 124, 1898.

[20]Shepard, E. M., Underground waters of Missouri: U. S. Geol. Survey Water-Supply Paper 195, p. 22, 1907.

[21]Branson, E. B., Central Missouri, etc., Guide Book, 15th Ann. Conf., The Kansas Geological Society, p. 37, 1941.

A. Graydon chert conglomerate capped with sandstone, foot of Bluff Street, Fulton, Callaway County.

B. View showing relation of hill of Burlington linestone below, to Graydon chert conglomerate above, U. S. Highway 54, SW ¼ sec. 21, T. 46 N., R. 10 W., Callaway County.

thickness is approached or developed, the formation usually outcrops as a bluff of some prominence, the best example being at the foot of Bluff street in the south part of the City of Fulton (Pl. VII, A).

Many other good exposures could be cited. They occur largely in the breaks or areas of rough topography, marginal to the characteristic upland topography of the district.

Lithologic Character. The Graydon formation is composed chiefly of chert boulders which appear to have been derived almost wholly from the Burlington, and to a lesser extent from the associated Keokuk formation of Mississippian age. The former immediately underlies the basal chert (Graydon) conglomerate over the greater portion of the district. An exception, however, has been noted in portions of Monroe County, particularly in the vicinity of Goss, in the southwestern portion of T. 55 N., R. 9 W., and north of Holliday, in the central portion of T. 55 N., R. 11 W., where the basal chert conglomerate and sandstone are absent and the overlying Cheltenham clay is in contact with the weathered shales and very argillaceous limestones of the Mississippian, Warsaw formation. In such instances, and particularly on highly weathered exposures, it is sometimes difficult to determine quickly the precise line of contact.

One of the best exposures of the conglomerate may be observed on Stinson Creek, in the south part of Fulton, Callaway County, near the center of the west line, SW¼ sec. 16, and the center of the east line, SE¼ sec. 17, T. 47 N., R. 9 W. Here the chert conglomerate is approximately 40 feet thick and is overlain by sandstone 5-8 feet thick. (Pl. VII, A.)

A splendid and easily accessible exposure of the basal conglomerate may be observed also three miles northwest of New Bloomfield, Callaway County, in the SW¼ sec. 21, T. 46 N., R. 10 W., in the deep cut just west of the Little Auxvasse Creek bridge on U. S. Highway No. 54. In the east end of the south wall of the cut the relation of the sandstone to the chert conglomerate is sharply demonstrated. In the north wall of the cut and near the east end, the contact between the unaltered crystalline, cherty Burlington limestone and the basal chert conglomerate is exposed. (Pl. VII, B.) In the middle of the north face the relation of the Cheltenham clay to the basal chert conglomerate and to local lenses of sandstone at its top, is also well developed. (Pl. VIII, A.)

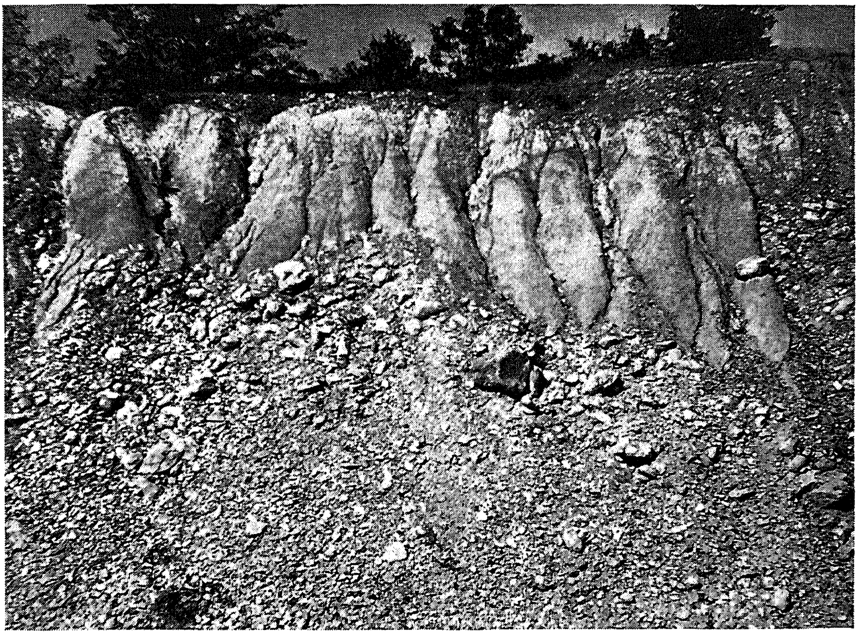
The basal conglomerate is also exposed in the floor of the open pits and shaft clay mines where it is known as the "bottom" or "flint" rock. Its upper surface is often coated with pyrite.

Sandstone lenses within the chert conglomerate, or interfingering beds of sandstone, or sandstone serving as a cement to the chert boulders, serve to indicate the gradational character of this member. Sandstone also forms the upper part of the basal member in the central portion of the northern district, although the thickness is limited to a few feet. (Pl. VIII, B.) The sandstone appears to thicken however, in a southerly direction and becomes an important part of the formation in the southern district. The sandstone is fine-grained and hard, and locally has been recemented into a quartzite. Lenses and streaks of coal or coal smut have been noted in the sandstone, and the upper surface, where it forms the "bottom rock" of the clay pits, is often thoroughly coated with pyrite and in some instances gypsum.

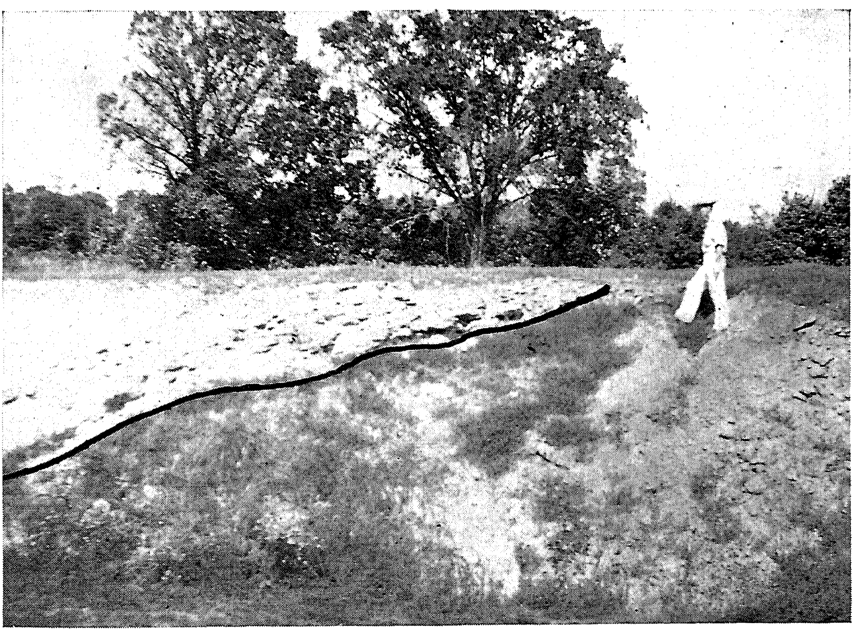
The sandstone becomes somewhat coarser in grain size in a southerly direction and, in the area contiguous to the Missouri River, some of it seems to have been derived from the St. Peter sandstone, which is present.

In exposures in the vicinity of Fulton, the sandstone is thin and distinctly bedded, particularly where it forms the cap or top of the Graydon formation. Excellent exposures of the sandstone may be observed at the foot of Bluff street, in the city of Fulton, NW¼ SE¼ SE¼ sec. 17, T. 47 N., R. 9 W., and in the cuts east and west of the bridge on U. S. Highway No. 54 over Little Auxvasse Creek, sec. 21, T. 46 N., R. 10 W., about three miles north of New Bloomfield.

Clay is a common constituent of the basal conglomerate and occurs as local lenses, or cementing the individual boulders. Some of the clay is sandy, in other instances less so. In color the clay varies from white to gray or blue or red. An interesting example of the occurrence of clay in association with the chert conglomerate may be observed in the quarry just north of the bridge over South Branch on State Highway No. 29 in the extreme southeast corner, sec. 12, T. 48 N., R. 6 W., Montgomery County, and about midway be-



A. View showing relation of Cheltenham clay to basal Graydon chert conglomerate, U. S. Highway 54, SW ¼ sec. 21, T. 46 N., R. 10 W., Callaway County.



B. View showing Graydon chert conglomerate with overlying sandstone wedge to left of man, SW ¼ sec. 21, T. 46 N., R. 10 W., Callaway County.

tween Montgomery City and Danville. At this interesting locality the Burlington and Chouteau limestones are being quarried. In the upper part of the face, and in the Burlington formation are caves filled with white to gray clay and chert conglomerate, the two at times being very closely associated.

The association of the clay with the chert conglomerate and sandstone is also well shown in the deep cut on U. S. Highway No. 54, west of the bridge over Auxvasse Creek, SW¼ sec. 21, T. 46 N., R. 10 W., southwest of Fulton, Callaway County (Pl. VIII, A). The clay occurs more commonly in the upper portion of the conglomerate and there appears to be a gradation into the Cheltenham clay seam in some instances, although often the contact is more sharply defined.

Stratigraphic Relations. The contact of the Graydon formation and the underlying formations marks one of the great unconformities of the Paleozoic group and one of the great unconformities of wide-spread distribution. In the northern district the formation is in contact with Mississippian formations chiefly, which range from the Chouteau, through the Burlington, Keokuk, Warsaw, Spergen, and St. Louis. Of these formations the Burlington is the immediately underlying formation over most of the area and it was the source of much if not all of the chert, which makes up the conglomerate portion of the member.

In the southern portions of Callaway, Montgomery, and Warren Counties, the Graydon appears to be in contact with Devonian and Ordovician limestones, and in the case of a few sink-hole like deposits located near the Missouri River it may be in contact with either the Cotter or Jefferson City dolomites.

It is evident from the foregoing that the Graydon was deposited upon a truncated or bevelled surface of great magnitude and areal complexity. This surface was developed in the long period of erosion which followed the close of the deposition of the limestones of Mississippian age.

The relations of the Graydon to the overlying Cheltenham are discussed in the chapter devoted to the latter.

Correlation. The basal chert conglomerate and sandstone of the northern district, and a similar conglomerate and sandstone in the southern district, occupy the same stratigraphic position and are believed to be correlatives. It should be remembered, however, that all parts of the Graydon formation were probably not deposited at precisely the same time.

A tentative correlation with an arkosic sand in the Cherokee group of the Forest City basin of northwestern Missouri is suggested. The sand was derived from the east face of a now buried granite ridge, which extends from north central Oklahoma across Kansas and into southeastern Nebraska. The sand is widely distributed, and may represent to a large extent deposits formed by streams flowing from the steep east face of the granite range, which was elevated during this period in the geologic history of the region. The arkosic sandstone and the Graydon conglomerate of this report would appear to have another common characteristic in that they both are initial deposits resulting from the rejuvenation of a low lying and previously static land mass.

The Graydon formation of this report may also be the equivalent in part of the Saline Creek cave conglomerate,[22] a deposit recognized as filling solution cavities in the pre-Pennsylvanian rocks of Morgan and Miller Counties. The lithologic and apparently stratigraphic similarity appears to be due, however, more to the unique conditions under which they were formed rather than to the exact equivalency in time of deposition.

A correlation of the Graydon sandstone and conglomerate as described by Shepard[23] in the type locality at Graydon Springs, Polk County, with the Clear Creek sandstone of the Cherokee group of Vernon, Barton, Cedar, and St. Clair Counties has been proposed by Greene.[24] In the opinion of the writer the present available evidence substantiates the validity of that correlation.

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[22]Ball, S. H., and Smith, A. F., Geology of Miller County: Missouri Bureau of Geology and Mines, Vol. 1, 2nd Series, p. 92, 1903.

[23]Shepard, Edward M., The geology of Greene County, Mo. Geol. Sur., Vol. XII, 1st Ser., p. 124, 1896.

[24]Greene, F. C., and Pond, W. F., The geology of Vernon County, Mo. Bur. Geol. and Mines, Vol. XIX, 2nd Ser., p. 44, 1926.

CHELTENHAM FORMATION.

INTRODUCTION.

This is the most important formation of the Cherokee group in east central Missouri, for in both the northern and southern districts, as well as in the St. Louis area, it contains high grade fire clay.

The name Cheltenham was first used by Wheeler,[25] who applied it to a fire clay seam occurring just above the base of the Cherokee group in the Cheltenham district situated in the south part of the City of St. Louis. There it was extensively mined and certain types of the clay at least were used for refractories, chief among them being those for the glass industry. The earliest application of the term to the fire clay seam occurring in the same position in the geologic section in east central Missouri is not known, but the similarity in position was suggested in an earlier report[26] and the equivalency of the clay in the two areas was acknowledged by Allen[27] in a later report. There does not appear to be any question regarding the validity of the correlation. Although the northern and southern districts of east central Missouri and the St. Louis area are not connected by a continuous seam of clay or any other continuous and related geologic unit, they do have, however, in the marginal areas between the southeast districts, pocket-like deposits of flint and occasionally semi-flint fire clay which indicate that the Cheltenham was continuous at one time over the entire area. The associated rocks also testify to the validity of the correlation of the clay as well as its assignment to the lower part of the Cherokee group and hence to the Pennsylvanian system. Recent studies have revealed the complex nature of the Cheltenham and in this report the name is used as a formational one.

The geologic position of the Cheltenham clay may be further sharply defined. The base is terminated by the basal Graydon chert conglomerate or sandstone and the top by a pronounced unconformity above which there occurs, almost without exception, a very bright green, high iron, high alkali,

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[25]Wheeler, H. A., Clay Deposits, Mo. Geol. Survey, Vol. XII, 1st Ser., p. 247, 1896.

[26]McQueen, H. S., Geologic relations of Diaspore and Flint Fire clays of Missouri, Jour. Amer. Ceram. Soc., Vol. 12, p. 690, 1929.

[27]Allen, V. T., The Cheltenham clay of Missouri, Mo. Geol. Survey, 59th Bien. Rept. State Geologist, App. V, p. 7, 1937.

low fusion clay, which fills shallow bowl or funnel-like depressions in the underlying Cheltenham clay.

Studies in east central Missouri have shown that the Cheltenham formation is made up of three distinct clays. That the Cheltenham clay of the St. Louis district contained more than one horizon also was a conclusion independently reached by Wanless and Weller[28] who stated: "In the St. Louis district all of the cyclothems below the Liverpool are merged into the Cheltenham fireclay". They[29] further stated: "In Montgomery County, Missouri, the Liverpool cyclothem cannot be recognized and the fire clay deposits extend up to the Mulky coal horizon". With this specific conclusion the writer does not agree, and the reasons will be apparent after a study of the stratigraphic descriptions, which will follow.

The various clays of the east central Missouri Cheltenham have definite chemical, physical, and mineralogical properties, and each clay exhibits differences in firing behavior tests. These clays represent at least three separate and distinct stages of deposition, with each stage being followed by a period of erosion of varying length during which the members were subjected to erosion and weathering, hence alteration to a greater or less extent. A summary of the arrangement or sequence and the general characteristics of the three members of the Cheltenham formation as defined in this report are given graphically in Plate IX. The three members of the Cheltenham, their character, geologic setting, thickness, and distribution may be described in detail as follows:

LOWER MEMBER.

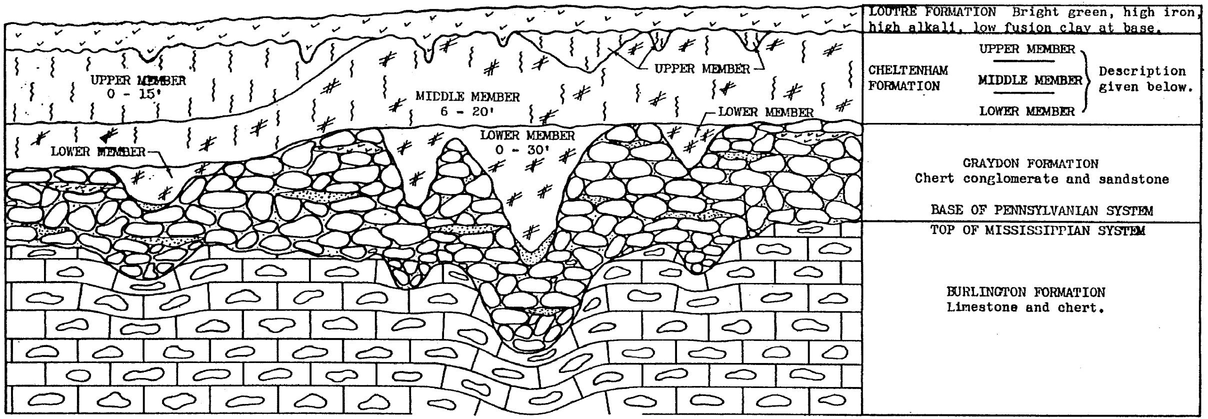
Name. In the study of the Cheltenham clays of east central Missouri, it became apparent at an early date that locally there occurred at the base, a clay quite different in physical properties and chemical composition from the overlying clays.

As studies of the clay were continued the differences became even more striking, and it became evident that the lower part was a very distinct unit. It is described as such in this report and the term lower member of the Cheltenham is applied to it.

[28]Wanless, Harold L., and Weller, J. Marvin, Correlation and extent of Pennsylvanian cyclothems, Bull. Geol. Soc. Am., Vol. 43, p. 1013, 1932.

[29]Idem., p. 1013.

DIAGRAMMATIC SECTION SHOWING DIVISIONS AND RELATIONS OF THE CHELTENHAM FORMATION



SUMMARY DESCRIPTION OF CLAYS OF CHELTENHAM FORMATION

UPPER CHELTENHAM	Light to dark gray plastic clay. Silica content more than 50%. Alumina content usually less than 30%. Clay is widely distributed although locally it occurs as pocket-like masses, or may be entirely absent. Mined at Fulton, Goss, Mexico, and Martinsburg. Thickness, 0-15 feet.
MIDDLE CHELTENHAM	Light gray, fairly hard, semi-plastic clay. Locally mottled purple and red at top and base, also locally sandy and pyritic particularly at base. Marked by many slickenside surfaces, a high waxy lustre, and a hackly fracture. Widely distributed over area and contributes large annual tonnage of clay mined. Mined at Fulton, Mexico, Farber, Vandalia, and Wellsville. Thickness, varies from 6 to 20 feet. Probably represented in southern district also.
LOWER CHELTENHAM	Very dark or fairly dark, black, brown, or gray semi-flint and flint fire clay. Former has slickensides, a higher lustre, is harder, and has a more hackly fracture than Middle Cheltenham. Flint clay is hard, fine-grained smooth, with conchoidal fracture. Distribution very erratic and pockety. Probably is clay in outlying pocket-like deposits in northern district and may be represented by diaspore and associated flint fire clay in southern district also. Thickness, 0-30 feet.

Occurrence. Although the lower member has a wide distribution geographically, it is nevertheless local or "pockety" in occurrence. Throughout the district the clays of the lower member occur filling pocket-like or funnel-like depressions, with a circular or ovate shaped top. The sides of these depressions are usually steep and may attain in a few instances a slope of 70° (Pl. X, A). The depressions are lined by chert conglomerate or sandstone of the Graydon formation.

In areal extent the pocket-like deposits are also variable and locally may be 200 feet or more in diameter or in the direction of the long axis of the clay mass. Between these clay filled depressions the Graydon chert conglomerate rises until it is in contact with the middle member of the Cheltenham formation. Hence, "rolls" or "horsebacks" of the Graydon separate areas of the lower clay member. In some deposits the arrangement is that of "low knobs" or "islands" of chert conglomerate, surrounded by "pools" of clay. This arrangement is even more striking after the clays are worked out and the depressions become filled with surface water (Pl. X, B).

The "rolls" or "horsebacks" of chert conglomerate often show an alignment in a northwest-southeast direction. This suggests folding after the deposition of the clay, which was possibly accompanied or followed by the formation of shallow sinks, developed along lines of weakness, and into which the clays slumped. They were thus protected from erosion, which followed the period of deposition.

Areal Distribution. The lower member is of wide occurrence although as previously mentioned, it is locally very patchy. The northernmost known outcrop is believed to be represented by slightly sandy flint fire clay occurring on the Dye farm, SW¼ SE¼ sec. 11, T. 55 N., R. 9 W., near Stoutsville, Monroe County. To the south it is well represented, locally, in certain pits worked by the A. P. Green Fire Brick Company at Mexico, Audrain County, where the maximum thickness of 30 feet is reported to have occurred. Farther south it is also found at Fulton, Callaway County, in the deeper portions of certain strip and shaft mines and more particularly in the southern part of that county, near Readsville, Reform, and Hams Prairie, where it is represented by numerous pocket-like depressions of flint fire clay.

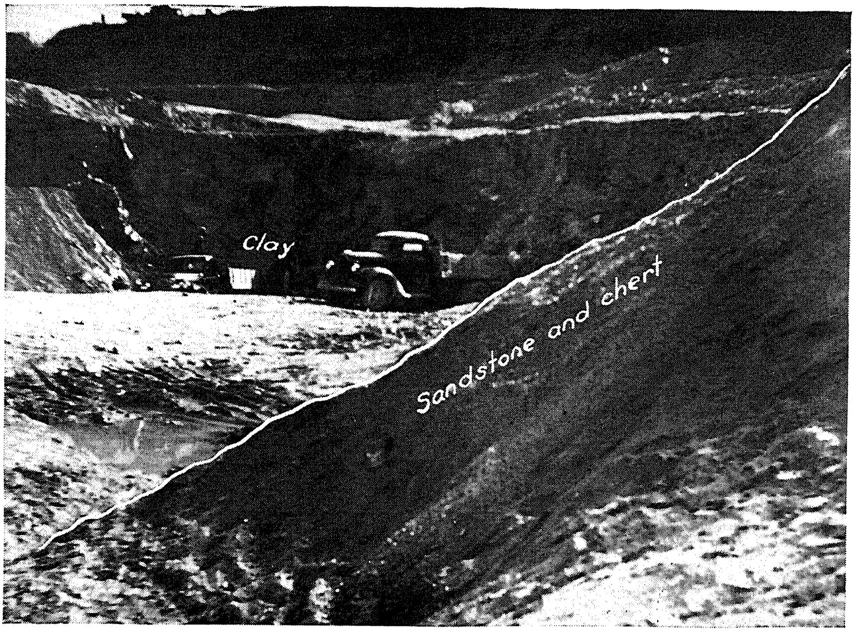
In the western part of the district being described it appears to be present as far west as 2 miles east of Columbia, Boone County, the flint fire clay outcrop on the Turner farm, SE¼ SW¼ sec. 17, T. 48 N., R. 12 W., being considered as a remnant of the Lower Cheltenham.

In the eastern part of the district it is represented by semi-flint and flint fire clay occurring as more or less local masses in the mines at Farber and Vandalia, and farther east by the deposits of hard smooth flint fire clays in T. 51 N., R. 1 W., near Whiteside, Lincoln County. On the east side of the Mississippi River, in Illinois, the flint and plastic fire clays of the Cheltenham seam have been described by Lamar,[30] who states, "The Illinois flint clays appear to be a northeastward extension of the Missouri deposits". The flint clay at least is possibly a representative of the lower Cheltenham formation as it is defined in this report.

In the southeastern portion of the northern district, semi-flint and flint fire clay occur as irregular masses in the mines at Wellsville, and again as pocket-like deposits of flint fire clay in Montgomery and Warren Counties (Pl. XI, A). The lower Cheltenham clay member is also probably represented in the larger and deeper sink-hole type deposits in the southern district, and it will be discussed in the chapters devoted to that district.

Thickness. The lower Cheltenham is variable in thickness. Although its wide distribution has been cited it should be remembered that it occurs as remnants filling comparatively shallow sink holes, consequently this member may be absent over wide areas, or at best represented by small local masses. As a result the thickness of the member is highly variable both locally and regionally. The minimum figure is zero. Thicknesses of 3, 5, 7, 10, and possibly 15 feet are locally not uncommon. Thicker deposits than the figures mentioned are the exception rather than the general rule. The greatest thickness reported for the district was 35 feet and was attained in a pit of the A. P. Green Fire Brick Company at Mexico. Although the exact relation of this thickness to the remainder of the deposit is not known, it would be reasonable for this thickness to become reduced to zero in a comparatively short horizontal

[30]Lamar, J. E., Refractory clays in Calhoun and Pike Counties, Illinois, Ill. State Geol. Survey, Report of Investigations, No. 22, p. 28.



A. Steeply dipping mass in foreground is sandstone and chert of Graydon formation forming one side of "horse back" or "roll". Note depression in background containing clay. Mexico Refractories Co., Stoltz pit, NW ¼ sec. 34, T. 48 N., R. 9 W., Callaway County.

B. View of Stoltz clay pit. Mass to right of truck in left center is Graydon conglomerate "horse" mentioned above. Note depression in front of center truck, also depression to rear.

distance. Such variations in thickness are particularly striking and well demonstrated at and near the "ridges" or "rolls" or "horsebacks", or the elevated masses of chert conglomerate and sandstone.

Topography. Insofar as the writer knows, the lower clay member does not influence the topography in any manner for in the area underlain by the Cheltenham formation it is generally covered. Even where it is represented on the outcrop by lense like masses of flint fire clay at the base of the bedded deposit or by local shallow sink hole type deposits, there is little or no relation to the topography. In fact if there were, the search for the flint fire clays in the northern district would be greatly simplified.

Lithologic Character. At least two types of clays are present in the lower member of the Cheltenham formation. They are distinctive and can be usually differentiated from each other and, with practice, from the clays forming the middle and upper members of the formation. The two types are flint fire clay and semi-flint to hard semi-plastic fire clay. In color they are dark, with dark gray, dark brown, and black being dominant. Locally the flint fire clay, as it occurs as lenses in the basal portion of the lower member, is lighter colored, a light smoky gray being not uncommon.

The flint fire clay is so called because of its smooth, fine-grained texture, and its habit of breaking with a conchoidal or shell-like fracture, and with sharp splintery edges like flint or chert. With prolonged weathering the clay spalls down into extremely fine angular fragments. This characteristic is better developed, however, in the flint fire clays obtained from outliers or deposits marginal to the area underlain by the more blanket-like deposits. This clay is comparatively hard, in fact much harder than any of the other clays of the Cheltenham formation. The flint clay shows a range in hardness within itself also. The clay of this type, which occurs in shallow pocket or shallow sink-hole type depressions and marginal to the main area, is harder and usually has a slightly higher fusion point than the flint clay occurring as lenses or masses within the main body of the lower member.

Where the harder semi-flint or flint fire clay types are adjacent to the elevated chert conglomerate masses or "rolls", it often has a slatey cleavage, which may be the result of differential movement of the clay mass into the sink-hole type structures. Excellent examples of this development have been observed in pit No. 4, A. P. Green Fire Brick Company, sec. 36, T. 51 N., R. 9 W., at Mexico, and in the Stoltz pit, Mexico Refractories Company, NW¼ sec. 34, T. 48 N., R. 9 W., north of Fulton, Callaway County.

A sample of this type of clay was obtained from the pit first mentioned and firing behavior tests made on it are discussed in chapter V. A sample of similar clay was obtained also from the pit last mentioned and the results of a chemical analysis are given in Plate XII.

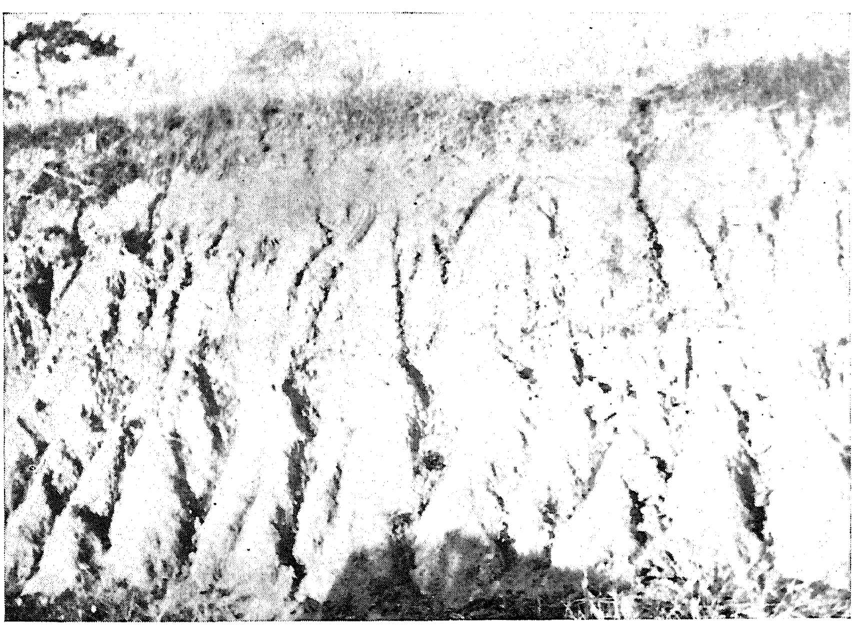
The mineralogical composition of the flint fire clay has been studied by Allen[31] and the results previously reported in an earlier publication are as follows:

"Flint clays can withstand a very high heat and are the most valuable type of refractory clay. The flint clays of Missouri are composed chiefly of halloysite ($Al_2O_3.2\ SiO_2.2\ H_2O.\ H_2O$) or kaolinite ($Al_2O_3.\ 2\ SiO_2.2\ H_2O$) of submicroscopic size, for under crossed-nicols of a petrographic microscope large areas are isotropic (pl. I). The curved or conchoidal fracture of flint clays is connected with the fine particles making up the clay. In addition some kaolinite may be present as micaceous plates or books of larger size. Some quartz or chert showing a mosaic of low interference colors under cross-nicols may be present, as well as an occasional grain of tourmaline, zircon or rutile. When allowance is made for the variations in the other minerals which may be present, the silica and alumina contents of the flint clays listed in Table 1 approach the theoretical composition of halloysite, but the chemically combined water is lower. It is known that part of the water of halloysite is easily lost even at room temperature and that the index of refraction increases with loss of water from 1.47 to 1.57.[32] The water content of the flint clays listed in Table 1 varies between 13.62 and 14.00 and the index of refraction of halloysite present in them varies between 1.563 and 1.570. Dr. Paul F. Kerr of Columbia University has made X-ray patterns of typical specimens of Mis-

[31]Allen, Victor T., The Cheltenham clay of Missouri, Missouri Geological Survey, 59th Bien. Rept., State Geol., App. V., pp. 11-13.

[32]Larsen, E. S., The microscopic determination of the nonopaque minerals: U. S. Geol. Survey Bull. 679, pp. 172, 173, 174, 1921.

A. General view of Laclede Christy Clay Products Co., Phipps mine near Wellsville, Montgomery County.



B. View of glacial clay, which forms upper part of stripping over many deposits of the northern district.

souri flint clays and reports[33] that their X-ray patterns are those of halloysite or microscopic kaolinite. The chemical and mineralogical compositions of the flint clays from Callaway, Audrain and Montgomery Counties are similar to that of the flint clays from the counties south of the Missouri River, such as Phelps and Franklin Counties. (Compare 1, 2, 3, with 4, 5, table 1). The flint clays of both[34] areas are a mixture of halloysite, kaolinite and quartz with other minerals in minor amounts and are so much alike that they may belong to the same formation, formed at the same time under similar conditions.

"Under the microscope the texture of some flint clays in thin section is uniform due to the similar arrangement of halloysite and kaolinite throughout. Many flint clays show areas of halloysite of various shapes surrounded by smaller grains of kaolinite and halloysite (Pl. I, d). Other flint clays contain pellets or oolites which are seldom spherical but ovate and flattened often in the horizontal plane. These oolites are composed either entirely of halloysite or of halloysite with kaolinite flakes scattered through them (Pl. I, a). In none was gibbsite or any other aluminum hydrate observed. Some of the pellets are sufficiently hard that they can be separated from the flint clay. Where the pellets are abundant they touch one another and aided by the presence of organic material a banding or bedding is formed (Pl. I, b). In some pits near Hams Prairie and New Florence this banding extends horizontally throughout the pit and shows no sign of disturbance. The horizontal attitude of the banding suggests that the arrangement of colloidal particles of the pellets took place when they were deposited. In only one thin section is this original sedimentary structure cut by a vertical vein of halloysite (Pl. I, c) which indicates there has been little secondary rearrangement and downward migration of the clay minerals which would be expected to accompany large scale removal of silica and other elements."

In the present report a chapter is devoted to the mineralogy of the clays, the results being obtained from X-ray studies by Dr. Paul G. Herold.

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[33]Written communication.

[34]Allen, Victor T., Mineral composition and origin of Missouri flint and diaspore clays: Missouri Geological Survey and Water Resources, 58th Bien. Rept., app. IV, pp. 7-9, 1935.

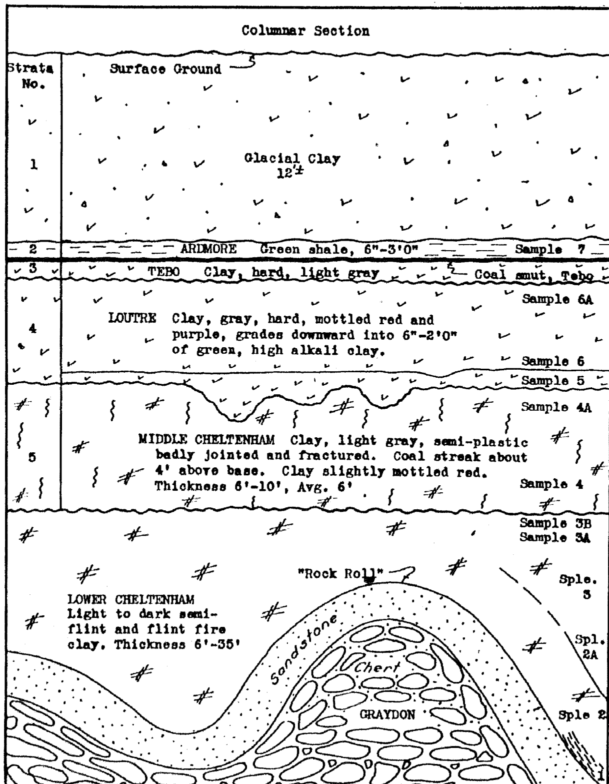
The chemical composition of the flint fire clay of the lower member of the Cheltenham likewise sets it apart from the other clays of the formation, and its composition further suggests that it represents a late or comparatively more nearly complete stage in the leaching or alteration history of the clays. Table 1 presents the chemical analyses of representative flint fire clays from widely separated points within the area underlain by the Cheltenham formation or from the marginal outlying deposits. The analyses are considered to be typical and average ones. They possess several outstanding characteristics as to composition, chief among them being a high degree of uniformity, as a whole. Among the component constituents there is also but small variation in composition.

The flint fire clays under discussion are also notable in that the fluxing impurities are comparatively low. Iron oxide (Fe_2O_3) exceeds one per cent in only one sample, and in that it occurs chiefly as sparingly disseminated pyrite. Lime (CaO) and magnesia (MgO) on the whole are very low and when combined exceed one per cent of the total in only two instances. Soda (Na_2O) and potash (K_2O) are likewise low and in no instance exceed one per cent. A study of these analyses shows that they are complete as to the sum of all constituents, and therefore there is but little, if any, room for constituents other than those reported.

A sample of flint fire clay from an outlying depression-like deposit has been subjected to firing behavior tests by Paul G. Herold and the results are presented in chapter V of this report.

The semi-flint, or perhaps locally semi-plastic clay makes up probably the greater part of the lower Cheltenham clay formation in the area of the blanket-like or wide-spread deposit. This is true even though the lower member is pockety in nature and appears to be a remnant of what was once a more wide-spread blanket-like deposit of clay. In the isolated depression-like deposits marginal to the main area underlain by the Cheltenham, the semi-flint clay is less common, and the flint fire clay is the dominant type. This may mean that comparatively late leaching may have brought about further alteration toward the flinty type of any semi-plastic or semi-flint clays that were originally present.

The semi-flint clay has a fairly smooth texture but lacks the very smooth one that so definitely characterizes the flint



Sample	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	Ign. Loss	Moisture	Totals	Description
7	56.26	20.65	4.94	0.99	0.37	2.24	0.48	4.70	5.60	2.29	98.52	Green phosphatic shale.
6A	55.06	27.25	2.43	1.48	0.24	0.56	0.34	0.80	9.52	2.08	99.76	Clay, dark gray, splintery fracture.
6	52.98	28.29	2.95	1.48	0.24	0.72	0.51	2.44	8.81	1.81	100.23	
5	56.04	21.06	5.64	1.48	0.51	1.60	0.45	5.07	5.08	1.92	98.81	Clay, green, high iron, high alkali.
4A	48.16	33.03	1.99	1.48	0.51	0.56	1.12*		11.04	1.11	99.00	Clay, greenish gray, slightly mottled, slickensided.
4	46.32	34.98	1.56	1.48	0.49	0.61	0.88*		11.78	1.27	99.37	Clay, light gray, semi-flint, smooth textured, fairly hard.
3B	46.52	34.05	1.99	1.48	0.49	0.49	1.34*		11.26	1.17	98.79	Clay, gray, hard, semi-flint.
3A	46.30	32.76	4.16	1.38	0.46	0.31	1.73*		10.73	1.23	98.06	Clay, gray, semi-flint, smooth textured, red and purple mottled.
3	47.30	34.86	1.56	1.38	0.41	0.34	1.17*		11.30	1.11	99.43	Gray clay, semi-flint, smooth, homogenous, satiny luster, well developed slickensides.
2A	47.88	32.41	1.73	1.38	0.51	0.33	1.26*		11.26	1.66	98.42	Clay, dark gray semi-flint.
2	45.62	33.91	2.43	1.38	0.51	0.86	2.21*		10.44	1.66	99.02	Clay, hard, dark gray, smooth, semi-flint clay, flint like.
1	44.54	35.46	1.66	1.28	0.69	0.51	1.34*		12.13	1.58	99.09	Hard slaty dark flint like clay adjacent to "Rock Roll".

Chemical Composition, Percent.

* Alkalies determined as Na_2O.

Vertical section and chemical composition of beds exposed in Mexico Refractories Co., Stoltz pit, NW ¼ sec. 34, T. 48 N., R. 9 W., Callaway County.

TABLE 1.

CHEMICAL ANALYSES OF FLINT FIRE CLAYS, LOWER MEMBER, CHELTENHAM FORMATION, NORTHERN DISTRICT.
H. W. MUNDT, ANALYST.

Sample No.	1	2	3	4	5	6	7	8	9
Ignition Loss	13.98%	13.86%	13.56%	13.78%	13.75%	14.01%	13.91%	13.90%	14.11%
Silica (SiO_2)	43.88	44.63	45.55	45.02	43.08	44.57	43.88	44.42	44.20
Alumina (Al_2O_3)	38.81	37.96	37.03	38.24	38.93	38.54	38.17	38.63	37.62
Iron (Fe_2O_3)	0.45	0.66	0.55	0.35	0.46	0.45	0.56	0.55	1.40
Titania (TiO_2)	2.39	2.42	2.19	2.28	2.21	2.36	2.64	2.12	2.72
Lime (CaO)	0.04	0.04	0.76	0.04	0.98	0.00	0.02	0.04	None
Magnesia (MgO)	0.14	0.12	0.32	0.34	0.64	0.08	0.84	0.10	None
Soda (Na_2O)	0.18	0.22	0.28	0.36	0.42	0.30	0.30	0.30	0.08
Potash (K_2O)	0.22	0.42	0.64	0.18	0.12	0.14	0.16	0.12	0.28
Totals	100.29	100.33	100.88	100.59	100.59	100.45	100.58	100.18	100.41

Sample No. 1 Flint fire clay, Sherman pit, NE ¼ NW ½ sec. 23, T. 46 N., R. 9 W., Callaway County, pocket-like or isolated deposit.
Sample No. 2 Flint fire clay, Beaven pit, SE ¼ NW ¼, sec. 16, T. 49N., R. 9 W., Callaway County, pocket-like or isolated deposit.
Sample No. 3 Flint fire clay from prospect on Tilton Turner farm, 2 miles east of Columbia, SE ¼ SW ¼, sec. 17, T. 48 N., R. 12 W., Boone County.
Sample No. 4 Flint fire clay occurring as a lense in Cheltenham semi-flint clay, mine, North American Refractories Company, Farber, Audrain County.
Sample No. 5 Flint fire clay occurring as a lense in Cheltenham semi-flint clay, mine, Wellsville Fire Brick Company, Wellsville, Mo.
Sample No. 6 Flint fire clay, Lewelling pit, SW ¼ SE ¼, sec. 5, T. 47 N., R. 4 W., south of High Hill, Montgomery County, from pocket-like or isolated deposit.
Sample No. 7 Flint fire clay, Buxton Benton pit, sec. 5, T. 46 N., R. 2 W., Warren County, pocket-like or isolated deposit.
Sample No. 8 Flint fire clay, from Harbison-Walker pit, Whiteside Area, SE ¼, sec. 19, T. 51 N., R. 1 W., Lincoln County, pocket-like or isolated deposit.
Sample No. 9 Flint fire clay, from outcrop, Richards Farm, SW ¼, NE ¼, sec. 27, T. 54 N., R. 7 W., northeast edge of Perry, Ralls County.

fire clay type. It breaks with an angular and conchoidal fracture, but not to the degree possessed by the flint fire clay. The clay is fairly hard, but less so than the associated flint clay, but more so than the other clays of the Cheltenham. It has a smooth greasy feel to the touch and usually a high luster. Slickensided surfaces, some of them with a high degree of polish, characterize this type of clay. These surfaces always dip toward the center of the containing depressions.

Pyrite and sand are occasionally present but occur chiefly in the areas adjacent to the elevated masses ("Hogbacks") of chert conglomerate. Coal is not uncommon and small discontinuous lenses or pencilings have been noted. Mineral charcoal has also been observed frequently. Coal, or dark brown or black semi-flint clay, the colors being due to a comparatively high organic content, often occur at the top of the lower member of the Cheltenham clay formation.

Insofar as obvious physical properties are concerned, it is sometimes difficult to draw a sharp line between the semi-flint and flint fire clays of the lower member. A color change was noted at least locally between the two types in the mine of the Wellsville Fire Brick Company at Wellsville, Montgomery County; in the mine of the North American Refractories Company at Farber; in the pit of the A. P. Green Fire Brick Company at Mexico, in Audrain County; and in pits located in the Hams Prairie locality south of Fulton, Callaway County. However, while the types of clay appear to grade into each other imperceptibly, on close inspection they may be differentiated either side of a limiting zone on the basis of "grain" or texture and hardness.

The mineralogical composition of this type of clay has been studied by Allen,[35] who reports it to be composed chiefly of the clay mineral, kaolinite. He further reports,[36] "In one thin section made from a clay taken from the bottom of the Laclede Christy Clay Products Co.'s pit near Wellsville, halloysite appears to be replaced by kaolinite (Pl. IV, c). Although many more sections were made from the same sample and from other clays from this pit, this is the only case of halloysite occurring in a plastic Cheltenham clay." The presence of halloysite may be significant in that the formation of that

[35]Op. cit. pp. 13-15.
[36]Idem. p. 15.

mineral may be a step in the alteration of this type of clay to flint fire clay. A further discussion regarding the mineralogy of this clay is contained in chapter VI.

In chemical composition the clay approaches that of flint fire clay. An examination of the analyses of semi-flint clay presented in Table 2 and a comparison with the flint fire clay analyses of Table 1 bring out some interesting features. The semi-flint clays are more variable in composition. The alumina-silica ratio is different, with the alumina being present in smaller amounts and the silica in greater amounts as compared with flint fire clay. Fluxing impurities are also higher in these clays, particularly the iron (Fe_2O_3) and the lime (CaO) and magnesia (MgO) combined. Another interesting point of comparison is the content of titania (TiO_2), which always appears to be concentrated as a product of weathering or leaching. In the semi-flint clays under discussion titania is present in variable amounts. In six of eight analyses it is less than two per cent of the whole, whereas in the case of the flint clays of Table 1 nine samples contained over two per cent of the whole. Thus, the increase in the direction of flint fire clay suggests that it is a product of leaching of semi-flint clay, which in turn was derived from the semi-plastic and originally the plastic type.

In some instances, lenses of semi-flint or even flint-like clay of low fusion are found in the lower member. This clay apparently was out of the zone of circulating ground water, which leached the clay and resulted in its alteration. It is referred to locally as "rubbery" or "lifeless" clay and it is rejected in mining because of its low fusion point, probably due to the content of iron and potash. A sample from a pit at Mexico, Audrain County, had the following chemical composition:

Chemical Analysis of "Rubbery" Clay
R. T. Rolufs, Analyst

Constituent	*Percent*
Ignition Loss (H_2O, +110°C.)	9.67
Moisture (H_2O, −110°C.)	1.17
Silica (SiO_2)	53.56
Alumina (Al_2O_3)	28.84
Ferric Oxide (Fe_2O_3)	2.77
Titania (TiO_2)	1.19
Lime (CaO)	0.31
Magnesia (MgO)	0.57
Soda (Na_2O)	0.11
Potash (K_2O)	1.35
Total	99.54

TABLE 2.

CHEMICAL ANALYSES, SEMI-FLINT CLAY INTERMEDIATE BETWEEN FLINT FIRE CLAY AND SEMI-PLASTIC CLAY, FROM LOWER MEMBER CHELTENHAM FORMATION, NORTHERN DISTRICT.

Sample No.	1	2	3	4[1]	5[1]	6	7	8
Ignition Loss (H_2O, + 110° C.)	13.50	12.75	13.06	11.93	12.53	12.11	11.30	11.26
Moisture (H_2O, — 110° C.)	NR	NR	NR	1.06	0.87	1.95	1.11	1.66
Silica (SiO_2)	45.86	48.12	45.92	47.08	45.88	48.58	47.30	47.88
Alumina (Al_2O_3)	36.71	35.16	35.79	35.35	36.21	31.20	34.86	32.41
Iron (Fe_2O_3)	0.73	0.72	0.75	1.44	1.96	1.56	1.56	1.73
Titania (TiO_2)	2.98	1.80	2.28	1.37	1.67	1.28	1.38	1.38
Lime (CaO)	0.06	0.06	0.06	0.30	0.20	0.37	0.41	0.51
Magnesia (MgO)	0.20	0.30	0.36	0.60	0.35	0.57	0.34	0.33
Soda (Na_2O)	0.36	0.38	0.44	0.23	0.23	....	....	....
Potash (K_2O)	0.20	0.30	0.41	0.38	0.23	....	....	....
Totals	100.60	99.58	99.07	99.74	100.13	97.67	98.26	97.16

N.R. Not reported.

Sample No. 1—Semi-flint clay. Mine, Harbison-Walker Refractories Company, Vandalia, Audrain County.

Sample No. 2—Semi-flint clay, Phipps mine, Laclede-Christy Clay Products Company, Wellsville, Audrain County.

Sample No. 3—Semi-flint clay, open pit formerly operated by Walsh Fire Brick Company, NW ¼ sec. 29, T. 47 N., R. 3 W., Warren County.

Sample No. 4—Semi-plastic Cheltenham clay, shaft mine, Harbison-Walker Refractories Company, Fulton, Callaway County.

Sample No. 5—Dark gray semi-plastic clay, near bottom open pit, A. P. Green Fire Brick Company, Mexico, Audrain County.

Sample No. 6—Semi-flint fire clay, very hard and dark. Top of lower member of Cheltenham clay. Pit No. 4, A. P. Green Fire Brick Co., Mexico, Audrain County.

Sample No. 7—Semi-flint clay, smooth greasy texture, upper part of lower member of Cheltenham clay. Mexico Refractories Company, Stoltz pit, SW ¼ sec. 34, T. 48 N., R. 9 W., Callaway County.

Sample No. 8—Semi-flint clay, dark, hard, at base of lower bench and near base of lower Cheltenham clay, Mexico Refractories Company, Stoltz pit, SW ¼ sec. 34, T. 48 N., R. 9 W., Callaway County.

[1]Allen, V. T., op. cit., p. 14.

In connection with firing behavior tests five samples were collected which represented different expressions, color, texture, etc., of the semi-flint clays. The results of these tests are considered in chapter V.

Correlation and stratigraphic relations. The widespread, although patchy distribution of the lower Cheltenham clay member has been commented upon, and the distribution as described, is in effect also a description of the correlation of the member over a wide area. The presence of this member has not been accurately determined in the area to the north and west in northern Missouri where younger rocks overlie the Cheltenham and the formation is some depth beneath the surface. There have been but few core drill holes put down and from them only a few of the cores are available. Churn drill samples are available but they are wholly unsatisfactory.

The occurrence of the lower member to the west is also not known. At the end of this chapter certain regional aspects of the correlation of the Cheltenham clay are considered. These need not be discussed further at this point.

A general correlation with the clays of the southern district of this report is possible, and some of the flint and diaspore clay occurring in the sink-hole type deposits are believed to be representative of the lower Cheltenham member.

Insofar as the stratigraphic relations are concerned the contact between the lower member and the underlying Graydon conglomerate would appear to be a gradational one. In other instances, however, the contact is sharp and smooth, but in others a limonitic, rust-like, veneer caps the conglomerate and suggests a weathered surface.

The relation to the overlying middle clay member is more sharply defined. After the deposition of the lower member gentle folding took place. Caves were developed along planes of structural weakness by the action of ground water, and the roofs, no longer able to support their own weight, slumped into these caves. An irregular surface, involving both the Graydon chert conglomerate and the overlying lower clay member of the Cheltenham, was produced. Exceptions to the foregoing statements might be cited, for in some instances horizontal bedding planes are reported to exist in this clay and apparently the clay has undergone no subsidence.[37] Such

[37]Ben K. Miller, oral communication.

an occurrence would suggest the pre-depositional existence of caves, and would also indicate a period of weathering between the Graydon conglomerate and the Cheltenham, since the former is involved in the sink-like structures.

The slaty, or bedded type of clay found adjacent to the chert conglomerate "rolls" and previously described as possibly resulting from differential movement of the clay against these chert masses, should be kept in mind however. Also the Graydon conglomerate floor was probably an irregular one locally and the bedding under consideration may have been retained even through mass subsidence of the clay.

Perhaps the sinks were formed prior to and after deposition of the clay as well. In certain instances the former is suggested for fairly hard dark colored clay has been found well below the base of the Cheltenham, and separated from that formation and the point of occurrence by a thick vertical section of cherty Burlington limestone of Mississippian age. Such an occurrence has been described previously in this report as occurring in a water well on the Robert S. Green property, NW¼ NE¼ SE¼ sec. 35, T. 51 N., R. 9 W., south of Mexico. Here the base of the Cheltenham clay was drilled at a depth of 100 feet and was followed by the Graydon conglomerate to a depth of approximately 110 feet, and the cherty Burlington limestone to 180 feet, where hard dark bluish clay was drilled from 180-190 feet.

That the occurrence was in a cave, is suggested by the continuation of the normal Burlington sequence from 190 to 265 feet. Other and similar occurrences are known in Audrain County. Whether the material is older than the Cheltenham clay, or is a representative of that clay cannot be definitely proved at this time. Its presence does show, however, that caves existed in the Mississippian limestones prior to the deposition of the first Pennsylvanian sediments, and some of them had openings connected with the surface and received clay sediments during the period of deposition. In any event a period of erosion and weathering followed. The irregular surface was bevelled, and thus, the irregular "patchy", "pockety" sink-filled masses of clay with associated islands or "horses" of chert conglomerate were produced. This period was an important one, as during it leaching of water soluble salts took place, with drainage of the water into the caves or sinks. The clays, which probably were originally of the plastic type, were depleted of silica and enriched of alumina.

The flint clay represents one and a more complete stage, the semi-flint, another and a less complete stage of alteration. Differential leaching, access to avenues of percolating ground water, changes in ground water level, or choking up of the bottoms of the sinks, are factors that might have resulted in one type of clay or another.

The beginning of deposition of the middle Cheltenham clay marked the close of the lower Cheltenham cycle. It also saw the covering over of what were now remnants of the lower Cheltenham, and temporarily at least, caused a cessation of further alteration of the lower clay.

MIDDLE MEMBER.

Name. This name is applied to a persistent and fairly continuous semi-plastic clay occurring in the middle of the Cheltenham formation. The middle member is an important one and there is obtained annually from it the largest tonnage of semi-plastic clay mined in the district.

Occurrence. The middle member is a typical example of a blanket-like, widespread deposit, and it forms the most persistent member of the Cheltenham formation. Unlike the lower member of the formation it is not subject to the irregularities resulting from the sink-hole like structures, which result in the patchy distribution and irregular thickness of that clay, nor was the top subjected to erosion that resulted in its removal over large areas, as was the upper member.

Areal Distribution: From the foregoing description of the mode of occurrence, it immediately becomes apparent that the middle member has a wide distribution, geographically, and that it will be found over a large area. In the northern portion of the northern district the clay is found in the vicinity of Goss, T. 55 N., R. 9 W., Monroe County. It also occurs in the northeastern part of the area in the vicinity of Perry, Ralls County, the occurrence having been described in a previous publication.[38]

[38]McQueen, H. S., Clay and coal resources of the Perry Area, 55th Bien. Rept., State Geol. App. III, pp. 102-112, 1929.

In the central portion of the northern district it is extensively mined. Large tonnages are taken from this member annually at Mexico, Farber, and Vandalia, in Audrain County and at Fulton, Callaway County. In the southeastern part of the area being discussed the clay is also mined on a large scale at and near Wellsville, Montgomery County. The clay is also known as far west as Columbia, where it is exposed in the lower few feet of the face in the pit, Edwards-Conley Brick Company, NE¼ SW¼, sec. 8, T. 48 N., R. 12 W.

The southern limits of the clay are probably coextensive with the limits of the Cheltenham formation as defined on the accompanying map. However, south of the area underlain by the formation are the marginal pocket or sink-hole or shallow depression type of deposits, and in some of them there occurs what is believed to be the middle member of the formation. The Bevan pit, SE¼ SE¼ sec. 16, T. 46 N., R. 9 W., Hams Prairie locality, south of Fulton, Callaway County, and the pit formerly worked by the Walsh Fire Brick Company, NW¼ sec. 29 and NE¼ sec. 30, T. 47 N., R. 3 W., near Pendleton Station, Warren County, are examples.

Thickness. The middle member of the formation is the most uniform with respect to thickness. Over a considerable part of the northern district in Audrain, Callaway, and Montgomery Counties it will average at least 15 feet in thickness. Thicknesses of 18, 20, and possibly in some local instances, 25 feet are also known. Insofar as the writer knows the middle member, within the area underlain continuously by the Cheltenham formation, is never absent over a large area, and even local absenses are not common.

An excellent example of the absence of this member may be observed, however, on Middle River, SE¼ SE¼, sec. 2, T. 46 N., R. 10 W., a short distance down stream from the bridge on U. S. Highway No. 54. Here the Cheltenham is very thin and limited to the lower clay member only. It is overlain by the lower clay zone of the Loutre formation, which will be described later, and it in turn is overlain by the under clay of the Tebo coal member. The entire section is well exposed in a steep bluff and the details of it are given on page 101. There are, however, several cases where the thickness is less than the average figure stated, and a minimum thickness, except very locally, of about 6 feet has been noted in a number of localities within the main area of production. Minimum thicknesses often occur adjacent to, or over the chert conglomerate "rolls".

Topography. The middle member does not have any pronounced effect upon the topography. In areas of outcrop, particularly along streams, it usually stands out because of the relative hardness and the ability to withstand erosion. It often forms low and discontinuous bluffs but otherwise no other features that deserve mention.

Lithologic Character. In addition to being uniformly distributed over the area underlain by the Cheltenham formation, and in addition to having a more uniform thickness than any of the other members, the middle member also possesses uniform characteristics of composition.

The characteristic color of the clay is commonly light gray, with a faint light olive cast. Locally, it may have a darker gray color, which is imparted by organic or carbonaceous matter. Near the top, and often at the base also, the clay is mottled blue, red, maroon, and purple. These variegated colors are particularly developed in the clay just beneath the local masses of high alkali, high iron clay, which occur at the base of the Loutre formation and extend down into it as small pocket-like masses. The variegated colors present at the base usually occur adjacent to horses or elevated masses of the Graydon chert conglomerate.

The clay is fine-grained. It is fairly smooth, but has a rougher texture and a more pronounced grain than the semiflint clay of the lower member. It breaks with a conchoidal fracture and pronounced edges but lacks the sharpness of of definition of these properties, as compared with those of the clay of the lower member.

The clay is fairly hard, much harder in fact than the clay of the upper member, but less so than the clays of the lower member. The hardness is indicated by the presence of many slickensides and striated surfaces with a high bright lustre or polish, which were formed in the differential movement of fairly hard masses of clay. As previously mentioned these surfaces are arranged in a manner roughly circular to the deeper depression-like areas, and always dip toward the center or lowest point.

In an earlier report describing the mineralogy, Allen[39] did not differentiate the clays of the Cheltenham in the manner of this report and classed them only as flint fire clays and plastic clays. Of the latter, he[40] further differentiated between "Plastic clays with kaolinite as the chief clay mineral" and "Plastic clays with a sericite-like mineral as the chief clay mineral".[41] The clay of the middle Cheltenham falls within the class first mentioned. Kaolinite is the chief clay mineral. Quartz was also found in practically every sample and ranged in grain size "from .01 to .3 mm." According to Allen[42] another clay mineral is present.

"It occurs in brown patches of irregular shape (Pl. II, a, b; and Pl. IV, a) which appear to be partly replaced by kaolinite. This is probably the hydromica of Galpin,[43] Somers and others which is reported by Somers[44] to be abundant in the clays of the St. Louis district and scarce or absent in the flint clays of Missouri. The writer observed a similar mineral in his studies of the underclays of Illinois coal and referred to it as potash beidellite,[45] because the mineral resembles beidellite in appearance, and yet is not normal beidellite for it contains potash and has a different X-ray pattern from the type beidellite. Grim[46] and Kerr have continued the study of this material from Illinois and favor the name sericite-like mineral for it. Regardless of what it is to be called, this mineral probably accounts for some of the potash, magnesia and iron as well as modifying somewhat the alumina silica ratios of the clays listed in Table 2.

"The other minor accessory minerals are pyrite, tourmaline, zircon, rutile, titantite and leucoxene, but with the exception of pyrite they constitute such a small part of the clay that they affect the composition only slightly."

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[39]Op. cit., pp. 13-15.

[40]Idem, p. 13.

[41]Idem, p. 15.

[42]Idem, pp. 14-15.

[43]Galpin, S. L., Studies of flint clays and their associates: Am. Ceramic Soc. Trans., vol. 14, pp. 306. 338, 1912.

[44]Somers, R. E., Microscopic study of clays: U. S. Geol. Survey Bull. 708, p. 294, 1922.

[45]Allen, Victor T., Petrographic and mineralogical study of the underclays of Illinois coal: Jour. Am. Ceramic Soc., vol. 15, pp. 564, 573, 1932.

[46]Grim, R. E., Petrology of the Pennsylvanian shales and noncalcareous underclays associated with Illinois coals: Bull. Am. Cer. Soc., vol. 14, pp. 113-119; pp. 129-34, 1935.

Much additional information regarding the mineralogy of this clay has been obtained as the result of X-ray studies. These results are presented in chapter VI of this report.

In addition to the foregoing mineralogical details the presence of pyrite should be mentioned. It often occurs in local areas, and although as disseminated minute crystals, the concentration is of sufficient extent to impart a dark bluish gray color to the clay, and to cause the clay to be rejected in mining operations as being unsuitable for the manufacture of high grade fire brick and refractories. In addition to the pyrite "clusters", the basal portion of the middle Cheltenham is marked locally by an impure, pyritic clay, the pyrite being in sufficient abundance to give the clay a bluish gray cast. The thickness of this clay is only a few inches to possibly a few feet. It also is rejected as valueless in mining operations.

Sand is also not uncommon to the middle clay member. It is concentrated, however, locally and occurs at the base of the member in certain instances as thin lenses or thin discontinuous beds of sandy clay. The thickness of the basal sandy clay is never over two feet. It also occurs in the same manner where this clay member is adjacent to elevated masses ("horsebacks") of the Graydon chert conglomerate, but in some localities, it is so thoroughly disseminated throughout the mass as to render the clay valueless. The grains are well rounded but only slightly frosted. In some instances the sand is concentrated in such a manner as to suggest bedding planes.

Chemical Composition. The chemical composition of the middle Cheltenham clay, Table 3, is different from that of the lower member, and somewhat different from that of the upper member. In a comparison with the analyses of the semi-flint clay of the lower member, Table 1, and the analyses of the semi-plastic clay of the middle member, Table 2, it will be apparent that the ratio of silica to alumina is higher in the latter. The iron (Fe_2O_3) content is also slightly higher than the average in this clay, and in the main appears to be due to the presence of disseminated, small crystals of pyrite previously described.

The other fluxes, lime and magnesia, and soda and potash, while present only in comparatively small amounts are slightly higher in the middle member than in the lower member, and as a result the P.C.E. (fusion point) value is lower.

TABLE 3.

CHEMICAL ANALYSES, SEMI-PLASTIC CLAY, FROM MIDDLE MEMBER OF CHELTENHAM FORMATION, NORTHERN DISTRICT.

R. T. ROLUFS AND H. W. MUNDT, ANALYSTS.

Sample No.	1[1]	2[1]	3[1]	4[1]	5	6	7
Ignition Loss (H_2O, + 110°C.)	10.14%	10.76%	10.53%	10.87%	9.80%	10.74	10.07%
Moisture (H_2O, — 110°C.)	1.08	0.84	0.83	ND	1.53	.81	.39
Silica (SiO_2)	54.24	52.14	53.94	53.07	54.74	48.90	53.64
Alumina (Al_2O_3)	30.56	32.50	28.26	29.07	30.29	33.20	29.20
Iron (Fe_2O_3)	1.44	1.60	1.98	1.11	1.73	1.47	2.25
Titania (TiO_2)	1.46	1.56	1.46	2.31	1.48	1.58	1.58
Lime (CaO)	0.15	0.25	0.50	0.06	0.05	.56	.49
Magnesia (MgO)	0.40	0.30	1.72	0.68	0.35	.34	.46
Soda (Na_2O)	0.09	0.16	0.19	0.74	ND	.10	.10
Potash (K_2O)	0.21	0.24	0.58	0.40	ND	1.53	1.22
Sulphur (S)	....	....	....	....	....	.006	.114
Phosphorus Pentoxide (P_2O_5)	....	....	....	....	....	.05	.03
Totals	99.77	100.35	99.99	98.31	99.97	99.286	99.544

ND. Not determined.

Sample No. 1—Dark gray plastic (semi-plastic) clay, Mexico Refractories Company, plant pit, Mexico, Audrain County.

Sample No. 2—Light gray plastic (semi-plastic) clay, A. P. Green Fire Brick Company, plant pit, Mexico, Audrain County.

Sample No. 3—Dark Gray plastic (semi-plastic) clay, lowest level, Laclede-Christy Clay Products Company, Phipps pit, Wellsville, Montgomery County.

Sample No. 4—Semi-flint clay, North American Refractories Company, plant mine, Farber, Audrain County.

Sample No. 5—Semi-plastic clay, lower part of outcrop, ravine on Levings farm, south side of Otter Creek, near south line, SW¼ SE¼ sec. 19, T. 55 N., R. 9 W., Monroe County.

Sample No. 6—Semi-plastic clay, middle member, pit No. 4, A. P. Green Fire Brick Company, sec. 36, T. 51 N., R. 9 W., Mexico, Audrain County, designated by company as Empire No. 111.

Sample No. 7—Semi-plastic clay, 6-15 thick, from Renner portion shaft mine at plant, Harbison-Walker Refractories Company, Vandalia, Audrain County.

[1]Allen, V. T., The Cheltenham Clay of Missouri, Mo. Geol. Survey, 59th Bien. Report, State Geologist, App. V, p. 14, 1937.

Two samples of what the writer considers to be typical middle Cheltenham clay, were collected for firing behavior tests, the results of which were obtained and are discussed by Dr. Herold in chapter V.

Correlation and Stratigraphic Relations. The correlation of the middle member can be made on the basis of appearance over a wide area. This has been indicated previously in the discussion of the distribution of this member in the northern district. In the southern district, it is not so easy to determine the exact equivalent in the sink-hole type deposits, due to the alteration the clays have undergone. The white, light colored, very uniform, massive flint clay found in so many pits in the southern district is, however, a possible correlative.

Insofar as the stratigraphic relations are concerned, it becomes apparent that an unconformity or "break" of considerable magnitude separates the middle from the lower member of the Cheltenham. It signifies the cessation of deposition of the lower member, the long period of erosion and weathering which followed and resulted in the alteration of the clays, and their isolation into sink-hole like depressions. Upon this bevelled or truncated surface the middle member was laid down. The initial deposit was often locally sandy and pyritic, but was followed by the deposition of the higher grade clay.

The relation of the middle member to the upper member is not as well defined. The contact where it has been observed, is sharp and a contrasting one due to the usual light color of the middle member and the usual dark color of the upper member. The contact is further contrasted by the differences in the types of clay.

The difference in thickness of the middle member may be due to non-deposition, but more likely it is due to erosion after deposition and prior to the deposition of the upper member. The character of the middle Cheltenham clay is such as to suggest it has been leached and altered, but not to the same extent as the lower member; thus the period of erosion which followed may not have been as long as the one which preceded its deposition.

Subsidence of the middle clay member is also indicated by the slickensided surfaces. Again they are arranged so that they are roughly circular in outline to and dip toward the center of the sink-like depressions. They are not as numerous perhaps as in the lower clay and less subsidence is therefore suggested. In any event after subsidence, the clay of the middle member was bevelled and upon the flat surface thus produced, the upper clay member was deposited.

UPPER MEMBER.

Name. This name is applied to a gray clay that is distinct in physical properties, chemical composition, and in firing behavior from the other clays of the Cheltenham formation. Although it is the least refractory of those clays, it is nonetheless a readily identifiable one, and deserves rank as a distinct unit with the other clays described.

Occurrence. Although the clay originally was deposited as a continuous or blanket-like deposit, it does not now have that expression. In fact, it appears to be continuous only locally, even though the points of occurrence would suggest a wide distribution. The clay has been observed in the western part of the area, in the pit of the Edwards-Conley Brick Company, NE¼ SW¼, sec. 8, T. 48 N., R. 12 W., at Columbia, Boone County. It is extensively mined in the vicinity of Fulton, Callaway County, the Weatherall pit, NW¼ SE¼ sec. 29, T. 48 N., R. 9 W., and the Lammers pit, SW¼ SW¼ sec. 29, T. 48 N., R. 9 W., Callaway County being examples.

The clay has also been observed in the Wellsville, Montgomery County locality, and it is present locally in the new pit of the Laclede-Christy Clay Products Company, SE¼ NE¼ sec. 9, T. 49 N., R. 6 W., south of that town. The clay has also been recognized in the Goss locality of Monroe County, T. 55 N., R. 9 W., the exposure in the General Refractories Company, Coy Rives pit in NW¼ sec. 28, T. 55 N., R. 9 W., being an excellent example. To the west of the main portion of the northern district the clay has been noted north of Holliday, Monroe County, SE¼ SW¼ NW¼ sec. 22, T. 55 N., R. 11 W., where both low grade semi-plastic and plastic fire clay outcrop in the ravine just west of the road. The upper member also outcrops in the vicinity of Lakenan, Shelby County, sec. 7, T. 56 N., R. 9 W., where it has been used in the manufacture of stoneware.

The clay has also been identified in well cuttings in the Boy Scout well at Camp Winnetka, SE¼ SE¼ sec. 11, T. 53

N., R. 14 W., southwest of Moberly, Randolph County, from 150 to 165 feet; in the C. L. Carpenter well, NW¼ SW¼ sec. 18, T. 55 N., R. 13 W., east of Jacksonville, Randolph County, from 145 to 150 feet, and in the C. O. Dillard well, sec. 1, T. 57 N., R. 17 W., near New Cambria, Macon County, from 130 to 140 feet. The underlying black slate from 140 to 160 feet in that well may be a part of the Cheltenham, also. The upper Cheltenham horizon is also suggested in the record of the test hole mine No. 46, M-K-T Coal Company, SE¼ NE¼ sec. 23, T. 57 N., R. 15 W., Macon County, between 247 and 268 feet. Most of that interval in this record is logged as dark slate or fire clay. In some of the foregoing instances other members of the Cheltenham may be present. However, the samples available are from churn drill holes only and specific testing of the material is not practicable because of mixing with material from above.

What is probably the upper part of the Cheltenham clay, has also been noted in Saline County, NE¼ NW¼ sec. 21, T. 51 N., R. 19 W., on Saline County Highway D, southeast of Slater. The clay is of low grade, and rests on the shaley limestones of the upper Warsaw (Spergen) formation. What is probably the Cheltenham clay has also been noted in the W½ SE¼ sec. 5, T. 46 N., R. 21 W., Pettis County, where plastic clay is associated with cannel coal in a depression or sinkhole deposit. Here the clay is underlain by the Burlington limestone of Mississippian age. Pocket-like deposits of gray plastic clay, possibly representing this member, have also been noted in the vicinity of El Dorado Springs in northwestern Cedar County and in adjacent portions of Vernon County, in west central Missouri. The clay observed does not appear to be high grade.

From the foregoing it appears that the upper Cheltenham clay is a widespread geologic unit. How far the clay extends in a northerly or northwesterly direction is a question that cannot be answered at this time. The available churn drill samples are either so finely pulverized or so badly contaminated with other material, or both, that positive identification is not possible. The material available in the form of cores from a test hole drilled in SW cor. NW¼ NW¼ sec. 21, T. 57 N., R. 34 W., near Saxton, Buchanan County, contains clays in the interval from 650 to 881 feet that may correlate in part with the clays of the Cheltenham described in this report.

In this connection it should be remembered, however, that in a northerly and westerly direction from the district being described, shale, sandstone, coal, occasionally beds of limestone, and deposits of siderite (iron carbonate) compose a thick section of Cherokee rocks older than Cheltenham clay. The character of these rocks and the environment presented by them is such that leaching of the Cheltenham clay might have been slight if not impossible. Consequently the clay under the foregoing situation may be present in the same condition as at the time of deposition.

There is also a possibility that some distance removed from the present area, the character of the clays making up the Cheltenham formation may be entirely different. The equivalent horizon might reasonably be composed of an entirely different material or a mixture of some other material and clay. This is again discussed later in this report.

Thickness. The surface of the upper member is a plane of erosion; hence, the thickness is variable. In many localities the clay is entirely absent or is represented by small pocket-like masses completely surrounded by clay of the middle Cheltenham. These masses range from a few inches across, and a few inches in thickness up to sizeable masses.

The maximum thickness known to the writer is about 15 feet and was observed in the pit on Loutre River on the Robertson farm, NE¼ NW¼ sec. 24, T. 49 N., R. 7 W., Callaway County. A thickness of 11 feet at least is exposed in the General Refractories Company, Coy Rives pit, NW¼ sec. 28, T. 55 N., R. 9 W., Monroe County, and a similar thickness is exposed in the upper portion of the Edwards Brick Company pit, sec. 8, T. 48 N., R. 12 W., at Columbia, Boone County.

Topography. The upper member does not appear to influence the topography. Because of the highly plastic nature on weathered surfaces it sometimes is well exposed in stream channels or banks. However, there is no expression that would result in finding covered deposits of this clay.

Lithologic Character. The clay of the upper member is uniform in general make up. It is nearly always a bluish gray color. It is fine-grained, but lacks the smooth, even texture of the lower clays. It is also not as hard, and the slickensided surfaces of the lower clays are almost lacking, and where present are not as highly developed. The clay has a similar mode of fracturing, that is, with conchoidal surfaces and fairly sharp edges, but in neither is the development as pronounced as in the lower clays.

Two features, however, serve to distinguish the clay. First, the clay upon weathering slacks or breaks down into extremely fine angular particles, and second, with prolonged surface weathering it becomes a gray, sticky, highly plastic mass. Neither of the foregoing properties is common to the other members of the Cheltenham.

In the mineralogical study of the Cheltenham clay, Allen[47] apparently did not specifically mention this clay, although it may be the one which he described as follows:

"In some thin sections there may be observed (in addition to kaolinite) minor amounts of another clay mineral, which has higher birefringence and generally but not always has a lower refractive index than kaolinite. It occurs in brown patches of irregular shape (Pl. II, a, b; and Pl. IV, a) which appear to be partly replaced by kaolinite. This is probably the hydromica of Galpin,[48] Somers,[49] and others, which is reported by Somers, to be abundant in the clays of the St. Louis district and scarce or absent in the flint clays of Missouri. The writer[50] observed a similar mineral in his studies of the underclays of Illinois coal and referred to it as potash beidellite, because the mineral resembles beidellite in appearance, and yet is not normal beidellite for it contains potash and has a different X-ray pattern from the type beidellite. Grim[51] and Kerr have continued the study of this material from Illinois and favor the name sericite-like mineral for it." For the same mineral, Keller[52] prefers to designate it as "clay mineral of high birefringence."

Samples of the clay have been collected in connection with the present survey and the mineralogy as revealed by X-ray analyses is given in chapter VI.

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[47]Allen, op. cit., pp. 14-15.

[48]Galpin, S. L., Studies of flint clays and their associates: Am. Ceramic Soc. Trans., vol. 14, pp. 306, 338, 1912.

[49]Somers, R. E., Miscroscopic study of clays: U. S. Geol. Survey Bull. 708, p. 294, 1922.

[50]Allen, Victor T., Petrographic and mineralogical study of the underclays of Illinois coal: Jour. Am. Ceramic Soc., vol. 15, pp. 564, 573, 1932.

[51]Grim, R. E., Petrology of the Pennsylvanian shales and noncalcareous underclays associated with Illinois coals: Bull. Am. Cer. Soc., vol. 14, pp. 113-119; pp. 129-34, 1935.

[52]Keller, W. D., oral statement.

Chemical Composition. This clay has the highest ratio of silica to alumina of any of the clays of the Cheltenham formation. The silica content approaches or exceeds 55 per cent and the alumina is less than 30 per cent. Fluxing impurities are higher and iron, chiefly as pyrite, is present. Carbonaceous material is often present and accounts for the gray color. Insofar as the chemical composition is concerned, the clay appears to be fairly uniform. A series of analyses is presented in Table 4.

TABLE 4.

CHEMICAL ANALYSES OF PLASTIC FIRE CLAYS, UPPER MEMBER CHELTENHAM FORMATION, NORTHERN DISTRICT.

R. T. ROLUFS, ANALYST.

Sample No.	1	2	3	4	5
Ignition Loss (H_2O, + 110°C.)	9.43%	9.29%	7.51%	9.56%	7.49%
Moisture (H_2O, − 110°C.)	1.72	.35	.88	.65	1.32
Silica (SiO_2)	56.46	57.20	56.10	50.96	68.16
Alumina (Al_2O_3)	26.46	26.90	24.47	29.91	18.45
Iron (Fe_2O_3)	1.82	2.25	3.64	2.69	2.51
Titania (TiO_2)	1.48	1.58	1.58	1.68	1.38
Lime (CaO)	0.27	.63	.61	.49	0.07
Magnesia (MgO)	0.40	.30	1.11	.38	0.39
Soda (Na_2O)	ND	.15	.17	.15	ND
Potash (K_2O)	ND	1.22	2.89	2.50	ND
Sulphur (S)	ND	.004	.164	.058	ND
Phosphorus Pentoxide (P_2O_5)	ND	.07	.15	.16	ND
Totals	98.04	99.944	99.274	99.188	99.77

ND. Not determined.

Sample No. 1—Plastic clay, plant pit 1, Edwards-Conley Brick Company, NE¼ SW¼ sec. 8, T. 48 N., R. 12 W., Columbia, Boone County.

Sample No. 2—Plastic clay, Coy Rives pit, S½ NW¼ sec. 28, T. 55 N., R. 9 W., near Goss, Monroe County.

Sample No. 3—Plastic clay, plant pit No. 4, A. P. Green Fire Brick Company, sec. 36, T. 51 N., R. 9 W., Mexico, Audrain County. Designated by company as "Foundry Clay".

Sample No. 4—Dark gray plastic clay, Weatherall pitt, operated for Mexico Refractories Company, by Hazelrigg Brothers, NW¼ SE¼ sec. 29, T. 48 N. R. 9 W.

Sample No. 5—Dark blue gray plastic clay, Cluskey Pottery pit, SW¼ SE¼ sec. 7, T. 56 N., R. 9 W., collected from small stock pile dug from pit eight (8) feet deep about a year ago.

Samples of the clay from the upper member of the Cheltenham clay have been fired, and the characteristics obtained are described in chapter V.

Correlation and Stratigraphic Relations. The upper member is recognized throughout the area by its physical properties, which serve to distinguish it from the other clay members of the formation. It is a widespread unit, even though locally absent, and additional geologic work of a regional nature may serve to indicate an even more wide distribution than present information will permit.

The stratigraphic relations of the upper member are well defined. The contact of the upper with the middle member has been discussed fully in the section devoted to the latter. It appears to be a sharp, smooth plane, and certain physical properties and expressions serve to differentiate the two.

The relation of the upper member to the overlying formations of the Cherokee group is more complex and indicates some of the features of this portion of the geologic column that have not been previously described. The following brief review of certain apparent historical events is, therefore, pertinent at this point.

After the deposition of the upper clay member, a period of gentle folding occurred. As a result the Cheltenham formation was changed from a nearly, if not horizontal position, into a series of folds or wrinkles. A period of erosion followed and the uneven surface formed by folding was bevelled into a nearly plane surface.

In this period of weathering some alteration of the upper clay member, and possibly the middle and lower clay members of the Cheltenham formation as well, appears to have taken place. The period and the degree of alteration, if the character of the upper clays is a criterion, was not as long, however, as that which followed the deposition of the middle member, and by the same token, not nearly as extensive as the long period which appears to have followed the deposition of the lower member. Some movement into previously existing and again rejuvenated sinks may have taken place at this time, but such subsidence was not as marked apparently as similar movements during lower and middle Cheltenham time.

The bevelled or truncated surface formed upon the gently folded Cheltenham clays now had a surface plan or arrangement whereby in various localities, the member at the surface was the lower Cheltenham; the outcrop on Middle River, SE¼ sec. 2, T. 46 N., R. 10 W., Callaway County being an example; or the member was the middle Cheltenham, examples being present in the strip pits at Mexico and Wellsville, and in the shaft mine at Vandalia; or the surface member was the upper Cheltenham, many good exposures of which have been described in previous paragraphs.

Several examples of the truncated top of the Cheltenham formation may be cited. In the plastic clay pit on the Weatherall farm, NW¼ SE¼ sec. 29, T. 48 N., R. 9 W., Callaway County, operated by Hazelrigg Brothers, for the Mexico Refractories Company, 10 feet of gray plastic upper Cheltenham clay are exposed. However, this clay occurs in low depressions, not altogether from subsidence into sinks, but probably more from post-Cheltenham folding, as is attested by nearby anticlinal or elevated masses of light colored semi-plastic middle Cheltenham clay, which is exposed in portions of the working face. Another interesting relation at this pit might be mentioned at this time. Although existing conditions did not permit a detailed study, it would appear that the green phosphatic shale at the base of the Ardmore formation rests upon the upper clay member, with representatives of the Loutre and Tebo formations being absent. The formations last mentioned appear to be represented, but in diminished thickness, however, in the nearby Lammers pit of the A. P. Green Fire Brick Company, SW¼ SW¼ sec. 29, T. 47 N., R. 9 W., the section in which is given on page 102.

Another excellent example that depicts the folding and erosion and perhaps local subsidence that followed the deposition of the upper Cheltenham clay may be observed in pit No. 4 of the A. P. Green Fire Brick Company at Mexico. Here the gray plastic upper clay occurs as small to fairly large isolated, pocket-like masses beneath the rocks of the overlying Loutre formation, which also rests in other portions of the pit upon the middle Cheltenham member as well. The clay produced from the upper member in this pit is called "Foundry" clay.

From the foregoing statements it is evident that an unconformity of some magnitude was developed at the top of the Cheltenham formation, but the period required was probably not as long as the two preceding ones.

There was deposited upon this bevelled surface the sediments of the succeeding formations. Over most of the area there occurs immediately above the Cheltenham clay a bright green, high iron, high alkali clay that represents the initial deposit of the Loutre formation. It occurs as a blanket-like deposit, with fingers or U or V shaped masses extending down into the clay members of the Cheltenham to a depth of at least 5 feet. The relations of the Loutre are fully described later.

In some localities the Loutre is very thin and the Tebo formation, which succeeds it, extends downward almost to the top of the Cheltenham clays. In other localities the Loutre and the Tebo formations are absent and the Ardmore formation rests upon the Cheltenham clay members with marked unconformity. Excellent examples of this contact may be observed in the Goss locality of Monroe County, the Rives pit, NW¼ sec. 28, T. 55 N., R. 9 W., being a point for observation. The section measured in this pit is given on page 88.

The foregoing relations are mentioned at this time, because between the deposition of each formation, the Cheltenham, the Loutre, the Tebo, and the Ardmore, there has been a period of erosion, of weathering of greater or less extent, which in some areas removed some, if not all, of the formations mentioned. It becomes obvious therefore, that in such periods when the Cheltenham clays were exposed at or near the surface, they were subjected to further weathering and alteration, and were brought to their present state at an early geologic date.

In the opinion of the writer, the most striking example of the change in composition of the Cheltenham clays as the result of leaching after deposition, is the relation and composition of the succeeding geologic formations exhibited by the present working face in the Stoltz pit, NW¼ sec. 34, T. 48 N., R. 9 W., north of Fulton, Callaway County, which is being operated for the Mexico Refractories Company by Hazelrigg Brothers. The geologic section and its chemical composition are given in Plate XII and the relation of the section to other sections is given in Plate V. The clays have a generally higher alumina content and a lower silica content with depth. Withal there is not much difference between the middle and lower members, and what may be a representative of the upper member is not greatly different, being only slightly higher in silica and lower in alumina, than the underlying clays.

These clays are slightly harder than usual and the deposit appears to be situated in a rather large depression. Leaching is believed to have been carried on to a greater extent than usual, particularly with respect to the middle and upper members, which it will be noted by reference to tables 3 and 4, are more nearly related in composition than they are on the general average.

Occurrence of Diaspore Clay. Insofar as present information is concerned, the occurrence of diaspore, a high alumina clay, or the closely related burley clay, has not been noted in the bedded deposit of the Cheltenham formation in the northern district, and any occurrence of these clays is an exception rather than the rule.

These exceptions may be noted however, (1) in Lincoln County, burley clay has occurred with flint fire clay, in sandstone lined sink-hole type deposits in the Whiteside locality; (2) In Warren County, about 5 miles south, and one mile east of Warrenton, where a small amount of high grade diaspore occurred in association with flint fire clay in a sandstone lined sink-hole type deposit typical of those found in the southern district; (3) In St. Charles County, about 12 miles south of Wright City, where the occurrence is reported to be similar to those previously mentioned.

These deposits are not described in detail, as the mode of occurrence is more common to that of the southern district, which is described fully in later pages of this report. The deposits do show, however, the close connection of the two districts, and the occurrence of high alumina clays where conditions favorable to complete leaching are present.

Regional Considerations. Although there has been some description of the possible extent of the Cheltenham clays in the preceding pages, further description and discussion of that problem and the regional geologic relations are pertinent at this time.

The formation has been divided into three members. An unconformity, which implies a period of erosion of greater or less extent separates each one, and finally the top of the formation was, locally at least, exposed at different periods during the early Cherokee history of the district.

Beneath the Cheltenham clay in the northern district is the Graydon conglomerate and sandstone, which represents an initial deposit in an advancing sea. The correlation of this formation with the Clear Creek sandstone of Vernon County and the suggestion that it is the correlative, if not the exact time, of an unnamed arkosic sandstone some distance below the Ardmore limestone in the Forest City basin area of northwestern Missouri, has been discussed previously. It would appear to be a deposit formed as the result of a regional rejuvenation of a low lying land mass. The formation of the Nemaha granite ridge, a now buried mountain range, which extends from north central Oklahoma, into northeastern Kansas and southeastern Nebraska, took place at this time in the geologic history and from the rapid weathering of the steep east face, there was derived the arkosic material mentioned.

Using the arkosic sandstone and the Graydon conglomerate as a datum some interesting figures may be presented. In the northern district described in this report, the interval between the Graydon conglomerate and the top of the Mississippian formations is zero, and the same is true where the Cheltenham clays locally rest upon the Mississippian, the Graydon being absent. In a northerly and westerly direction, however, the interval increases. In the test diamond drill hole, SW cor. NW¼ NW¼ sec. 21, T. 57 N., R. 34 W., near Saxton, Buchanan County, the interval from the top of the arkosic sand to the top of the Mississippian measures 190 feet. In a diamond drill hole, SE cor NW¼ sec. 4, T. 59 N., R. 38 W., at Forest City, Holt County, the same interval measures 251 feet. The increase continues in a northwesterly direction, and near the east face of the granite ridge, the interval from the top of the main body of arkosic sand to the top of the Mississippian was found to be 620 feet thick in the Arab Oil Company, No. 1 Ogle well, sec. 9, T. 1 N., R. 14 E., Richardson County, southeastern Nebraska. From the foregoing it is apparent that a considerable thickness of sediments below the Graydon was either not deposited in the northern district of east central Missouri, or else it was completely removed by erosion after deposition.

The presence, however, of a few limited isolated, sink-hole type deposits of shale and sandstone of an unnamed formation, obviously older than the Graydon conglomerate and the overlying Cheltenham clay, is evidence that some of these older rocks were deposited. The weathering and reduction of them to a clay residuum may well have furnished the material that constitutes a part of the Cheltenham clay.

In this connection, it should also be recalled that the Graydon conglomerate overlaps formations ranging from probably the Potosi of Ozarkian age to the Warsaw of Mississippian age.

These formations, and those that intervene between them, may have been highly weathered during early Cherokee time, and they too may have yielded a clay residuum that contributed a considerable amount of material to the Cheltenham clays.

The relation of the Cheltenham clay to the overlying strata in the northern district has been discussed previously. It is of interest to note certain additional regional details, however, at this point. Although the Cheltenham clay has been defined as consisting of three members in contact with each other, they may well be separated from each other in the area to the north and west by a considerable thickness of intervening strata. The top of the arkosic sand, previously mentioned, and possibly the equivalent in part of the Graydon and the base of the Ardmore formation form convenient planes for measurement. In the northern district, it will be recalled that the Ardmore formation in some localities rests upon the Cheltenham clays, which separate it from the Graydon conglomerate, the thickness of the interval being less than 20 feet in some instances. In other localities the Loutre and Tebo formations separate the Cheltenham from the Ardmore. Using the maximum thicknesses available for the northern district, the interval from the base of the Ardmore formation to the top of the Cheltenham is not over 20 feet, and to the top of the Graydon the interval is not over 90 feet, at a maximum.

The two diamond drill holes previously mentioned may again be used. In the Saxton hole, the Cheltenham clay cannot be specifically defined. The top of the arkosic sand, however, is readily determined from an examination of the cores. The same is true regarding the base of the Ardmore. In this well the Ardmore-arkosic sand interval measures 233 feet, which is a considerable expansion of the figure of not over 90 feet in the northern district. Within this interval is a series of sandstone, coal, black slate, and shale. Of the latter there are several thick intervals separated by intervening strata, which may well represent the western expression of the Cheltenham clays.

The diamond drill hole at Forest City shows that the Ardmore-arkosic sand interval increases in a westerly direction and in that well the interval measures 323 feet in thickness. Again several thick shale sections are present and may represent in part the members of the Cheltenham clay of the northern district.

The foregoing recital is presented in order to show the complex early Pennsylvanian geologic history of the district and the surrounding area. It is a history of deposition of sediments, of long periods of erosion and weathering, and of folding, all of which have contributed to the process of alteration and production of the present day high grade Cheltenham fire clays of east central Missouri.

LOUTRE FORMATION.

Name. Upon the now bevelled, yet locally irregular surface of the Cheltenham clay, there was deposited a succession of strata to which the name Loutre formation is applied in this report.

The name is taken from Loutre River, and its tributary, Little Loutre Creek, along both of which excellent exposures may be observed, in Audrain, Callaway, and Montgomery Counties. The area of typical outcrop lies within the southern half of the Wellsville quadrangle.

Type Locality. One of the best sections of the formation, and what is considered to be the type for this report, is exposed in the new open pit of the Laclede-Christy Clay Products Company, on the east side of the valley of Little Loutre Creek in the SE¼ NE¼ sec. 9, T. 49 N., R. 6 W., Montgomery County, where the following section of the formation was measured.

Section of Loutre Formation

Name and Lithology	*Thickness Feet*	*Inches*
Tebo Formation:		
Clay, gray, weathers into nodular, angular lumps, badly fractured, and stained yellow along joints and fractured surfaces; a lenticular sandstone and sandy clay is locally developed at the base....	1	0
Loutre Formation:		
1. Clay, light gray to greenish gray, weathers with hackly fracture, intricately jointed, and stained; buff limestone nodules one foot in diameter in upper portion; top of this bed is wavy and very irregular	3	4
2. Clay, bright green to grayish green, very pyritic, no perceptible break with No. 1 and the two appear to be gradational.......	6	0
3. Clay, hard, black with coal smut, pyritic	0	2
4. Clay, green, similar to No. 2	0	1
5. Clay, green, containing irregular and discontinuous, ovoid-shaped nodules of pisolitic siderite with radical structure. Extends down until underlying clay as U or V shaped masses, thickness ranges from 8 inches to	2	
Cheltenham Formation:		
Fire clay, dark to light gray, hard, semi-plastic	20	0

The full section exposed in this pit, of which the foregoing is a portion is given on page 100. A section similar to the foregoing type section has also been reported by Hinds[53] as occurring in and near the Carr Coal Mine, sec. 28, T. 50 N., R. 7 W., Callaway County.

Description of Members. A full and complete section of the Loutre formation and one which shows all details, thicknesses, and the lithologic characteristics, has nowhere been observed by the writer. From studies of the formation, the following generalized section, as measured from the base to the top is presented as follows:

Generalized Section, Loutre Formation

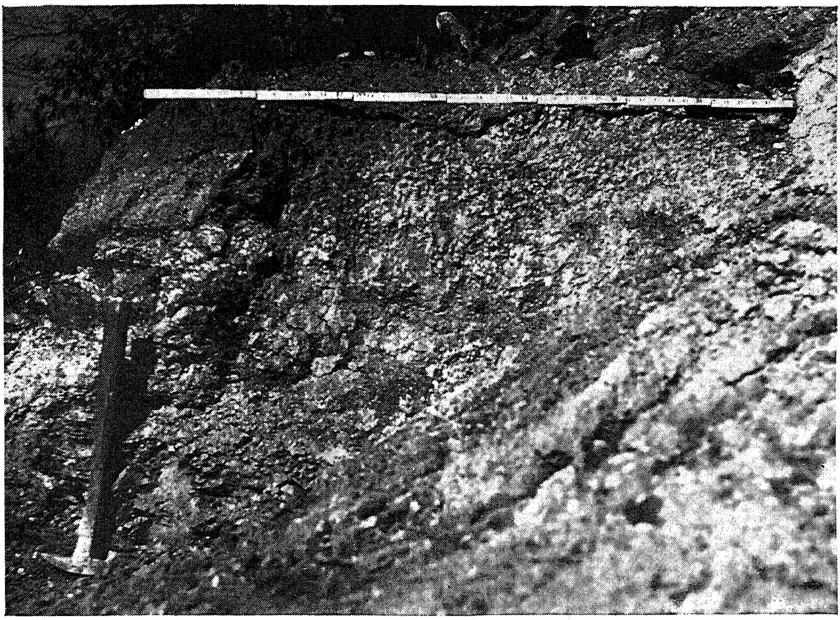
Lithologic Character	*Thickness Feet*	*Inches*
1. Bright green colored, high iron, high alkali, low fusion clay from 6 inches to	5	
2. Gray or greenish gray clay, locally used for refractory material, the "blue" or "dry mill clay" of eastern Audrain County. Locally contains boulders or nodules of dark gray limestone. Thickness ranges from 2 to	15	
3. Limestone, nodular, dark gray almost black, very fine grained, and hard, contains much clay locally	3	
4. Clay, gray and green, with limestone nodules	5	

The basal member is bright green in color and varies from a soft plastic clay or clay shale to a hard, semi-plastic clay. It is further characterized by the fact that it extends down into the upper Cheltenham clay as sharply outlined V or U-shaped pocket-like masses, up to five feet in diameter and on the average about two feet in depth. In surface plan the green clay occurs as rough circular areas, but in some instances shallow "troughs" or "gullies", aligned in a northwest-southeast direction, are filled with the material.

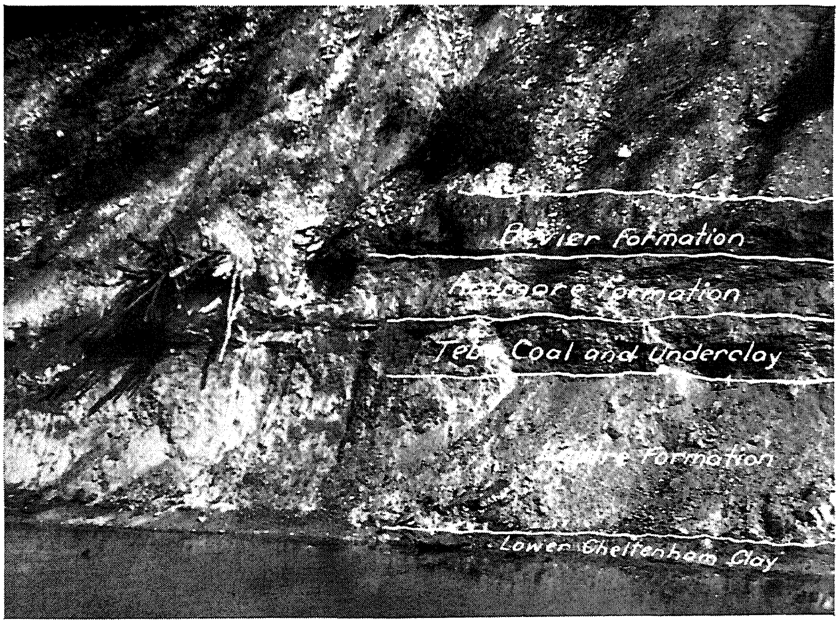
The uniformly green color of this clay is due to the presence of ferrous (iron) oxide, the presence of which has often been noted in other initial sedimentary deposits. The high alkali (potassium) content in association with ferrous oxide is suggestive also of an initial deposit.

The distribution of this clay is highly interesting. It is present in every pit that has been opened in the area of the

[53]Hinds, Henry, The coal deposits of Missouri, Mo. Bur. Geol. and Mines, Vol. XI, 2nd Ser., p. 63, 1912.



A. Close view of siderite nodule embedded in base of clay, Loutre formation. Hammer head marks contact with underlying Cheltenham clay. Middle River section, SE ¼ sec. 2, T. 46 N., R. 10 W., Callaway County.



B. View of section on Middle River, downstream from crossing of U. S. Highway 54, SE ¼ sec. 2, T. 46 N., R. 10 W. Debris marks abandoned coal mining operation.

blanket deposit of the Cheltenham clay, except possibly around the margins of the area where this clay and related strata have been removed by erosion and younger rocks rest upon the Cheltenham clay (Pls. V and VI).

The clay is avoided in mining operations and insofar as its refractory value is concerned it is "poison" as every miner and operator knows, and locally that name is applied to it.

In Callaway and possibly adjoining counties, siderite or iron carbonate ranging in size from small oolitic particles to large concretions have been observed associated with this clay. A very large concretion, measuring 6 by 3 by 2 feet may be observed at stream level in the excellent section of the Loutre and associated formations exposed on Middle River, in the SE¼, sec. 2, T. 46 N., R. 10 W., Callaway County, a short distance south of the crossing of U. S. Highway No. 54 (Pl. XIII, A). Here the siderite has a radial structure and on the whole is unoxidized. What appears to be hematite, resulting from the oxidization of siderite, both massive and oolitic in character, and somewhat similar to the red clay or ironstone of the foregoing sections, occurs at a prospect on the Huesgens farm in the NW¼ sec. 4, T. 45 N., R. 10 W., Callaway County, in the northern district. The relations are poorly exposed, however.

In chemical composition the clay is not unlike the upper part of the Cheltenham clay insofar as the alumina-silica ratio is concerned; however, the high alkali content, particularly potassium, the high magnesia, and the high iron content, result in a low fusion point, which always characterizes this clay and makes it wholly undesirable for refractory purposes. In fact, the pockets or filled depressions of it, which extend below the general level or top of the upper Cheltenham clay and cannot be removed in the general stripping operations, are therefore thoroughly cleaned out by hand.

The chemical composition of this clay is indicated by the following analyses:

TABLE 5.

Chemical Analyses of Green "Poison" Clay, Loutre Formation
R. T. Rolufs, Analyst

Sample No.	1	2	3
Ignition Loss (H_2O, +110°C.)	9.87%	9.39%	5.08%
Moisture (H_2O, −110°C.)			1.92
Silica (SiO_2)	55.90	58.46	56.04
Alumina (Al_2O_3)	21.35	23.62	21.06
Iron (Fe_2O_3)	5.40	4.07	5.64
Titania (TiO_2)	1.50	1.17	1.48
Calcium (CaO)	0.08	0.60	0.51
Magnesia (MgO)	1.23	1.61	1.60
Soda (Na_2O)	0.72	0.45	0.45
Potash (K_2O)	2.55	1.08	5.07
Totals	98.60	100.45	98.81

Sample No. 1 Green clay filling small depression in Cheltenham clay, Laclede-Christy Clay Products Company, Phipps mine, Wellsville, Montgomery County.
Sample No. 2 Green clay filling small depression in Cheltenham clay, A. P. Green Fire Brick Company Plant pit, Mexico, Audrain County.
Sample No. 3 Green clay filling pockets in Cheltenham clay, Mexico Refractories Company, Stoltz pit, NW¼ Sec. 34, T. 48 N., R. 9 W., northeast of Fulton, Callaway County.

In its optical properties this clay is reported by Allen[54] to be different from the underlying Cheltenham clay for it contains a sericite-like mineral with a higher birefringence than that of kaolinite. For this clay mineral Grim, Bray and Bradley[55] have suggested the name, illite.

The green clay is usually followed, and apparently without any break, by a greenish gray clay of varying thickness. Locally there may be a sharp contrast in color, but not always. The succeeding clay is hard, breaks into angular nodules, has a slightly conchoidal fracture and the general appearance of a semi-plastic clay. In some localities, particularly in eastern Audrain County, it is sufficiently pure to be used for certain refractory purposes, chiefly plastic mortars and cement. The term "dry mill" is locally used to describe it.

The clay varies greatly in thickness. In the section in the fire clay pit just south of the plant, Edwards Conley Brick Company at Columbia, Boone County, sec. 8, T. 48 N., R. 12 W., the green basal clay member is immediately followed by limestone, the usually intervening gray clay being absent. Exposures in the clay pits at Mexico indicate it is also thin, being not over two feet. Probably one of the best exposures is on

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[54]Op. cit., p. 16.
[55]Grim, Bray and Bradley, The mica in agrillaceous sediments, Amer. Min., Vol. XXII (1937) pp. 813-29.

Middle River, south of the bridge on U. S. Highway No. 54, approximately in the center, SE¼ SE¼ sec. 2, T. 46 N., R. 10 W., where nine feet of dark gray lumpy very plastic clay may be observed (Pl. XIII, B). The upper surface of the clay is in contact with the underclay of the Tebo coal member, and the upper one inch is weathered to a very plastic, slightly laminated clay. The basal two feet is green clay containing the siderite concretions previously described. The maximum thickness is suggested by prospect diamond drill holes located in the vicinity of Vandalia, where at least 15 feet is recorded, and near that town and near Farber, a short distance west, the clay has an average thickness of 8 feet.

In chemical composition the clay is somewhat similar in alumina-silica ratio to the upper member of the Cheltenham formation, and the source of the material for the two was possibly the same. The iron content, however, is usually higher. In some localities the clay is sufficiently pure to permit utilization as described, but in others it is too impure or too thin for use.

A careful study of this problem suggests that a period of erosion followed the deposition of the Loutre formation of which the "dry mill" clay, now being described, is a member. Also the strata overlying this clay were removed at least locally and the period of weathering was such that the clay was altered to some extent. Additional alteration of the underlying Cheltenham clays may have taken place also. On the other hand, the overlying beds in some areas were not removed by erosion, therefore, the "dry mill" clay was not made available for purification by circulating ground water. In the following table several analyses of the dry mill clay are presented. The results show the differences in composition. A comparison of this table should be made with the analyses of the green clay occurring at the base of this zone, (Table 5) and with the analyses of the upper part of the Cheltenham clay, (Table 4).

On surface exposures the clay generally exhibits a yellow staining around the angular fragments produced by weathering and along the joint planes which cut it. This staining is due to the presence of melanterite (Fe_2SO_4), a sulphate of iron. Associated with it is gypsum (selenite, $CaSO_4$) or calcium sulphate. Both were probably derived from the weathering of the overlying Tebo coal. Both are fluxes and the sampling of exposures of the clay should be done only after the face has been thoroughly cleansed of these minerals.

TABLE 6.

Chemical Analyses of Clay Samples from the Gray "Dry Mill" Clay

Sample No.	1	2	3
Ignition Loss (H_2O,+110°C.)	9.71%	13.43%	8.81%
Moisture (H_2O,−110°C.)	1.54	....	1.81
Silica (SiO_2)	53.84	52.00	52.98
Alumina (Al_2O_3)	29.61	28.87	28.29
Iron (Fe_2O_3)	2.10	3.47	2.95
Titania (TiO_2)	1.07	1.38	1.48
Lime (CaO)	0.35	0.07	0.24
Magnesia (MgO)	0.78	0.31	0.72
Soda (Na_2O)	0.15	...	0.51
Potash (K_2O)	0.53	...	2.44
Totals	99.68	99.53	100.23

Sample No. 1 Dry mill clay, immediately overlying green "poison" clay. Mine North American Refractories Company, Farber, Audrain County.

Sample No. 2 From outcrop on Middle River approximate center SE¼ SE¼ Sec. 2, T. 46 N., R. 10 W., Callaway County; nodular surfaces were cleaned, prior to analysis, of coating of gypsum (selenite) crystals and powdery melanterite (Fe_2SO_4).

Sample No. 3 Dark gray semi-plastic clay, immediately above green "poison" clay. Mexico Refractories Company pit, SW¼ Sec. 27, T. 48 N., R. 9 W., northeast of Fulton, Callaway County.

The dry mill clay zone is overlain by limestone where the full Loutre sequence is present. The limestone is fine-grained to dense, and very hard. It is characterized by a dark brown mottling, which with the lighter colored matrix, gives fresh surfaces of the rock a conglomeratic appearance. It is believed to be algal in origin, or at least related to some organic structure. That the appearance is not misleading is indicated by the manner of weathering, for the harder, dark brown, rounded portions, sometimes measuring several inches in diameter, weather from the softer matrix and form in effect a boulder bed.

The thickness of the limestone appears to be variable, but nowhere does it appear to exceed 2½ feet. In the clay pits at Mexico, however, the limestone is overlain by 2½ feet of a gray clay, which contains nodules of limestone exactly similar to the underlying limestone and the two are considered to be of the same general sequence.

The limestone has a wide distribution, but withal it may be absent locally. It is well developed in the ravine adjacent to the main valley immediately east of the fire clay pit of the Edwards-Conley Brick Company, approximately center, south line, NE¼ SW¼ sec. 8, T. 49 N., R. 12 W., just east of Columbia, Boone County. At this point the limestone is in contact with the green "Poison" clay which is at the base of the formation. In the fire clay pits at Mexico the two are separated by as much as three feet of clay (dry mill). In eastern Audrain County, in the mines at Farber and Vandalia, the "dry mill clay" with an average thickness of eight feet intervenes between the two. The limestone is also present as weathered nodules in the new pit, Laclede-Christy Clay Products Company, SE¼ NE¼ sec. 9, T. 49 N., R. 6 W., Montgomery County.

The limestone is absent in the splendid section exposed on Middle River, approximate center, SE¼ SE¼ sec. 2, T. 46 N., R. 10 W., Callaway County, located downstream from the bridge on U. S. Highway 54. At this locality the underlying gray clay with the green "poison" clay at the base is in contact with the underclay of the overlying Tebo coal.

The limestone is also absent in the Mexico Refractories Company Pit, on the Stoltz farm, NW¼ sec. 34, T. 48 N., R. 9 W., northeast of Fulton, Callaway County. Again the Tebo coal underclay is in contact with the clay of the Loutre member. At this locality all of the clays have undergone alteration with an attendant leaching of soluble salts, with a resultant hardening so that they are all semi-plastic in character (Pl. XII).

As previously mentioned, the limestone and an overlying and associated clay are present in the clay pits at Mexico. However, both are absent approximately 2½ miles north, near the common north corner of sections 1 and 2, T. 51 N., R. 9 W., Audrain County, where the unweathered underclay of the Tebo coal rests upon the highly weathered "dry mill clay" of the Loutre formation. No exposures of the Loutre member have been observed in the extreme northern portion of the northern district. In the vicinity of Goss, Monroe County, and Lakenan, Shelby County, a marked unconformity is apparent for phosphatic shale of the Ardmore formation is in contact with the Cheltenham formation. In both localities the Loutre and Tebo formations are absent.

The upper unit of the Loutre formation consists of clay. It is of the usual underclay type, with a conchoidal fracture, and the habit of breaking into angular fragments with fairly sharp edges. The clay is gray or green on fresh surfaces, but weathers locally into a yellow color. As previously mentioned, it contains nodules of limestone in the clay pits at Mexico and it is thought to be closely related to the widespread limestone described above as underlying it. The thickness of this clay does not exceed 2½ feet.

In addition to local or short periods of weathering, which interrupted the deposition of the Loutre formation, a much longer period of erosion and weathering followed the deposition of the formation as a whole. This period was of sufficient duration to result in the removal of the upper members, a splendid example being on Middle River, center SE¼ SE¼ sec. 2, T. 46 N., R. 10 W., Callaway County.

During this period the underclay ("Blue, dry mill") of the member was purified, locally at least, to the extent that it is used for refractory cements and motars. Physically, it was changed from a soft plastic to a fairly hard, semi-plastic, and perhaps even a semi-flint fire clay, as in the case of the clay as now developed in the Mexico Refractories pit, NW¼ sec. 34, T. 48 N., R. 9 W., Callaway County.

The limestone bed of the Loutre member may be used as a guide in prospecting. Its habit of weathering into a mass of boulders, its mottled appearance, and its compact and hard nature, are characteristics by which it may be identified. The presence of this limestone suggests that it is in an area that geologically is "low" or synclinal, hence in the period of erosion that followed, it was not removed by erosion, as it seems to have been in structurally higher areas. Hence its presence may well reflect an area in which the underlying Cheltenham clay may have a thickness greater than the average, and its presence, therefore, may well be a guide to the occurrence also of the flint and semi-flint clays of the lower member. Such is certainly the case at Mexico, Vandalia, and Wellsville.

TEBO FORMATION.

Name. The name Tebo[56] was originally given by Marbut to a coal seam, the type locality of which is on Tebo Creek, Henry County. There is associated with the coal an underclay and an overlying black "roof slate", which appear to make a unit. In order to describe properly these units, the

[56]Marbut, C. F., Geology of the Calhoun Kuadrangle, Mo. Geol. Surv., Vol. XII, 1st Ser., p. 36, 1898.

name Tebo is raised in rank to that of a formation. It overlies the Loutre formation unconformably and is succeeded also unconformably by the Ardmore formation. The coal is possibly the correlative of the lower Ardmore coal of north central Missouri and that name proposed by Gordon[57] has priority. The name, lower Ardmore, however, is confusing because of the use of the term Ardmore for the formation, which overlies it. Furthermore, the term Tebo is in common usage in central Missouri, and it has been used in previous reports of the Survey and in unpublished theses, describing certain central Missouri areas, which have been submitted for advanced degrees in the Department of Geology, University of Missouri. The name Tebo formation as used in this report, has, in ascending order, the following sequence:

1. Underclay
2. Coal
3. Black slate

The basal unit, the underclay, has the usual characteristics. It is gray in color, slightly hard, has the habit of breaking with fairly sharp edges and a conchoidal fracture. It weathers into angular lumps, and the interstitial areas between them are commonly coated with the minerals, melanterite and selenite.

The underclay is variable in thickness. In pit Number 4, A. P. Green Fire Brick Company, Mexico, Audrain County, the clay ranges in thickness from an inch or 2 to 2½ feet in a distance of 100 feet. It is 3½ feet thick in the pit at the plant, Mexico Refractories Company, Mexico, Audrain County, and that figure possibly approaches the maximum. The underclay rests unconformably upon the various units of the Loutre formation. In some instances it is an easy matter to establish the contact, but in others, where the clays of the two are in contact, the problem of separation is a more difficult one. In one observed instance, north of Mexico, near the north common corner, secs. 1 and 2, T. 51 N., R. 9 W., Audrain County, the Tebo underclay rests upon the lower clay of the Loutre. Here the latter has been thoroughly weathered to a highly plastic clay, 2½ feet thick. Similar weathering, but only for a distance of an inch or so, serves to separate the same clays in the splendid section on Middle River, a short distance down-

[57]Op. cit. p. 21.

stream from the bridge on U. S. Highway No. 54, center SE¼ SE¼ sec. 2, T. 46 N., R. 10 W., Callaway County (Pl. XIII, B).

The same clays may be distinguished in the pit of the Mexico Refractories Company, NW¼ sec. 34, T. 48 N., R. 9 W., Callaway County. The Tebo underclay, one foot thick, consists of typical gray underclay. The underlying lower clay member of the Loutre was evidently altered prior to the deposition of the Tebo, for it consists of hard semi-plastic gray clay with red and purple mottling.

An excellent exposure of the contact of the Tebo underclay with the limestone of the Loutre formation may be observed in the creek tributary to Hinkson Creek, southwest of the coal washer in the N½ SE¼ NE¼ sec. 27, T. 49 N., R. 12 W., east of Columbia, Boone County. Exposures of the Tebo underclay in contact with the upper clay of the Loutre may be observed in the large open pits at Mexico, Audrain County. The underlying clay of the latter contains limestone nodules, hence the identification of the two clays is not difficult.

The contact of the Tebo underclay and the upper clay member of the Loutre formation is also exposed in the new pit of the Laclede-Christy Clay Products Company, SE¼ NE¼ sec. 9, T. 44 N., R. 6 W., south of Wellsville, Montgomery County. At this locality, thin discontinuous lenses of hard fine-grained sandstone and sandy shale mark the base of the Tebo underclay. The clay is also sandy, much more so in fact than usual.

The Tebo underclay is not used for refractories, for where it is overlain by the coal and black slate of the Tebo member, it does not appear to have had an opportunity to be leached. Where the clay has been leached, however, alteration appears to have taken place. An example that may be cited is the Mexico Refractories Company Pit, NW¼ sec. 34, T. 48 N., R. 9 W., where the Tebo underclay, only one foot thick and here, a fairly hard semi-plastic type, is immediately overlain by the basal, phosphatic green shale of the Ardmore formation.

The coal of the Tebo member, and the unit for which the name was originally given, is persistent over a large area. The coal has a bright luster, is somewhat brittle, and breaks down into comparatively small pieces. It has a high pyrite content, and weathered exposures always show melanterite (Fe_2SO_4) and selenite ($CaSO_4$).

The coal varies greatly in thickness, the variations being noted locally and in comparatively short distances. In pit No. 4, A. P. Green Fire Brick Company, Mexico, a thickness ranging from 6 inches to 3 feet may be observed within a horizontal distance of about 100 feet. North of Mexico, near the north common corner, secs. 1 and 2, T. 51 N., R. 9 W., the coal is represented by coal smut 2 inches thick, and a similar smut, one inch thick, represents the coal in the Mexico Refractories Company, Stoltz pit, NW¼ sec. 34, T. 48 N., R. 9 W., Callaway County.

The Tebo coal is present in the vicinity of Columbia, and one excellent exposure, showing clearly the relations of the coal, seven inches thick, to the underclay and the overlying black slate, may be observed on the creek southwest of the coal plant, N½ SE¼ NE¼ sec. 27, T. 49 N., R. 12 W.

In the vicinity of Wellsville, Montgomery County, the coal is also present and it has been mined locally. The coal reaches the maximum thickness in this area, and four feet have been noted in the plant mine of the Wellsville Fire Brick Company, Wellsville, Montgomery County. It was mined at one time south of that town. However, in the new pit, Laclede-Christy Clay Products Company, SE¼ NE¼ sec. 9, T. 49 N., R. 6 W., the coal varies from nothing to four inches in thickness and grades laterally from coal into slate, or the two may be intermixed.

The coal is also present in eastern Audrain County, and in the vicinity of Vandalia and Farber it reaches a thickness of 2½ feet. It was extensively mined at one time in the former locality.

Although the coal has no particular economic significance in relation to the clay, it does have a bearing on the prospecting and sampling of the underlying clays. Where the coal outcrops it is invariably coated with gypsum (Selenite, ($CaSO_4$), melanterite (Iron Sulphate, Fe_2SO_4), and locally iron oxide. Just as invariably, the same minerals are found in the fractures of the underlying clays, and selenite crystals occur strewn over the weathered surfaces. In such instances, it is obvious that the faces of clay must be thoroughly cleaned off and carried a sufficient distance back from the outcrop to preclude contamination of the samples. A case, in point, may be cited. On Middle River, center SE¼ SE¼ sec. 2, T.

46 N., R. 10 W., the lower clay member of the Loutre formation is well developed with a thickness of nine feet. It is separated from the Tebo coal by an underclay six inches thick. The Loutre clay shows many angular faces, fractures, and joints, all of which are stained yellow, and coated with small crystals of gypsum (calcium sulphate, $CaSO_4$). In addition, the clay has a sour astringent taste, due to the presence of melanterite (iron sulphate, Fe_2SO_4). Obviously such a clay would have a low fusion point. The clay, however, when large pieces were carefully trimmed to remove these fluxing impurities, was of good quality (the iron from included pyrite being excepted), as the following chemical analysis will show:

Chemical Analysis Loutre Clay
R. T. Rolufs, Analyst

Constituent	*Percent*
Ignition Loss ($H_2O+110°C.$)	11.11
Moisture ($H_2O-110°C.$)	2.32
Silica (SiO_2)	52.00
Alumina (Al_2O_3)	28.87
Iron (Fe_2O_3)	3.47
Titania (TiO_2)	1.38
Lime (CaO)	0.07
Magnesia (MgO)	0.31
Total	99.53

The upper member of the Tebo formation consists of black slate. It is hard, fissile, and weathers into thin plates. It immediately follows the coal, although locally a few inches of gray clay may separate the two. The thickness of the slate ranges from a few inches to about two feet. It is best developed where the Tebo coal is also present and the exposures of that coal, previously described, will also provide excellent exposures of the overlying black slate.

A period of weathering of sufficient duration to remove the Tebo member followed its deposition. Locally the entire sequence is gone and in other instances only the underclay remains. During the period of weathering, the Tebo underclay, where present, was weathered, as were the clays of the Loutre and Cheltenham formations. Weathering of the last two continued and the clays appear to have been even more altered in those localities where the Tebo underclay, as well as the associated coal and black slate, was removed.

Northwest of the area under consideration, the interval between the Tebo coal and the Ardmore limestone increases to at least fifty feet. Whether or not a similar thickness was ever present within the clay district is a matter of conjecture, but if so, the duration of the period of erosion would have been longer in order to permit the complete removal of the thickness mentioned.

The Tebo underclay and a thin coal smut alone remain in the Stoltz pit, NW¼ sec. 34, T. 48 N., R. 9 W., operated by the Mexico Refractories Company, but in the Lammers pit, SW¼ sec. 29, T. 47 N., R. 9 W., operated by the A. P. Green Fire Brick Company, the Tebo formation appears to have been entirely removed. The Tebo formation was observed northwest of Halliday, Monroe County, but in the extreme northern portion near Goss, Monroe County, at the Rives pit, sec. 28 T. 55 N., R. 9 W., and at Lakenan, Shelby County, sec. 7, T. 56 N., R. 9 W., it is again absent and the Ardmore formation rests upon the upper member of the Cheltenham formation. These relations are indicated in Plate V, which is a north-south diagrammatic cross section.

ARDMORE FORMATION.

Aside from the coal beds, the only single layer in the lower part of the Cherokee, to which a name has been given, is the nodular limestone lying a few feet below the Bevier coal bed. This limestone was termed the Ardmore limestone by Gordon,[58] whose description is so concise it is repeated as follows:

"Ardmore Limestone—This is an irregular, marly and concretionary limestone underlying the Bevier coal, and separated from it by from 6 to 18 inches of clay. It appears in numerous exposures in the vicinity of Ardmore (Macon County). It is generally persistent and probably co-extensive with the associated coal. Examinations beyond the limits of the sheet southwestward indicate its presence outside of the area where the Bevier coal is known to exist. The limestone is quite fossiliferous, usually abounding in *Spirifer cameratus, Athyris subtilita, Mesalobus mesalobus, Productus costata, Zaphrentis* and other forms. The lower layers are commonly more regularly stratified, while the upper consist, for the most

[58]Gordon, C. H., A report on the Bevier sheet: Missouri Geol. Survey, Sheet Rept. No. 2, p. 20, 1893.

part, of irregular concretionary nodules of limestone imbedded in a marly clay."

The Ardmore formation is one of the most persistent and widespread members of the Cherokee group. It is well developed in the western counties of the State, and in Vernon County,[59] what is believed to be the exact equivalent, has been called the Rich Hill limestone. The persistency in character and the wide distribution of the Ardmore[60] [61] has been mentioned in other reports and the correlation of the Ardmore limestone with the Verdigris limestone of Oklahoma has been discussed.

Because of the splendid development of the limestone beds in the Ardmore formation, and because it may be used as a guide in prospecting, both in field observations and in drilling, it is believed that a full discussion is appropriate and pertinent.

The numerous splendid outcrops of the Ardmore throughout the northern district show that it is a more complex unit than the original description by Gordon[62] would indicate, and that it consists of more than one limestone, with interbedded shale. Locally the limestones are absent and the Ardmore is represented by green shale of varying thickness, marked in the basal few inches by black-colored nodules of calcium phosphate. In view of the sequence, the term Ardmore is used in this report as a formation for the succession of strata above mentioned and which will be described in detail.

The following section of the Ardmore formation was measured one mile northeast of the village of Ardmore, along the county road just west of the center east line, sec. 24, T. 56 N., R. 15 W., Macon County.

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[59]Greene, F. C., and Pond, W. F., The geology of Vernon County, Mo. Bureau of Geol. and Mines, Vol. XIX, 2nd Ser., pp. 51-52, 1926.

[60]Greene, F. C., Oil and gas pools of western Missouri, Mo. Bureau Geol. and Mines, 57th Bien. Rept., App. II, pp. 14, 15, 16, 1933.

[61]Greene, F. C., and McQueen, H. S., Geology of northwestern Missouri, Mo. Geol. Surv., Vol. XXV, 2nd Ser., p. 23, 1938.

[62]Op. cit.

Measured Section of Ardmore Formation

Number	*Lithology*	*Thickness Feet*	*Inches*
1.	Yellow clay and platy sandstone residuum		
	Bevier Formation:		
2.	Bevier coal, poorly exposed	2	
3.	Underclay, gray	1	3
	Ardmore Formation:		
4.	Limestone, blue gray, mottled, weathers light gray, upper two feet weathers very nodular, lower two feet are more massive and fossiliferous, with crinoid segments and brachiopods being common, fossils weather loose	4	0
5	Limestone, very siliceous, glauconitic. Appears to grade upward into No. 4. Weathers into a fossiliferous tripolitic chert	0	6
6	Shale, grayish green, calcareous, very poorly exposed, and almost wholly covered	4	0
7.	Limestone, dense, hard, rings when struck with hammer, bluish gray, but weeathers brown and into two beds	0	8
8.	Shale, olive drab poorly exposed to base of hill, and lower part of interval may contain other strata	9	0

The upper bed of the Ardmore, No. 4 of the foregoing section, is splendidly exposed in an abandoned highway quarry, northeast of College Mound, NE¼ SE¼, sec. 27, T. 56 N., R. 15 W., Macon County. The exposed thickness is four feet, and the limestone is dark bluish gray, with small dark colored nodules. Upon weathering it forms a highly nodular rubble. The nodular inclusions and the general arrangement of the limestone is highly suggestive of a reef of algal or similar organic material. Brachiopods and crinoid segments are also present.

Excellent exposures of the Ardmore formation are also present in the vicinity of Columbia, Boone County. Although the sections below are incorporated into the general section (Pl. VI) they are again repeated. The following section may be observed in detail in the N½ SE¼ NE¼ sec. 27, T. 49 N., R. 12 W., in the creek tributary to Hinkson Creek, northeast of Columbia, Boone County. The numbers in parentheses, thus (29), following the strata number correspond with the same number of the section given on page 98.

Measured Section of Ardmore Formation

Number	Lithology	Thickness Feet	Thickness Inches
1.	Limestone, dense, blue, hard, weathers very nodular	1	6
2.	Shale or clay, gray, poorly exposed	2	2
3.	Limestone, blue, hard, massive bed, uneven lower surface, weathers to a gray color and into a nodular crinkey surface. Also weathers along joint planes into rectangular blocks, slightly fossiliferous	2	0
4.	Shale, gray, buff, fissile	1	0
5.	Shaley, gray, platy, very calcareous, contains limestone nodules	1	7
6.	(29) Limestone, gray, soft very earthy, and shaley, marl-like, highly fossiliferous, basal 2 inches is harder limestone	1	2
7.	(30) Limestone, hard, dense, blue brown to buff, very wavy irregular lower surface	1	6
Tebo Formation:			
8	(31) Slate, black, hard, fissile	1	8
9.	(32) Coal, bright, brittle	0	7
10.	(33) Underclay, gray, plastic, outer surface of angular weathered faces and joints stained yellow	2	6
Loutre Formation:			
11.	(34) Limestone, gray, weathers buff, weathers very nodular and with slightly angular ball-like rubble, exposed to stream level	0	8

Another splendid section in the same general locality as the foregoing shows the relation of the Ardmore member to the Bevier coal. This section measured on Hinkson Creek 200 yards west of bridge, SW¼ SE¼ NE¼ sec. 27, T. 49 N., R. 12 W., northeast of Columbia, is as follows. The number in parentheses again refers to the detailed section, page 98.

Measured Section of Ardmore Formation

Number	Lithology	Thickness Feet	Thickness Inches
Bevier Formation:			
1.	Black slate, exposed	3+	
2.	(24) Coal, Bevier, 2 feet 6 inches to	3	
3.	(25) Underclay	1	6
Ardmore Formation:			
4.	(26) Limestone, very massive, dark blue, weathers nodular	3	0
5.	(27) Shale, gray, with limestone concretions in upper 3 inches, grades upward into No. 4	1	0
6.	(28) Limestone, dense, blue	0	8
7.	(29) Limestone, shaly or marly, very fossiliferous, especially in the thin discontinuous platy portions	1	6
8.	Limestone, gray, very nodular, exposed to water level	2	0

In the locality of Mexico, Audrain County, the Ardmore is well exposed, particularly in the deeper clay pits, where the limestone beds stand out conspicuously.

The section in the Mexico Refractories Company plant pit, sec. 13, T. 51 N., R. 9 W., is given on Plate V, but the details may again be described as follows:

Ardmore Section, Mexico Refractories Co. Pit

Number	Lithology	Thickness Feet	Thickness Inches
1.	Limestone, gray, weathers buff, and very nodular, argillaceous...	3	0
2.	Limestone, gray, buff, very earthy, and shaley, weathers nodular, slightly fossiliferous	4	0
3.	Shale, dark colored, weathers blocky and splintery	4	0

In the eastern portion of the district, the Ardmore is also well developed. In the Laclede-Christy Clay Products Company pit, SE¼ NE¼ sec. 9, T. 49 N., R. 6 W., south of Wellsville, the Ardmore formation is present and the section totalling 13 feet in thickness and the related strata are given in detail on page 100 and the relations of that section to others of the district on Plate VI.

In the general locality of Fulton, the Ardmore formation is thin and shows considerable variation in character. In the section on Middle River, center SE¼ SE¼ sec. 2, T. 46 N., R. 10 W., the Ardmore is represented by hard, slaty shale, the basal 2 inches being very dark gray, the middle 8 inches being a lighter gray, while the upper 6 inches being greenish gray in color. In the lower 2 to 3 inches, the shale is literally packed with flattened nodules of calcium phosphate, and similar nodules were also noted about 9 inches above the base. Upon weathering of the shale, the nodules stand out in relief and are also marked by a rusty color. The shale varies in thickness from 9 to 14 inches, due to the fact that it was deposited upon a truncated, yet irregular surface. The underlying gray clay of the Tebo shows slight and small scale folding. In this same locality, the phosphatic shale is also present in the A. P. Green Fire Brick Company, Lammers pit, SW¼ sec. 29, T. 47 N., R. 9 W., Callaway County, where it is 12 inches thick. The green phosphatic shale is also present with a thickness of three feet in the Mexico Refractories, Stoltz pit, NW¼ sec. 34, T. 48 N., R. 9 W., Callaway County. The relation of the phosphatic shale to the limestone beds of the Ardmore is shown by the sections in the clay pits at Mexico. North of Mexico, NW cor. sec. 1, T. 51 N., R. 9 W., Audrain County, slightly variegated shale, marked by phosphatic nodules, again marks the base of the Ardmore. Here the shale, nearly two feet in thickness, grades upward into a nodular, very shaly limestone 2 feet thick, which in turn is overlain by three feet of buff to green clay shale. Similar relations were also noted in the Rives pit, NW¼ sec. 28, T. 55

N., R. 9 W., near Goss, Monroe County, where the following section is exposed:

Section of Ardmore Formation, Rives Pit

Number	*Lithology*	*Thickness Feet*	*Inches*
1.	Chert, representing the weathered expression of a very siliceous limestone	1	6
2.	Shale, green to gray, fissile, weathers gray	1	0
3.	Limestone, buff, earthy, spotted, dense, very nodular, poorly exposed	0	6
4.	Clay, green plastic with black nodules of calcium phosphate	1	0
	Cheltenham Formation:		
5.	Clay, gray, semi-plastice, exposed	11	0

In the same locality, Vaughn farm, NW¼ NW¼ sec. 29, T. 55 N., R. 9 W., an almost identical section to that given above is present. The variation in the thickness of the basal phosphatic shale, however, is sharply brought out in this same locality, for on the Levings farm in an outcrop in a deep ravine tributary to, and south of Otter Creek, SW¼ NE¼ sec. 19, T. 55 N., R. 9 W., Monroe County, the shale, with the characteristic phosphatic nodules at the base, and the bouldery or nodular limestone at the top, is present with a thickness of 10 feet. Similar thicknesses of the shale are also known near Wellsville, Montgomery County.

The Ardmore limestones are the thickest ones of the geologic column in the northern district with the possibility of the upper Fort Scott, which is of local distribution only. Thicknesses for various localities have been given. In addition to those the limestones and the associated shales reach a thickness of nearly 20 feet in the vicinity of Vandalia. The Ardmore is usually overlain by the Bevier coal, and normally underlain by the Tebo coal, which further identifies it. Consequently, the limestone can be used in prospecting as its presence will indicate that the Cheltenham clay formation is below it. The interval between the two is variable in the central portion of the district, where it ranges from 7½ to possibly 25 feet. As previously mentioned, the Ardmore rests upon the Cheltenham clay in some localities in Monroe and Shelby Counties.

The geologic history of the Ardmore formation is not unlike that of the other members of the Cherokee group which have been described. It was laid down upon a truncated surface, which ranged from Cheltenham clay to the Tebo black slate. (Pls. V and VI.) It was deposited under somewhat variable conditions, and while in the main the sediments are of marine origin, they no doubt accumulated near shore. After the close of Ardmore time local movements and erosion produced an irregular surface upon which the succeeding beds of the Bevier member were deposited (Pls. V and VI). In the interim, weathering continued and locally may again have brought about continued, even though slight, changes in the underlying fire clays.

BEVIER FORMATION.

The name, Bevier,[63] was applied by Gordon to a comparatively thick and economically important coal, which is extensively mined in the vicinity of Bevier, Macon County, and in the contiguous counties of north central Missouri.

Throughout the central portion of the northern clay district the Bevier coal, where present, is always underlain by a gray typical underclay and overlain by a black slate, except where the latter has been removed by erosion.

The underclay is a typical one. It is gray in color, weathers into angular fragments, and has a conchoidal fracture. On dry surfaces it is fairly hard, yet plastic. Pyrite is a common mineral. The thickness of the underclay ranges from one to possibly four feet. The underclay is not used for the manufacture of fire brick, and in the northern district the exposures studied do not appear to have been altered by leaching.

The overlying Bevier coal is mined in many parts of the area, and particularly in the vicinity of Columbia and Fulton, where a thickness of three feet is common. At Mexico the coal as developed in the rock overburden at the plant pit, Mexico Refractories Company, is mixed with black slate. The coal is normally overlain by black slate or dark clay, up to four feet in thickness, which forms the "roof slate" in the areas where the Bevier was mined.

The sediments of the Bevier formation were deposited in fresh to brackish water, which marked a change from the marine conditions which prevailed through much of Ardmore time. The coal was developed in a swamp of great dimensions for it is found over a large area in Missouri and its correlatives are present in eastern Kansas and southern Iowa.

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[63]Op. cit., p. 20.

The close of Bevier time was again marked by local movement, at least followed by erosion of sufficient duration to result in the local removal of the roof slate and the coal, the best example for observation being in the Lammers pit of the A. P. Green Fire Brick Company, SW¼ sec. 29, T. 47 N., R. 9 W., south of Fulton. In that pit the complete truncation of the coal, which has a maximum thickness of three feet, by the overlying Lagonda shale may be observed. The period of erosion, however, was apparently not a long one.

LAGONDA FORMATION.

Name: The Lagonda,[64] herein designated as a formation, was originally named by Gordon, from the village of that name in Chariton County. He stated that in using the name "Lagonda sandstones and shale—we have thus designated the arenaceous deposit varying from 18 to 50 feet in thickness, immediately overlying the Bevier coal and constituting the uppermost division of the Lower Coal Measures." The original definition of the Lagonda included the interval from the top of the Bevier coal to the base of the Fort Scott limestone, and as such it formed the uppermost unit of the Cherokee group. Although the stratigraphy of the Henrietta group was not studied in detail in connection with the preparation of this report, some information was obtained that should be described. In the writer's opinion there is a distinct unconformity within the Lagonda shale of original definition and, as this unconformity manifests events of importance in the geologic history of the clays, it will be discussed. The writer is not unmindful, however, that in order to determine finally the magnitude of the unconformity much additional work is necessary, particularly in western Missouri.

The Lagonda shale as defined in this report consists of gray to buff colored shale locally marked by red mottling. Sand is common to the shale, and in places forms lenses or thin discontinuous beds. In some localities, however, the shale is free from sand and is represented by gray, highly plastic, laminated clay shale. One of the best exposures of this type of material may be observed in the Lammers pit of the A. P. Green Fire Brick Company, SW¼ sec. 29, T. 47 N., R. 9 W., where the shale measures 9 feet in thickness, and sharply and completely

[64] Op. cit., pp. 19-20.

truncates the underlying Bevier coal. The section measured in this pit is given on page 102. As developed at this locality, the Lagonda shale at the base is gray, smooth textured, fine-grained, and has an oily feel to the touch. This clay resembles closely a clay of the southern district, which in one locality, the Bueker pit, sec. 30, T. 43 N., R. 5 W., north of Owensville, Gasconade County, serves as a thin capping, a few feet in thickness over the flint fire clay of the deposit. The clays are likewise similar in chemical composition as the following analyses show. However, they differ from a highly plastic clay of somewhat similar appearance, which so often fills cracks and joint planes in the underlying flint fire clay and diaspore clay in the filled-sink area, and to which the term "hoghide" is locally applied. An analysis of that clay is given also for comparison in Table 7.

TABLE 7.

Chemical Analyses of Plastic Clays, Lagonda Formation

Sample No.	1	2	3
Ignition Loss (H_2O, +110°C.)	7.67%	10.59%	13.16%
Moisture (H_2O, −110°C.)	4.70	3.31	
Silica (SiO_2)	55.94	50.22	40.13
Alumina (Al_2O_3)	24.61	26.79	38.54
Iron (Fe_2O_3)	1.91	5.55	2.28
Titania (TiO_2)	1.88	1.28	2.15
Lime (CaO)	0.71	0.41	0.34
Magnesia (MgO)	0.87	0.55	0.32
Soda (Na_2O)	N.D.	0.59	N.D.
Potash (K_2O)	N.D.	0.74	N.D.
Totals	98.29	99.62	99.05

Sample No. 1 Gray very plastic clay, A. P. Green Fire Brick Company (Lammers) pit, SW¼ SW¼ sec. 29, T. 47 N., R. 9 W., southwest of Fulton, Callaway County.

Sample No. 2 Plastic clay immediately beneath gravelly overburden, and overlying flint fire clay, General Refractories (Bueker) pit, NE Cor. SE¼ sec. 25, T. 43 N., R. 6 W., Gasconade County.

Sample No. 3 Gray plastic, sticky clay filling joint planes in flint clay, Travis pit, NE¼ SE¼ sec. 29, T. 41 N., R. 7 W., Maries County.

N. D.—Not determined.

It is possible that the difference in chemical composition may be due to leaching, or on the other hand, the clay may be mixed in the joint planes with clay derived from the more aluminous material, hence the difference in composition.

In the Lammers pit, the Lagonda shale is also buff to red in color. The latter is particularly well developed from one to two feet and four to five feet above the base. The laminated character of the shale is also well expressed at this locality. The Lagonda is well exposed in a number of other localities. Among those they may be mentioned are: SE¼ SE¼ sec. 1, T. 46 N., R. 10 W., Callaway County, where 9 feet, 6 inches, of blue gray to light greenish gray sandy shale is exposed above the Bevier formation and below the Squirrel sandstone; in the NE¼ SW¼ sec. 12, T. 47 N., R. 10 W., Callaway County where 10 feet 4 inches of blue sandy shale is present, with the Bevier formation below and the Squirrel sandstone above; in the coal strip pit, SW¼ NW¼ sec. 26, T. 49 N., R. 12 W., Boone County, where the formation is seven feet thick, and consists of greenish gray, blocky shale; in the Mexico Refractories Company plant pit at Mexico, Audrain County, where four feet of blocky drab purple shale is exposed in the material being stripped; and in the new pit of the Laclede-Christy Clay Products Company, SE¼ NE¼ sec. 9, T. 49 N., R. 6 W., near Wellsville, Montgomery County, where the shale measures at least 12 feet in thickness and consists of yellow, buff, or gray blocky shale.

The Lagonda formation increases greatly in thickness in a northwesterly direction and in northwestern Missouri it may attain a thickness of nearly 50 feet. In that direction a coal seam, the Bedford, and the thin beds of sandstone are associated with shale to make up this formation.

The Lagonda is separated from the underlying Bevier by an unconformity and in places in this clay district and other areas completely cuts it out of the section. The best example of this unconformity, as previously mentioned, is in the Lammers pit, SW¼ SW¼ sec. 29, T. 47 N., R. 9 W., Callaway County.

The Lagonda is overlain unconformably by a section of shale, the base of which is usually marked in the district by the Squirrel sandstone. This unit was originally included in the Lagonda and also formed the top of the Cherokee group, as originally defined. In the northern clay district, overlap by this unit, however, has completely removed or reduced the Lagonda formation in thickness and it appears to have been completely overlapped except locally in the southern district. Hence, it would appear that a period of erosion intervened between the deposition of the Lagonda shale and the overlying sandstone and shale.

The overlying sandstone, the Squirrel, is well developed in many sections and it will be discussed in succeeding pages devoted to the Henrietta group. It represents an initial deposit of clastic material, seemingly deposited over a wide area. It rests with distinct unconformity upon the underlying Lagonda. With the succeeding shales and limestones it appears to form a definite sequence, and in the writer's opinion, properly belongs to the lower Fort Scott.

A period of weathering prevailed between the deposition of the Lagonda and the deposition of the Squirrel sand. Further leaching of the Cheltenham clay took place, and some further settling of the clay masses into the small local sinks may have occurred.

HENRIETTA GROUP.

The name, Henrietta, from a postoffice (now abandoned) in Johnson County, Missouri, was first used by Marbut in a physiographic sense in 1896, and first given stratigraphic definition by Keyes,[65] who included in it the Pawnee limestone, Labette ("Marmaton") shale, and Fort Scott limestone. As mapped by Marbut[66] in the Clinton, Calhoun, Lexington, and Richmond sheets, the Henrietta included beds in the upper part of the Cherokee, but he definitely stated that it was intended to include the Fort Scott limestone at the base and the Pawnee limestone at the top. The Henrietta,[67] has been the subject of a very recent detailed study by members of the Iowa, Kansas, and Missouri Geological Surveys. As a result of this study, Cline proposed new names for members of the Fort Scott limestone, which are discussed in the present report, and as a result the cap rock of the Mulky coal, formerly designated as the lower Fort Scott limestone, was named the Blackjack Creek limestone; the "Rhomboidal" limestone, overlying the Summit coal, was named the Houx limestone, and the "Chaetetes" limestone, underlying the Lexington coal, was named the Higginsville limestone.

The distribution of the Fort Scott formation in the northern district is comparatively limited and appears to be confined principally to several synclinal or structurally low areas.

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[65]Keyes, C. R., Stages of the Des Moines, etc.: Iowa Acad. Sci. Proc., Vol. 4, pp. 22-24, 1896.

[66]Marbut, C. F., Geological descriptions of the Clinton, Calhoun, Lexington and Richmond sheets: Missouri Geol. Survey, Vol. 12, Pt. 2, 1898.

[67]Cline, L. M., Traverse of upper Des Moines and lower Missouri series for Jackson County, Missouri and Appanoose County, Iowa: Bull. Am. Assoc. Pet. Geol. Vol. 25, pp. 25-72, 1941.

The best exposures of the formation are just west of the west edge of the map accompanying this report, in the NW¼ NW¼ SE¼ sec. 27, T. 49 N., R. 12 W., and the NW¼ SE¼ NE¼ sec. 27, T. 49 N., R. 12 W., northeast of Columbia, Boone County. These localities are situated near the bottom of the pronounced syncline, which lies southwest of and parallel to the steep flank of the Browns anticline, one of the most prominent structural features in central Missouri. The section given on page 98 of this report was measured in the above described localities. Another locality, similarly situated with respect to the Browns Station anticline, but not connected with the Boone County exposures is situated in the W½, T. 47 N., R. 9 W., and a considerable portion of T. 47 N., R. 10 W., and the adjacent portions of T. 48 N., R. 10 W., and T. 46 N., R. 10 W., all in Callaway County. Excellent sections are available for study in sec. 1, T. 46 N., R. 10 W., Callaway County, where the following described section is situated.

Section of the Henrietta group, SE¼ and SW¼ Sec. 1, T. 46 N., R. 10 W., Callaway County

Number	*Lithology*	*Thickness Feet*	*Inches*
Henrietta Group:			
Fort Scott Formation:			
1.	Limestone, buff to brown, massive to thick bedded, sandy, argillaceous, very fossiliferous with brachiopods and bryozoa	6+	
2.	Shale, blue to gray, thin bedded very plastic, sandy	1	10
3.	Covered interval, probably shale	4	0
4.	Shale, greenish gray, plastic with small ovoid-shaped concretions of limestone	2	0
5.	Limestone, nodular, blue, dense very shaley, weathers irregularly	4	1
6.	Limestone, blue, dense, distinctly nodular, weathers brown	7	3
7.	Limestone, blue, weathers buff, dense, argillaceous, sandy, dolomitic, weathers brown and into slabby thin beds. Appears more massive bedded on fresh surfaces	12	3
8.	Shale, blue-green, plastic	2	10
9.	Limestone, phosphatic, siliceous, argillaceous, dark blue to black, weathers to a light gray, slightly oolitic, very hard. Upper surface smooth, lower surface uneven, upper 1/16 to 1/8 inch splits off into smooth fresh surfaces, with bright, distinct cleavage. Limestone is irregular in thickness and possibly lenticular, contains discinoid brachiopods in abundance. Limestone is exactly similar in character and position to that found in Willoughby flint fire clay pit, SW¼ NE¼ SE¼ sec. 30, T. 41 N., R. 7 W., southeast of Belle, Maries County, in the southern district	0	1½
10.	Interval poorly exposed, float suggests blue green shale	8	6
11.	Sandstone (Squirrel) soft, very shaly, micaceous	5	4
Cherokee Group:			
Lagonda Formation:			
12.	Shale, blue gray to light greenish gray, sandy, weathers brown	9	6
Bevier Formation:			
13.	Shale, dark blue to black, thin bedded	3	0
14.	Shale or clay, gray	0	3
15.	Coal (Bevier)	3	0
16.	Underclay, gray	3+	

In the section above numbers 1 to 7, inclusive were measured near the east line SE¼ SE¼ SW¼ sec. 1, T. 46 N., R. 10 W., numbers 8 to 16 inclusive were measured 100-150 yards from SE cor., and on south line, SE¼ SE¼ sec. 1, T. 46 N., R. 10 W. In both localities bed No. 7 was present and was used to tie sections together. Numbers 10 and 11 would be placed in the Cherokee group as originally defined. The writer, however, believes they are more closely related to the Henrietta group.

The Henrietta is also exposed occasionally in the deeper clay pits at Mexico, and the basal portion of the formation may be observed at present in the plant pit, Mexico Refractories Company at Mexico, Audrain County, sec. 13, T. 51 N., R. 9 W., the section being given in detail on page 105.

As indicated by the sections referred to, the Fort Scott consists of alternating beds of shale and limestone below which there is a section of shale, the base of which is marked by a sandstone, the Squirrel. The latter appears to be best developed in the deeper portions of the synclinal areas. Although it is usually placed in the upper part of the Cherokee, the writer believes that more detailed work will show that it more properly belongs at the base of the Henrietta.

The limestones of the Fort Scott are thin bedded and the individual beds are usually of no great thickness except in the Fulton area. The limestones are characteristically gray or gray blue in color but invariably weather to a buff color. Fossils are common, with some of the beds containing large numbers of them. The basal limestones often contain in the insoluble residues a porous spongy type of glauconite, and silicified fossil fragments. The residues have been found to be helpful in making correlations. Although specific attention was not given to the problem, it would appear that the upper portion of the Fort Scott becomes a comparatively thick limestone in the Fulton area, a total thickness of over 23 feet of limestone being attained. The shale beds, which are interbedded with the limestone in the vicinity of Columbia, appear to be absent.

The shale of the Fort Scott formation is dominantly green or gray. In the synclinal area northeast of Columbia there is a persistent red shale, which serves to identify readily the upper part of the formation. This red clay shale is also widely distributed at the same horizon throughout the area of Fort

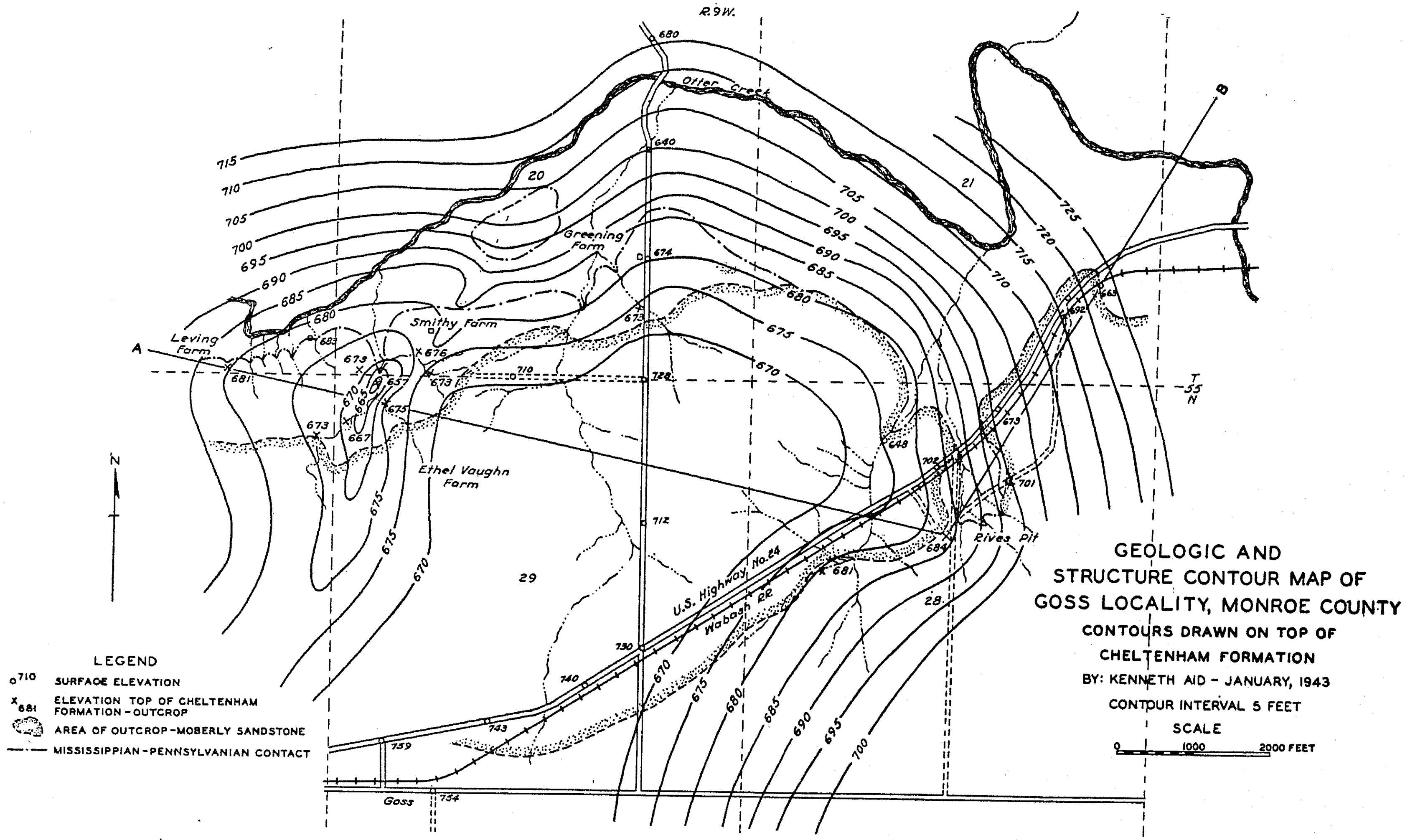
Scott outcrop in western Missouri. In the lower part of the formation in the Columbia area there are black slatey shales, which represent the Mulky and Summit coals of northern and western Missouri. While the full thickness of the Henrietta group is not present in the northern district, it would appear that most of the Fort Scott formation is present, and as given in the sections in this report, a total over 50 feet is available for observation.

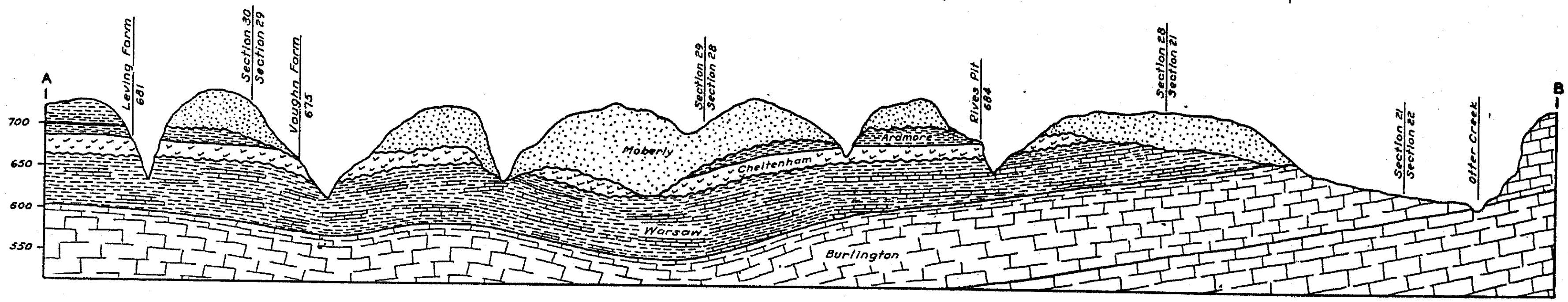
Although the Fort Scott has no particular economic significance as it pertains to the fire clay resources, it can be used as a guide in prospecting for clay. As pointed out it seems to occur in greatest thickness in synclinal areas, hence in areas where the Cheltenham also may be thickest. The presence of the Fort Scott formation, however, also indicates a very considerable thickness of overburden, and consequently presents problems in economical mining operations, particularly from open pits.

The Fort Scott formation of the Henrietta group is separated from the underlying Cherokee group by a distinct unconformity. This "break" is manifested by the reduced thickness of the Lagonda shale in the northern district. In addition there appears to be an unconformity within the Fort Scott in the northern district, which may be manifested by the red and green shale previously described. In comparing sections measured in the vicinity of Columbia with those measured in the vicinity of Fulton, it would appear that the interval from or slightly below, the base of the black slate representing the Mulky coal horizon to a point at, or near, the base of the Higginsville limestone, which is well developed at Columbia, is missing in the vicinity of Fulton. This unconformity is also marked in the southern district. There the relation to the underlying beds is more sharply defined, and the events in the historical geology, manifested by the unconformity, are more readily interpreted.

MOBERLY SANDSTONE.

In Monroe County, in the northern portion of the district, there occurs a sandstone deposit which is comparatively narrow, but very long. It is known to occur for many miles west of the western margin of the map accompanying this report, upon which it has been outlined.


GEOLOGIC AND
STRUCTURE CONTOUR MAP OF
GOSS LOCALITY, MONROE COUNTY
CONTOURS DRAWN ON TOP OF
CHELTENHAM FORMATION
BY: KENNETH AID - JANUARY, 1943
CONTOUR INTERVAL 5 FEET
SCALE
0 1000 2000 FEET
LEGEND
o710 SURFACE ELEVATION
x681 ELEVATION TOP OF CHELTENHAM FORMATION - OUTCROP
AREA OF OUTCROP - MOBERLY SANDSTONE
MISSISSIPPIAN - PENNSYLVANIAN CONTACT
R.9W.
T. 55 N.
N
Otter Creek
Greening Farm
Smithy Farm
Leving Farm
Ethel Vaughn Farm
Rives Pit
U.S. Highway No. 24
Wabash RR
Goss
A
B
20
21
28
29


A
B
700
650
600
550
Leving Farm 681
Section 30 Section 29
Vaughn Farm 675
Section 29 Section 28
Rives Pit 684
Section 28 Section 21
Section 21 Section 22
Otter Creek
Moberly
Ardmore
Cheltenham
Warsaw
Burlington

SECTION A - B

In addition to the two dimensions given above, the sandstone cuts down into the Pennsylvanian and Mississippian formations. It represents the filling of a channel with sandstone by an ancient river. To this standstone the name Moberly was first given by Marbut.[68] Near the east edge of the town of Stoutsville, Monroe County, the sandstone is in contact with the Keokuk-Burlington cherty limestones. At and in the vicinity of the Rives clay deposit, sec. 28, T. 55 N., R. 9 W., the sandstone is in contact with the Ardmore and Cheltenham formations, respectively. North of this deposit, however, the sandstone appears to be thicker, and the original valley, now filled, was much deeper. Here the sandstone is probably in contact with the Mississippian, Warsaw formation.

The deepest part of the channel as it is developed in the vicinity of the Rives clay deposit, sec. 28, T. 55 N., R. 9 W., Monroe County, is probably just north of the Wabash Railroad and State Highway No. 24. Here it is probably over 80 feet thick. The deep part of the channel may be restricted in width and comparatively narrow, but after it was filled the sandstone spread out over a fairly level surface until near the Rives deposit, it is about one mile in width (Pl. XIV).

The sandstone is uniform in character. It is fine grained, very micaceous, and friable. The grains are not particularly well rounded. Lenses or thin beds of green shale are not uncommon and locally it also becomes a shale with sandstone lenses.[69] Cross bedding is remarkably well developed in some localities, an example being the exposure in the cut, Wabash Railroad, immediately east of the crossing of the road, formerly State Highway No. 10, now abandoned, and further located in the SE¼ SW¼ sec. 21, T. 55 N., R. 9 W.

The presence of the sandstone in this area is important with respect to prospecting for clay. In the area of this channel deposit the Cheltenham may be entirely cut out or reduced in thickness. In addition, near the sides of this ancient valley the clay may be weathered and contaminated and these points should be kept in mind.

In the western part of the State, where a closely related sandstone, the Warrensburg, is present, considerable information has been obtained regarding the age. It was formerly in-

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[68] Marbut, C. F., Sheet Rept. 12, Mo. Geol. Surv., Vol. 12, pt. 2, 1st Ser., pp. 323, 324, 331-332, 350, 1898.

[69] Aid, Kenneth, oral communication.

cluded in the Pleasanton formation, and in the Des Moines Series. It is now believed to mark the contact of the Des Moines and Missouri series, and to be an initial and channel deposit of the latter. In the Monroe County area an unconformity of some magnitude therefore is present between the base of the sandstone and the underlying Pennsylvanian and Mississippian formations.

PLEISTOCENE SERIES.

The uplands of the northern district are capped by Pleistocene glacial drift, which varies in composition and thickness. The drift usually consists of yellow clay, in which boulders of igneous and metamorphic rocks are included. Such rocks were derived from a distant area. Limestone is also not uncommon to the glacial drift and in most instances is of local derivation. Large boulders of the rocks mentioned often mark the base of the drift, and an excellent exposure may be observed in the Lammers pit, SW¼ SW¼ sec. 29, T. 47 N., R. 9 W., south of Fulton, Callaway County. The drift probably increases in thickness in a northerly direction and in some localities it reaches a thickness of 60 feet or more. Good exposures of the drift may be observed where the clay is mined from open pits, those at Mexico, Fulton, and Wellsville being good examples (Pl. XI, B).

MEASURED SECTIONS

Section Measured in the Vicinity of Columbia, Boone County

Number	*Lithology*	*Thickness Feet*	*Inches*
	Henrietta Group:		
	Fort Scott Formation:		
1.	Limestone, gray, dense, much calcite occurs as boulders	1	0
2.	Covered	1	0
3.	Limestone, one bed, gray, dense to fine-grained, fossiliferous	0	6
4.	Covered. Shale ?	1±	0
5.	Limestone, light gray, fine grained	2	3
6.	Limestone, dense, blue gray, very irregularly and wavy bedded, fragmental at top, very fossiliferous with crinoid segments and foraminifera being abundant	3	9
7.	Shale, green platy at base, dark gray at top	1	6
8.	Limestone, hard, weathers buff, very earthy, poorly exposed	2	0
9.	Covered	2	0
10.	Limestone, in two beds, lower being fine grained, compact, buff colored, fossiliferous in narrow zones, with brachiopods being common, upper bed 11 inches thick, fine grained, gray, weathering buff, psuedo-oolitic and fossiliferous in upper four inches	1	8
11.	Shale, red and green, former with hard red concretions, both colors appear to be intimately mixed. Interval, however, is poorly exposed	8	4
12.	Limestone, (Houx) brown to gray, dense, hard, blocky in one massive bed, fossiliferous, thickness 1′8″ to	2	4
13.	Shale, or clay, gray, weathers buff	0	8

Section Measured in the Vicinity of Columbia, Boone County (continued)

Number	*Lithology*	*Thickness Feet*	*Inches*
14.	Slate, black, clayey at base, blocky in middle and more fissile in upper portion, horizon of Summit coal	1	8
15.	Clay, green in basal portion, gray in upper portion, nodular, hackly fracture, selenite crystals on weathered surface	6	0
16.	Limestone, (Black Jack Creek) blue, weathering buff, very earthy, dense, nodular, lower two feet more massive, upper 6 inches very soft and earthy; bed does not weather prominently	2	6
17.	Clay shale, dark green, weathers gray	0	7
18.	Clay shale and slate, black with impure thin coal seams, particularly near base, and forms prominent six inch band in exposure, horizon of Mulky coal	1	2
19.	Clay shale, gray, mottled by pyrite which occurs disseminated and as small clusters, local argillaceous limestone lense near base	8	3
20.	Sand (Squirrel), brown, fine-grained, compact, weathers into thin bed with shaly partings, basal contact is irregular, prominently exposed	4	9
Cherokee Group:			
Lagonda Formation:			
21.	Shale, sandy at base, greenish gray, blocky	7	0
22.	Shale, or clay, bluish gray	5	4
Bevier Formation:			
23.	Slate, black	3	0
24.	Coal, (Bevier) varies in thickness up to	3	0
25.	Clay, gray, typical underclay	1	6
Ardmore Formation:			
26.	Limestone, dark blue, very massive, weathers nodular	3±	0
27.	Shale, gray, with limestone concretions similar to No. 26 in upper inches, appear to grade into No. 26	1	0
28.	Limestone, dense, blue	0	8
29.	Limestone, impure, very shaly, soft, very fossiliferous	1	6
30.	Limestone, blue brown to buff, very nodular, hard, dense, base very wavy	1	6
Tebo Formation:			
31.	Slate, black, hard, fissile	1	8
32.	Coal, Tebo, brittle, bright luster	0	7
33.	Clay, gray, nodular, stained yellow along joints and fractured surfaces. Typical underclay	2	6
Loutre Formation:			
34.	Limestone, brown, fine-grained very nodular or bouldery, with considerable clay, very fossiliferous	2	6
35.	Clay, bright green, highly plastic, the typical pocket filling clay everywhere present immediately above No. 36. Top weathered and not well exposed	0	5
Cheltenham Formation:			
36.	Clay, upper Cheltenham, dark to light gray, semi-plastic at base, highly weathered and stained yellow at top, nodular fracture with yellow staining on exposed surfaces	17±	0
Graydon Formation:			
37.	Chert conglomerate, boulders of varying size, some clay	8±	0
Mississippian System:			
Burlington Formation:			
38.	Limestone, gray, crystalline, fossilerous, cherty.		

Beds numbered 1 to 12 inclusive were measured in a ditch along east side of county road in NW¼ NW¼ SE¼ sec. 27, T. 49 N., R. 12 W., on west limb of well developed syncline. Beds numbered 13 to 20 were measured on Hinkson Creek and on east and more steeply dipping limb of same syncline in NW¼ SE¼ NE¼ sec. 27, T. 49 N., R. 12 W.

Beds numbered 21 to 24 inclusive were measured in coal strip pit in SW¼ NW¼ sec 26, T. 49 N., R. 12 W. Beds numbered 25 to 29 inclusive were measured along south side of Hinkson Creek 200 yards west of bridge, SW¼ SE¼ NE¼ sec. 27, T. 49 N., R. 12 W. Beds numbered 29 to 33 inclusive measured along creek N½ SE¼ NE¼ sec. 27, T. 49 N., R. 12 W., and between sections containing beds 13 to 20 and 21 to 24. Beds numbered 34 to 38 were measured in pit Edwards-Conley Brick Company and ravine adjacent thereto, near center south line NE¼ SE¼ sec. 8, T. 48 N., R. 12 W., immediately east of City of Columbia. In preparing the above measured section corresponding beds were carried from one local section measured to another.

Section exposed in pit, Laclede-Christy Clay Products Company, SE¼ NE¼ Sec. 9, T. 49 N., R. 6 W., 2½ miles south of Wellsville, Montgomery County.

Number	*Lithology*	*Thickness Feet*	*Inches*
	Glacial Clay		
	Pennsylvania System:		
	Cherokee Group:		
	Lagonda Formation:		
1.	Shale, gray, weathers yellow or buff, blocky	10±	0
	Bevier Formation:		
2.	Slate, black and shale, gray	1	0
3.	Coal	1	0
4.	Clay, shaly, dark greenish gray, hackly fracture	6±	0
	Ardmore Formation:		
5.	Limestone, one massive bed, gray, with darker mottling, dense, fossiliferous, upper surface very irregular with amplitude of 18 inches	5	0
6.	Limestone, dense, argillaceous, slightly fossiliferous. Contact with No. 7 is gradational	1	0
7.	Shale, buff, olive, hard, blocky and massive, upper two feet more clayey and olive drab in color, and grades into No. 8	7	0
8.	Shale, very dark similar to above but with dark limestone concretions (niggerheads)	1	0
	Tebo Formation:		
9.	Shale, gray and black, weathers buff, slightly nodular	1	0
10.	Coal, impure intermixed with black slate. Thickness varies	0	4
11.	Clay, gray, weathers into nodular, angular lumps, badly fractured and stained yellow along joints and fractured surfaces, local sandstone and sandy clay lense at base	1	0
	Loutre Formation:		
12.	Clay, light gray to greenish gray, weathers with hackly fracture, intricately jointed and stained, buff limestone nodules one foot in diameter in upper portion, top of bed is wavy and very irregular	3	4
13.	Clay, bright green to grayish green, very pyritic, no perceptible break with No. 12, and the two appear to be gradational	6	0
14.	Clay, hard, black with coal smut, pyritic	0	2
15.	Clay, green, as in No. 13	0	1
16.	Clay, green, containing irregular discontinuous ovoid nodules of pisolitic siderite with radial structure	0	8
	Cheltenham Formation:		
17.	Clay, dark to light gray, hard, semi-plastic, average thickness by drilling reported to be	20	

Section measured on Middle River on east side of valley on U. S. Highway 54, extending south down creek, NE¼, SE¼ to SE¼ SE¼, Sec. 2, T .46 N., R 10 W., Callaway County.

Number	*Lithology*	*Thickness Feet*	*Inches*
	Henrietta Group		
	Fort Scott Formation		
1.	Limestone, earthy, very nodular and shaley in basal 1½ feet, weathers with marked horizontal fluting. Weathered	5	6
2.	Limestone, nodular, wavey bedded, yellowish gray on weathered surface, gray blue on fresh surface, fine-grained, and with fragmental to psuedo-oolitic texture	1	1
3.	Shale, green, platy	2	0
4.	Limestone, very nodular and bouldery, ranges from zero to	0	2
5.	Shale, dark, almost black and dark green	6	0
6.	Shale, buff, very sandy, thin bedded	7	0
7.	Sandstone (Squirrel) buff fine-grained not well exposed	1	0
	Cherokee Group		
	Lagonda Formation		
8.	Shale, buff, poorly exposed, covered with talus	11	0
	Bevier Formation		
9.	Shale, or slate black	4	0
10.	Coal (Bevier)	2	6
11.	Underclay, gray	3	8
	Ardmore Formation		
12.	Shale, dark gray, hard, slaty, weathers greenish and into flat angular pieces, in upper part gray, greenish gray in middle part, basal part is shale, or clay, dark gray, hard and slaty, with many flattened disc-like concretions of calcium phosphate in the lower 2 or 3 inches, thickness ranges from 9 inches to..	1	2
	Tebo Formation		
13.	Slate, black, coal, contact with No. 12 is uneven and locally No. 12 cuts down into top of No. 14	0	4
14.	Coal, black, very dirty grades upward into No. 13, varies from 2 inches to	0	4
15.	Underclay, hard, angular, plastic, contact with Nos. 14 and 16 is sharp	0	7
16.	Clay, top 1 inch weathered to a very plastic gray shale, which makes well defined contact with No. 15, grades into a gray lumpy clay with conchoidal fracture. Selenite and melanterite coat weathered surfaces. Grades downward near base into a basal green colored high alkali, plastic clay, 2 feet thick which contains a nodule of pisolitic siderite 6 by 3 by 2 feet	9	0
	Cheltenham Formation (Lower member)		
17.	Flint fire clay, sandy, and semi-flint clay, poorly exposed to water level	2	0

Section of Fort Scott formation exposed on U. S. Highway 54, south edge of Fulton, Callaway County, near center of south line, SE¼ sec. 17, T. 47 N., R. 9 W.

Number	*Lithology*	*Thickness Feet*	*Inches*
1.	Limestone, (Higginsville?) buff, fine-grained, very earthy, nodular throughout with upper three feet being particularly so; with very thin shaley streaks between nodules, entire mass weathers thin bedded, and lower 9 feet is platy	12	0
2.	Shale, greenish gray, massive with nodules of limestone as above	1	0
3.	Shale, greenish	1	
4.	Calcium phosphate concretions, discontinuous, bearing discinoid brachiopods	0	¼
5.	Shale, green to almost black	3	0
6.	Sandstone (Squirrel), gray, extremely fine-grained, compact in two beds, forms base of Fort Scott	3	0

Section measured in A. P. Green Fire Brick Company, Lammers pit, SW¼ SW¼ sec. 29, T. 47 N., R. 9 W., south of Fulton.

Number	Lithology	Thickness Feet	Thickness Inches
1.	Soil, red, 2 feet to	3	
	Glacial Drift		
2.	Clay, brown yellow with many large limestone boulders at base	5	0
	Henrietta Group		
	Fort Scott Formation		
3.	Shale, olive drab, upper portion poorly exposed, probable thickness is	10(?)	0
4.	Sandstone (Squirrel), buff, brown, very fine-grained, calcareous, hard, blocky	1	0
	Cherokee Group		
	Lagonda Formation		
5.	Shale, red, one to two feet and four to five feet above base, buff-colored two to four feet and five to nine feet four inches; shale is laminated	9	0
6.	Clay or shale, gray, highly plastic, tough, sticky, rubbery laminated, looks like clay of southern district, known as "hog-hide"; separated from No. 7 by an angular unconformity	1	0
	Bevier Formation		
7.	Coal, very dirty and soft, with much black clay, due to very obvious angular unconformity the coal ranges in thickness from 0 to	3	0
8.	Clay, dark gray, hard, semi-plastic type, very plastic when wet	3	6
	Ardmore Formation		
9.	Shale, or hard clay, dark green with locally many dark-colored nodules and flat discontinuous slabs of calcium-phosphate	0	10
	Tebo Formation		
10.	Clay, plastic, very dark, with much coal smut, forms distinct band	0	2
	Loutre Formation (?)		
11.	Clay, light gray, plastic, fairly hard	4	0
	Cheltenham Formation		
12.	Clay, plastic, dark gray, contact with 11 not distinct (Upper member)	6	8

Section measured in Mexico Refractories Company pit, Stoltz farm, NW¼ sec. 34, T. 48 N., R. 9 W., Callaway County.

Number	*Lithology*	*Thickness Feet*	*Inches*
1.	Glacial drift.		
	Cherokee Group:		
	Ardmore formation		
2.	Shale, olive green, brown, clayey, blocky to platy, 6 inches and 12 inches above base are zones of nodular, disc-like calcium phosphate pebbles about 2 inches thick, which stand out because of darker color, shale above upper zone is brighter green in color	3	0
	Tebo formation		
3.	Clay, hard, light greenish gray, rough grain, upper surface has a thin, one inch, persistent residual coal smut in sharp contact with No. 2. Thickness nine inches to	1	0
	Loutre formation		
4.	Clay, hard, semi-flint-like, gray, mottled red and purple contact with No. 3 not sharp. Grades downward into six inches to two feet of green alkali clay which fills characteristic pockets or depressions in underlying clay, a coal smut about 1 inch thick occurs at or near base	6	0
	Cheltenham formation		
5.	Clay, light greenish, gray, hard semi-flint clay, thoroughly jointed and fractured. One face about 10 feet thick with hard dark coaly clay, 2 inches thick about 4 feet above base; clay slightly mottled red and pink above coaly material, less so below. This is the upper bench being worked. Thickness averages about	4	0
6.	Clay, gray, to greenish gray or very dark gray, the colors being irregular and gradational darker color, however, seems to be confined to deeper funnel-like depressions. Some of darker almost black clay is platy, thin bedded and hard, particularly adjacent to rolls; slickensides beautifully developed, particularly adjacent to holes, this is the lower bench and ranges in thickness from a few feet to	20+	0
	Graydon formation		
7.	Chert conglomerate, hard, upper surface encrusted with pyrite.		

Driller's log, diamond drill hole drilled by Harbison-Walker Refractories Company near shaft mine at Fulton, Callaway County, Missouri. Correlation of formations by H. S. McQueen.

Number	*Lithology*	*Thickness in Feet*	*Depth in Feet*
Glacial drift			
1.	Surface	50	50
2.	Sand and lime	10	60
Henrietta Group			
Fort Scott formation			
3.	Lime	16	76
4.	Blue shale	3	79
5.	Lime rock	3	82
6.	Lime rock	4	86
Cherokee Group			
Lagonda formation			
7.	Shale	5	91
8.	Shale	6	97
Bevier formation			
9.	Coal	3	100
10.	Dark clay	2	102
Ardmore formation			
11.	Green clay	3	105
Tebo formation			
12.	Dark clay	3	108
Loutre formation			
13.	Gray clay (Good)	16	124
14.	Green clay	3	127
Cheltenham formation			
(Upper member)			
15.	Hard gray clay (good)	8	135
(Middle member)			
16.	Green clay sandy	8	143
17.	Sandy clay	2	145

Section exposed in Mexico Refractories Company, plant pit, sec. 13, T. 51 N., R. 9 W., at Mexico, Audrain County. Measured by H. S. McQueen and Garland Gott.

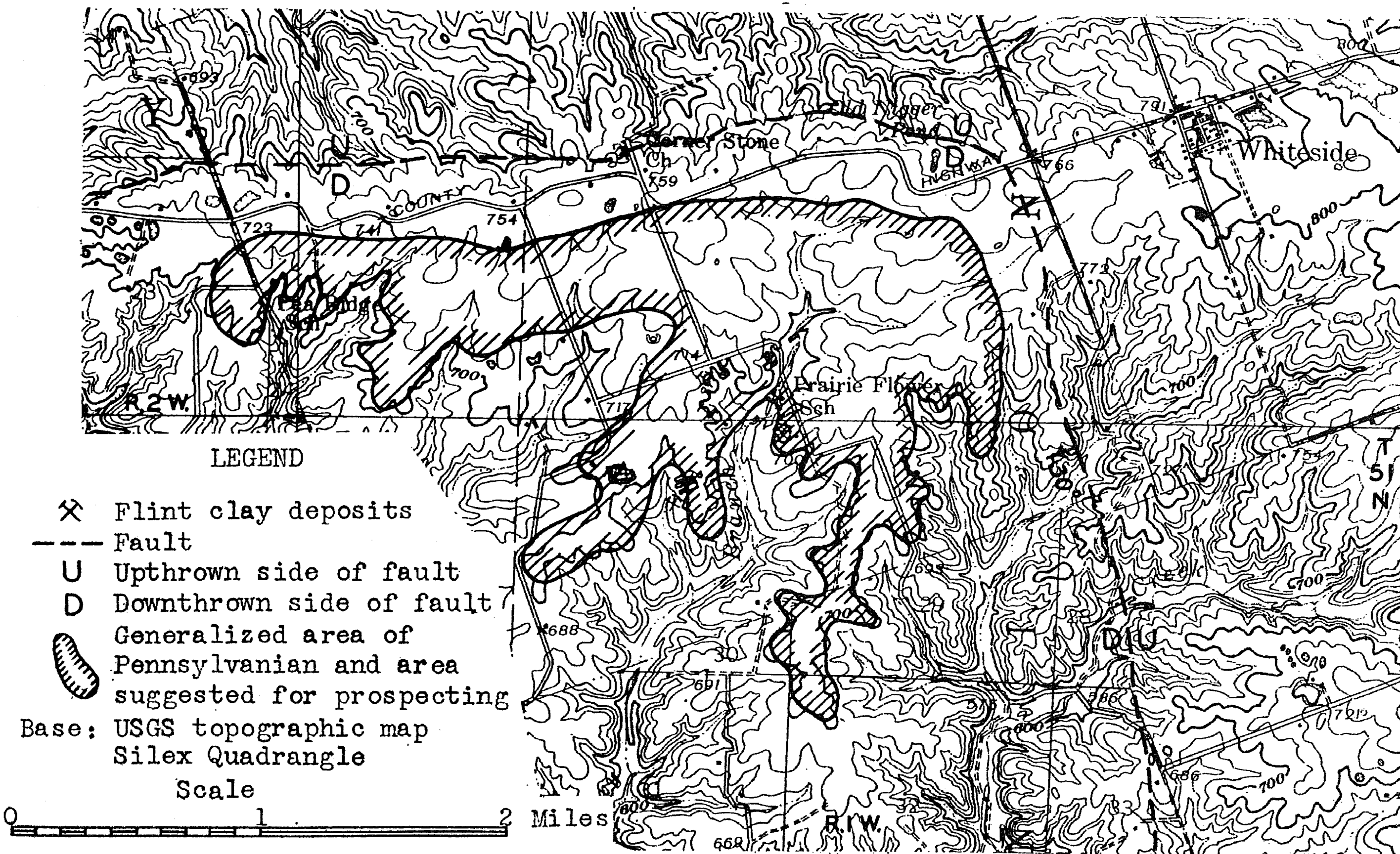
Number	*Lithology*	*Thickness Feet*	*Inches*
1.	Glacial clay and boulders.		
	Henrietta Group		
	Fort Scott formation		
2.	Limestone, yellow, earthy, fossiliferous	3	0
	Cherokee Group		
	Lagonda formation		
3.	Shale, drab to purple dark just above coal, blocky	4	0
	Bevier formation		
4.	Coal, and black slate	2	0
5.	Underclay, gray	1±	0
	Ardmore formation		
6.	Limestone, gray, very earthy, fossilferous, weathers nodular	3	0
7.	Limestone, as above, more shaley	4	0
8.	Shale, dark colored, weathers blocky and splintery	4	0
	Tebo formation		
9.	Slate, black, almost coal	2	0
10.	Coal, ranges in thickness from 6 inches to	1	6
11.	Clay, gray, plastic	1	0
	Loutre formation		
12.	Clay, hard, gray, hackly, semi-plastic type, with plant remains and mineral charcoal	4	0
13.	Clay, similar to above, but sharply separated from it, with many nodules of dark gray fine-grained limestone	2	0
14.	Limestone, hard, dark gray, fine-grained, mottled, appearance is suggestive of algae	2	0
15.	Clay, dark gray, hard, semi-plastic type, ranges in thickness from 3 to 8 feet; grades downward into green, high alkali, clay up to 3 feet in thickness which fills pockets in underlying clay, average	5	0
	Cheltenham formation		
16.	Clay, light greenish gray, to dark gray, locally pink mottled semi-plastic type, (Middle member)	18	0
17.	Clay, dark gray, hard, semi-flint type occurs in pocket-like depressions, (Lower member) up to	10	0
	Graydon formation		
18.	Chert, pyrite encrusted.		

Section measured in pit No. 4, A. P. Green Fire Brick Company at Mexico, Audrain County, sec. 36, T. 51 N., R. 9 W.

Number	Lithology	Thickness Feet	Thickness Inches
Glacial drift			
Cherokee Group:			
Ardmore formation			
1.	Limestone, gray, shaley, nodular from 2 to	5	0
2.	Shale, green in upper part, gray and with limestone nodules in lower part	5	0
Tebo formation			
3.	Slate, black	2	0
4.	Coal, very uneven lower contact, varies greatly in thickness in short distances from nothing to	3	0
Loutre formation			
5.	Clay, gray, plastic	0	6
6.	Clay, gray, overlapped by No. 4, varies from nothing to	2	0
7.	Clay, green, with limestone nodules, pinches out and is overlapped by No. 4, varies from nothing to	2	6
8.	Limestone, dark gray, hard, fine-grained, mottled by dark brown roughly circular areas which weathers out making a bouldery rubble	2	0
9.	Clay, gray, grading downward into green, high alkali clay, which fills pockets and shallow valleys in underlying clay	2	0
Cheltenham formation			
10.	Clay, light gray, but locally darker, fairly hard, semi-flint type, (Middle member). Varies in thickness but probably averages	18	0
11.	Clay, dark gray, locally, black, hard, semi-flint to flint fire clay type, fills funnel-like depressions, hence varies greatly in thickness. (Lower member). Greatest thickness reported to be 45 feet, average	10	0
Graydon formation			
12.	Chert conglomerate, incrusted with pyrite, and locally sandstone, hard, fine-grained.		

GEOLOGIC STRUCTURE.

Over most of the northern district, and certainly through the heart of the clay producing portion, there is a mantle of glacial clay of varying thickness, which masks to a large extent the rock outcrops. As a result it is very difficult to determine the local geologic structure. In certain portions of the area, however, particularly near the major streams, erosion has resulted in stripping off this mantle, and some information has been obtained regarding the major structural features. In addition, over a considerable portion of the northern district fresh water is obtained from formations ranging from the Mississippian limestones to the St. Peter sandstone of Ordovician age. As a result a considerable number of farm wells, and wells drilled for industrial supplies in the larger towns and cities have been drilled. Complete and accurate records have been obtained on many of them, and they afford information pertaining to the regional structure. If the broader structural



Geologic map of Whiteside Clay locality, Lincoln County.

pattern is considered, the northern district is marked by a series of large scale regional anticlines and synclines, which trend in a northwest-southeast direction.

Chief and most prominent among these regional anticlines is the Lincoln fold,[70 71] which has been described in detail in other reports. It forms in effect the eastern limits of the northern district. This feature is an assymetrical anticline, the southwest side being marked by steep dips and extensive faulting of the strata, while the northeast side appears to be marked by comparatively gentle dips. The strike of the axis of the fold is northwest-southeast and it extends from a point in the extreme southeastern corner of Lincoln County northwestward through Pike, Ralls, Shelby, Knox, and Putnam Counties and thence into southern Iowa, at least. The geologic history of the Lincoln fold is complex. It is a feature that was perhaps marked by more than one period of uplift, one of which occurred sometime after the deposition of the Cheltenham clays. As a result, the clays were completely stripped from the axis or top of this regional feature. However, what is considered to be pocket or sink-hole type deposits of flint fire clay, which probably represent the lower member of the Cheltenham occur in the Whiteside, Lincoln area, T. 51 N., Rs. 1 and 2 W. On the accompanying map (Pl. XV), a fault on the steep southwest side of the fold has been indicated. From a point about 2 miles west of Auburn to a point about three-fourths of a mile west of Whiteside, the strike of the fault is slightly west of north. At or near a point on Lincoln County Highway K, three-fourths of a mile west of Whiteside, the strike changes abruptly to a westerly direction. Within the arc thus described and on the downthrown side of the fault plane, there is an area in which high grade flint fire clay occurs. The area recommended for prospecting is outlined on the map mentioned. Other and similar changes in strike along the southwest and often faulted flank of the Lincoln fold no doubt occur. Where such changes of strike coincide with high upland areas in northern Lincoln and adjacent portions of southern Pike County, additional areas favorable for prospecting will be found.

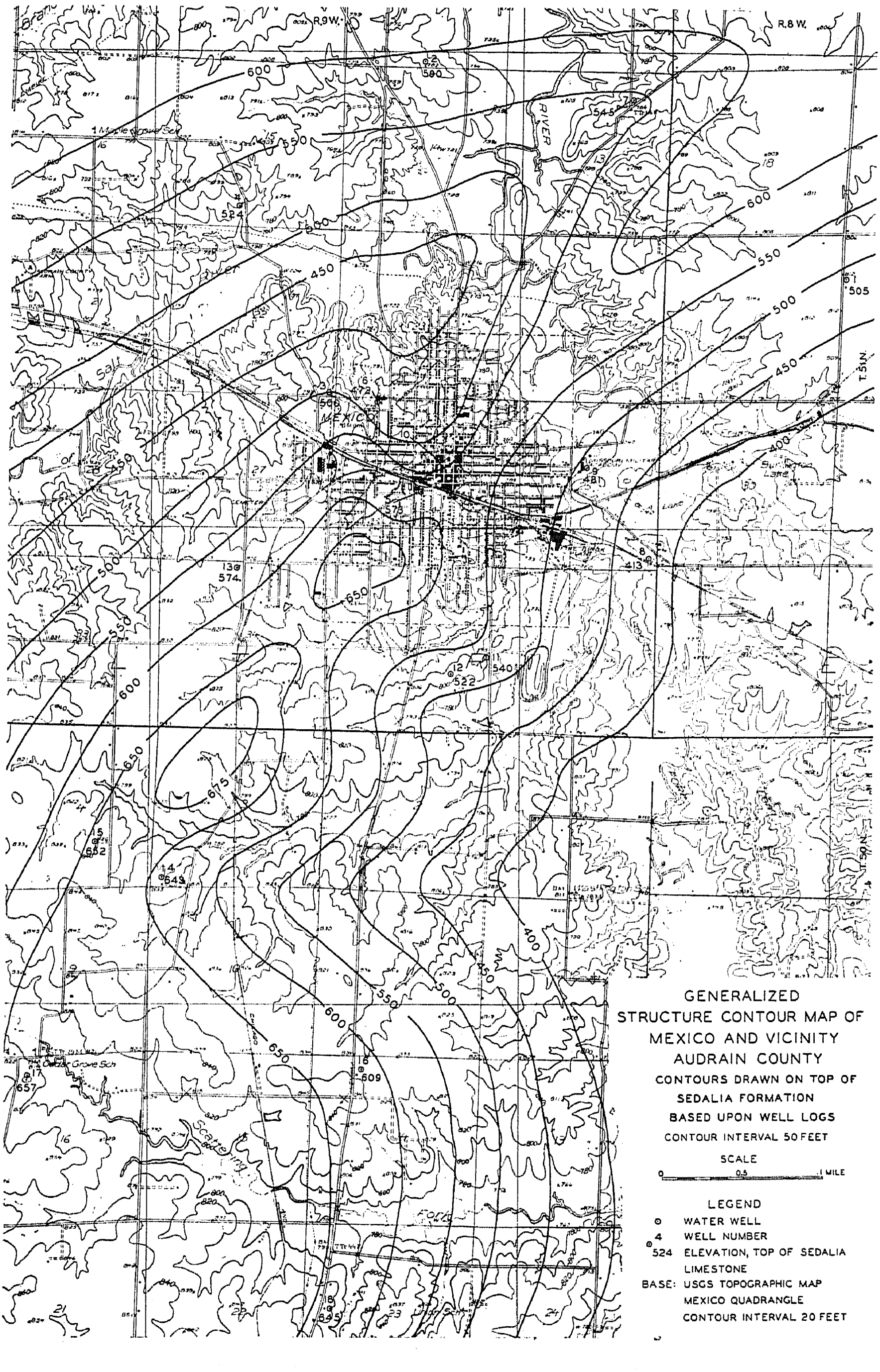
[70]Krey, Frank, Structural reconnaissance o fthe Mississippi Valley area, Mo. Bur. Geol. and Mines, Vol. XVIII, 1924.

[71]McQueen, H. S., Hinchey, Norman S., and Aid, Kenneth, The Lincoln fold, in Lincoln, Pike and Ralls counties, northeastern Missouri, Guide Book, 15th Ann. Conf., The Kansas Geological Society, pp. 99-110, 1941.

The west limits of the district cannot be precisely defined from a structural standpoint. However, a short distance beyond the west limits of the map accompanying this report, there is another regional anticlinal feature known as the Browns Station anticline. It does not appear to be of the same magnitude as the Lincoln fold with respect to amount of vertical uplift, extent, or width. It is, however, a large feature. Again the strike of the axis is northwest-southeast and, like the Lincoln fold, the southwest side is marked by steep dips in the strata. Faulting is known to occur in the vicinity of the Edwards-Conley Brick Company plant, sec. 8, T. 48 N., R. 12 W., at Columbia according to Moore,[72] and the faulting and general structural complexity of the Gillaspie School area, northeast of Columbia, Boone County, have long been of interest to the members of the faculty and the student body of the Department of Geology, University of Missouri. These areas are believed to be related to the same general line of folding on which the Browns anticline is situated.

Intermediate between the Browns anticline and the Lincoln fold are a series of parallel anticlines or upfolds and accompanying synclines. Unlike these two features, which are generally marked by satisfactory rock outcrops, the intermediate features are more or less obscured by a mantle of glacial drift, and expressions of them are reflected by water wells, which indicate abnormally high or low structural anomalies. One such feature has been reflected in the general vicinity of Laddonia, Audrain County. In the Lewellen farm well, NE¼ SW¼ sec. 11, T. 51 N., R. 7 W., glacial clay rests upon Mississippian, Burlington limestones, the normally intervening Pennsylvanian strata, including the Cheltenham fire clays being absent. Structurally this well is very high. Just east of this well the Cheltenham clays are present on the Kelly farm, NE¼ SE¼ SW¼ sec. 12, T. 51 N., R. 7 W., and further east along West Fork, Cuivre River and southeast of the Black School, NW cor. SW¼ SE¼ sec. 8, T. 51 N., R. 6 W., the Cheltenham clay and the associated strata are relatively close to the surface. The size and shape of this feature is not known. The regional structural features of the northern district are shown by the accompany-

[72]Moore, Geo. E., Stratigraphy of the northern half of the Columbia quadrangle, Boone County, Missouri, unpublished thesis, Department of Geology, University of Missouri, p. 56, 1938.


GENERALIZED
STRUCTURE CONTOUR MAP OF
MEXICO AND VICINITY
AUDRAIN COUNTY
CONTOURS DRAWN ON TOP OF
SEDALIA FORMATION
BASED UPON WELL LOGS
CONTOUR INTERVAL 50 FEET
SCALE
0 0.5 1 MILE
LEGEND
WATER WELL
4 WELL NUMBER
524 ELEVATION, TOP OF SEDALIA LIMESTONE
BASE: USGS TOPOGRAPHIC MAP
MEXICO QUADRANGLE
CONTOUR INTERVAL 20 FEET
R.9W.
R.8 W.
T.51N.
T.50N.
MEXICO
RIVER
Salt River
Maple Grove Sch
Cedar Grove Sch

ing geologic structure sections, Plates II, III, and IV. These have been prepared from well logs of record, by Garland B. Gott and the writer. In a few local instances outcrop data have been used, also.

The area in the vicinity of Rush Hill, Audrain County, also appears to be high and the Cheltenham clay should be relatively close to the surface.

There is also, a relatively high area in the vicinity of Gant settlement, SE¼ sec. 4, T. 50 N., R. 10 W., Audrain County, where the Graydon conglomerate and the underlying Burlington limestone are exposed in the valley of Davis Creek. The area of this feature is indicated on the accompanying map as a large one. However, more recent work would indicate that the area is actually smaller than that shown.

One of the most interesting features, that has resulted from the present investigation, is the presence of an anticlinal feature of considerable magnitude striking northeast-southwest, or approximately at right angles to the direction taken by the features previously described. The axis passes through the city of Mexico, in fact, the presence of this feature was first indicated by the logs of industrial water wells drilled in that city. A generalized map of this structural feature is presented in Plate XVI. It will be noted that the fire clay deposits worked at the A. P. Green Fire Brick Company in the SW¼ sec. 25, and the W½ sec. 36, T. 51 N., R. 9 W., are located on the east flank of this feature.

There are, no doubt, other folds of similar alignment in the northern district, but their presence will only be revealed by drilling. Several areas that appear to be structurally above or below normal are considered in the section devoted to suggestions and areas for prospecting. The Goss locality, Monroe County, is an example of a structural low. (Pl. XIV.)

A few brief remarks regarding the structural history of the district, as it affected the Cheltenham clays, are appropriate. The available evidence indicates that the northwest-southeast line of folding was first developed and recurrent movement took place along such lines until after the close of Mississippian time, when a notable period of uplift took place. In the weathering of the elevated areas, the chert which now makes up the Graydon sandstone was no doubt derived. Some of it may have been deposited later in the low or synclinal areas adjacent to the areas of uplift. A later period of folding involved the northwest-southeast line as is evidenced by the presence of formations of the Henrietta group in synclinal areas, southwest of the Browns anticline in the vicinity of Columbia and Fulton.

The date of the development of the northeast-southwest line of folding is not known. On the top of the feature described at Mexico, there was marked thinning of the Mississippian section prior to the deposition of the overlying Pennsylvanian rocks. The latter are also involved, thus indicating that movement on this axis also occurred during or after the close of Pennsylvanian time.

When the northern district is considered as a whole, it appears to have the form of a structurally high area, and in effect, that of a structural plateau. The statement is made in spite of the two regional features previously described, namely, the Lincoln fold and the Browns anticline. To the east of the former is the Illinois basin, and to the west of the latter, particularly along its northwest projection is a portion, at least, of the Forest City basin. Certainly in both basins Pennsylvanian formations older than the Graydon formation occur, an indication that deposition was going on, while the northern district was either then a land surface, or else was being stripped of sediments almost as rapidly as they accumulated.

Throughout this report reference is made to shallow pocket-like, sink-hole type depressions in which the lower Cheltenham clay particularly is found. These structures are local. Their relation to the regional features is not fully known, but they may have been developed by action of ground water on the relatively soluble Burlington limestones, along planes of weakness, associated with the major structural features. The fact that the "rolls" or "horsebacks" have a northwest-southeast trend, suggests some connection with the regional folds having the same direction.

MINING METHODS.

The Cheltenham clay in the northern district is obtained from open pits and shaft mines. In the earlier history of the district, the shaft mines were used almost exclusively, but with the development of equipment capable of large scale stripping operations, many large open pits have been developed, those at Mexico, Audrain County, and Wellsville, Montgomery County, being examples.

In underground operations the room and pillar system is used. In areas where a considerable thickness of rock overlies the clay being mined, it is necessary to timber closely in order to hold the roof. In some main entries retimbering at frequent intervals is necessary due to the crushing of the timbers by the subsidence of the roof. One of the most difficult problems encountered in underground mining is presented by the "rolls" or "horsebacks" in the conglomerate floor. These rolls often have a relief of 20 feet or more. In order to maintain the proper grade and in order to reach the accompanying clay filled depressions, it is necessary to drive through the hard chert ridges, the expense adding considerably to the cost of mining. The mineable clay is often thin over the "rolls" and it is necessary to take also some of the clay above the Cheltenham, which is wasted, or as in the case of the blue "dry mill", used only to a limited extent.

In open pit mining, small-sized churn drills are used to drill holes into the overburden, which consists of glacial clay, shale, limestone, black slate, and coal. The maximum thickness being moved is about 70 feet. The overburden is then shot down and loaded by power shovels of varying sizes into dump trucks and hauled to the point of disposal.

The surface of the clay is finally cleaned by tractor drawn scrapers to remove the remaining material. In the case of the pocket-like depressions of green, high alkali, "poison" clay hand cleaning is resorted to in order to remove completely such objectionable material.

The following table prepared by Bradley and Miller,[73] presents the total cost of stripping as well as the cost of the individual items thereof.

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[73]Bradley, R. S., and Miller, B. K., Prospecting, Developing, and Mining semiplastic fire in Missouri: Amer. Inst. Min. and Met. Engrs. Mining Technology, Technical publication, No. 1328, p. 7, July, 1941.

Table 8.—Breakdown of Stripping Cost per Cubic Yard Bank Measurement.

Item	Loading: 1½-yd. Lima Diesel-powered shovel	Hauling: 4 to 5-yd. Hug trucks (end dump)	Dumping: Bulldozer, motor patrol and dumpman	Total
Labor	$0.00934	$0.0196	$0.0092	$0.03814
Oil, grease and gas	0.00376	0.0119	0.0043	0.01996
Insurance, compensation and Social Security	0.00097	0.0012	0.0005	0.00267
Equipment depreciation	0.02500	0.0350	0.0034	0.06340
Maintenance, repair and miscellaneous	0.00780	0.0086	0.0048	0.02120
Total	$0.04687	$0.0763	$0.0222	$0.14537

Shot holes are drilled into the clay, with auger type drills and the clay is blasted down and loaded by hand, where careful selection is desired, or by power shovels. Trucks are used to transport the clay to the plants or to loading points located on railroads.

Bradley and Miller[74] have given some interesting figures on mining costs in open pit operations and have shown that with a certain crew and equipment the total cost is .33 to .37 cents per ton, delivered at the plant located near the mine.

PROSPECTING METHODS.

Prospecting for the Cheltenham clays in the northern district has undergone changes in the last few years, and is now on a more scientific basis.

In former years, a clay deposit might have been opened as a result of an outcrop or the drilling of a water well, or discovered in mining coal. It soon became apparent, however, that the Cheltenham formation was a more or less continuous deposit and would be found over a large area in east-central Missouri. If there were no variations in the quality and thickness of the clay, there would be no need for detailed prospecting. As pointed out in this report, however, such variations do exist and prospecting must be resorted to.

[74] Op. cit., p. 9.

In recent years the diamond drill has been used almost exclusively for prospecting. Various types of bits are used for existing conditions, and those in common use in the Audrain County portion of the district have been enumerated by Bradley and Miller.[75]

> "Large fish tail, for drilling through soil and glacial drift.
> Small fish tail, for cleaning out casings.
> Tungsten carbide, for drilling soft clays and shales.
> Black carbon (diamond), for hard clay and rock.
> Bortz (white diamond), for drilling hard clay and rock.
> Sawtooth (stellited points), for shales, broken limestone, flint conglomerate, and where subjected to severe shock and chattering."

In areas where the overburden is not excessive in thickness, nor contains excessive thicknesses of limestone or other rock, the power auger has been used. A type in common use is the Parmanco, which operates on the rotary principle, the bits being a fish tail-auger type. As depth is desired additional sections of the auger are added at the top. Considerable speed is obtained with this type drill. No water is needed in this type of drilling which is an advantage. Such a drill is adopted for preliminary prospecting under the conditions enumerated. For detailed prospecting and for the collection of samples for testing, the diamond drill with the core samples obtained thereby, is probably most satisfactory. A combination of the two types of drill have been used, however, in the prospecting of some areas.

SUGGESTIONS FOR PROSPECTING.

The description of the Cheltenham fire clay bearing formation has indicated that it is a complex unit, and one variable in make up, irregular in thickness, and also irregular in the distribution of the three component members. If these variations did not occur, no prospecting would be necessary, and the discovery of a clay deposit would be a simple matter. This is certainly not the case as the variables mentioned will attest.

In the preparation of this report attention and thought has been given to the matter of prospecting, not the mechanical

[75] Op. cit., p. 5.

side or the problems of type and nature of drilling, but rather geological clues that would possibly be of some aid in locating additional deposits. The following comments may therefore be of some interest.

The most desirable and refractory clay is that found in the lower member of the Cheltenham formation. As previously described, it occurs as more or less isolated or spotty deposits, the clay filling depressions or sink-like structures. Those observed to date, in the area underlain more or less continuously by the Cheltenham formation, are of no great size, and the deposits of flint fire clay marginal to the main Cheltenham area and probably the correlative of the lower member are likewise small.

It is therefore apparent that prospecting for such deposits might be in the nature of a hit or miss proposition. Due to "rolls or "horsebacks" of Graydon chert conglomerate between which the clay of the lower member thickens, an underground mining problem, in the form of maintenance of grade and at the same time the mining of all of the clay, is presented. It cannot be done, although in some instances a considerable amount of the clay is recovered.

It is obvious that the only method of mining that will permit complete recovery, as well as careful selection of all clay in such depressions, is from an open pit. Therefore, in considering the problem and the areas for prospecting, the factor of the overburden is the first one to consider.

It appears that the overburden is less over the crests of the larger upfolds or anticlines, and it is also evident that thinning of the individual formations may be expected over them, also. This is also true of the clays of the Cheltenham formation. As pointed out previously, a period of uplift and erosion may have intervened between the deposition of the lower member and the middle member of the Cheltenham clay. Therefore, the possibilities of finding large, thick bodies of the lower clay on the crests of the larger anticlines are considered to be limited.

It would therefore seem to follow that the best possibilities for finding large bodies of this clay would be in the accompanying downwarped synclinal areas. This is probably true. It should be remembered, however, that the regional ground water table in the synclinal areas may have been such as to have prevented any large scale or thorough leaching of the clays, and consequently, the quality might not be of the best.

The writer suggests, therefore, that the flanks of these anticlines, a number of which have been described in the chapter related to structure, be prospected for the best deposits of the lower clay member. The relation of an area to an anticline can be determined by the altitude of any given geological unit, of which there are many in the formations of the Cherokee group. Elevations and specific locations of each prospect hole should be obtained and the data used in the preparation of a structural contour map.

In this connection a few hints are suggested. A thin section of Pennsylvanian formations with some of them absent or unusually thin would be evidence of the presence of a structural high. Also the comparative elevation of the top of the easily determined Graydon conglomerate might also be useful. In the use of the latter, the sink hole like structures might cause some local variation, but this trouble would not be so pronounced in a regional program. Having established a favorable area for the possible occurrence of the lower clay, it will be necessary to resort to close drilling to prove its presence. In such drilling sharp local variations in the Graydon chert conglomerate floor will be significant and helpful.

The problem of finding a satisfactory deposit of the middle member is not as difficult. There are, however, certain conditions that make for poor quality clay in this member. Probably the most troublesome impurity is quartz sand. It occurs quite often in the basal few inches of the member, and again in that portion of the clay immediately adjacent to the "horses" or elevated masses of the Graydon formation. In neither instance, however, is the presence in such amounts as to cause the wasting of any appreciable amount of clay in mining operations.

The main problem and trouble from sand is obtained where the grains are embedded in, and thoroughly disseminated in fairly large quantities throughout the clay mass. An example may be cited. In the large strip pits operated in the vicinity of Mexico the middle member of the Cheltenham is usually free from sand. North of that city about four miles in the extreme northeast corner of sec. 2, T. 52 N., R. 9 W., there is an excellent exposure of the middle Cheltenham, but unfortunately it is too sandy on the whole to be useable. This may represent a local condition, but on the other hand the writer believes that more sandy clays occur in the area adjacent to the axes of the regional anticlines, and sand derived from these features, some of which stood out as islands during the deposition of at least a part of the clay, was deposited along with the clay.

The same conditions that have been described for the lower clay member may prevail for the middle member in synclinal areas, namely, the conditions for leaching may not have been favorable. Thus a position or an area intermediate between the structural highs and the lows is again suggested.

The problem of prospecting for the upper plastic clay member of the Cheltenham is the simplest one of all. It quite obviously is thin or present only as small isolated masses in the area adjacent to and down the flanks of the regional anticlinal structures. Just as obviously, it is present as a more continuous and thick deposit in the synclinal areas. Excellent examples may be cited by the occurrence in a syncline in the Goss locality (Pl. XIV), Monroe County, in the syncline south and southwest of Fulton, the Weatherall and Lammers pits being examples; under the same conditions just east of Columbia, at the Edwards-Conley Brick Company plant; and in a very obvious and pronounced low in the vicinity of the Robertson pit, NW¼ NW¼ sec. 3, T. 49 N., R. 7 W., Callaway County, south of Martinsburg.

In the cuttings from the Dixie Inn well, in the SE cor. sec. 25, T. 51 N., R. 9 W., on U. S. Highway 54, just east of Mexico, what appears to be a good development of the upper member is indicated by the cuttings. It is interesting to note that this well is located in a fairly deep synclinal area east of the northeast-southwest trending anticline, which has been described as passing through the city of Mexico (Pl. XVI).

From the foregoing, it would appear logical to use the upper member in interpreting the structural conditions prevailing in an area. The absence of this clay over anticline features and its presence in downwarped or synclinal features may well be remembered in prospecting.

Prospecting for pocket-like deposits of flint fire clay, and occasionally associated semi-flint and plastic fire clays in the areas marginal to the Cheltenham formation presents a somewhat different problem. As a rule such deposits are overlain by a thin veneer of surface clay and chert gravel, and the lack of surface expressions is a retarding factor in their discovery. The rapidly increasing use of the auger-type rotary drill, however, will result in finding many additional deposits even in an unsystematic program of prospecting.

What should be done or what guides should be used in order to eliminate such haphazard prospecting methods? The use of the map accompanying this report is suggested. A study of it reveals a considerable concentration of marginal flint fire clay deposits in certain areas; among them may be mentioned the Hams Prairie, Toledo, Reform, and Readsville localities in Callaway County; the Americus locality, which is probably a part of the Readsville; the extensive area in the vicinity of New Florence and High Hill in Montgomery County; the Jonesburg locality in Montgomery and Warren Counties; and the extensive area south and southwest of Warrenton, and a smaller area near Wright City in Warren County. The concentration of these pits is not an accident, nor is their presence a testimony to the energy and keen observation of the clay hunter, even though many of them were found by observing some surface expression.

Because of the relative small size of the deposits, these localities should be drilled closely and in a systematic manner. Elevations of the surface of each hole and its location should be plotted. The elevation of the rock surface should be recorded, and with such systematic work a structural pattern could well be evolved that would lead to other deposits. The fact that the "horsebacks", which separate the clay in the main area of the Cheltenham formation are aligned in a northwest-southeast direction, should be kept in mind as the same thing should be true in connection with the marginal deposits. After all they are the uncovered remnants of the lower Cheltenham clay, which are overlain within the main area by the middle and upper clay members, as well as younger strata.

In the discussion of prospecting for the lower Cheltenham clay in the main area, the suggestion was made that in the deeper portions of the synclinal areas the clay was possibly not as thoroughly leached as it would be on the flanks. The marginal deposits, however, may be an exception to this statement. The concentration of these deposits is such as to suggest structural control. Although detailed field studies of the conditions have not been possible, there is a suggestion that the occurrence is in the deeper portions of synclinal areas. It should be remembered that in the area marginal to the southern limits of the Cheltenham, the formations are rising to the southeast toward the general area known as the Ozark uplift. It is quite possible the deposits have been more favorably situated for leaching than the same deposits down the dip, and it is also quite possible that they have been subjected to leaching over a longer period, because of their updip position, the regional thinning of the overlying strata above them, and the magnification of the separating unconformities.

The suggestion of synclinal occurrence can be checked. (1). Are the deposits around any particular area small? (2). Are the deposits in the middle of such areas larger and deeper? (3). Does the Graydon chert conglomerate have a generally lower elevation in the center of the areas of concentration of suggested areas for prospecting?

Where to prospect is a question that is often asked. The answer, insofar as the marginal deposits are concerned, has been given, and the areas of concentration described and shown on the map. The following areas might be worthy of consideration in prospecting for Cheltenham clays. The use of the clay map (in pocket) will be particularly helpful in this connection.

Audrain County:

1. The area lying on the east and west flanks of the anticlinal feature shown in Plate XVI, and along its projected axis to the northeast and southeast.

2. In the triangular area lying south of the Wabash and Alton Railroads between Mexico and Centralia; from Centralia to the Gant locality (T. 50 N., R. 10 W.), and from the Gant locality to Mexico.

3. In the vicinity of Rush Hill, NE¼ T. 51 N., R. 8 W., and the NW¼ T. 51 N., R. 7 W., and the adjoining portions of T. 52 N., Rs. 7 and 8 W.

4. In the vicinity of the town of Laddonia, and particularly along west fork of Cuivre River in the sections 16 and 21, T. 51 N., R. 6 W., and the area to the east to Hickory Creek.

MISSOURI BUREAU OF GEOLOGY AND MINES

H. A. Buehler, Director

RECONNAISSANCE GEOLOGIC MAP

of

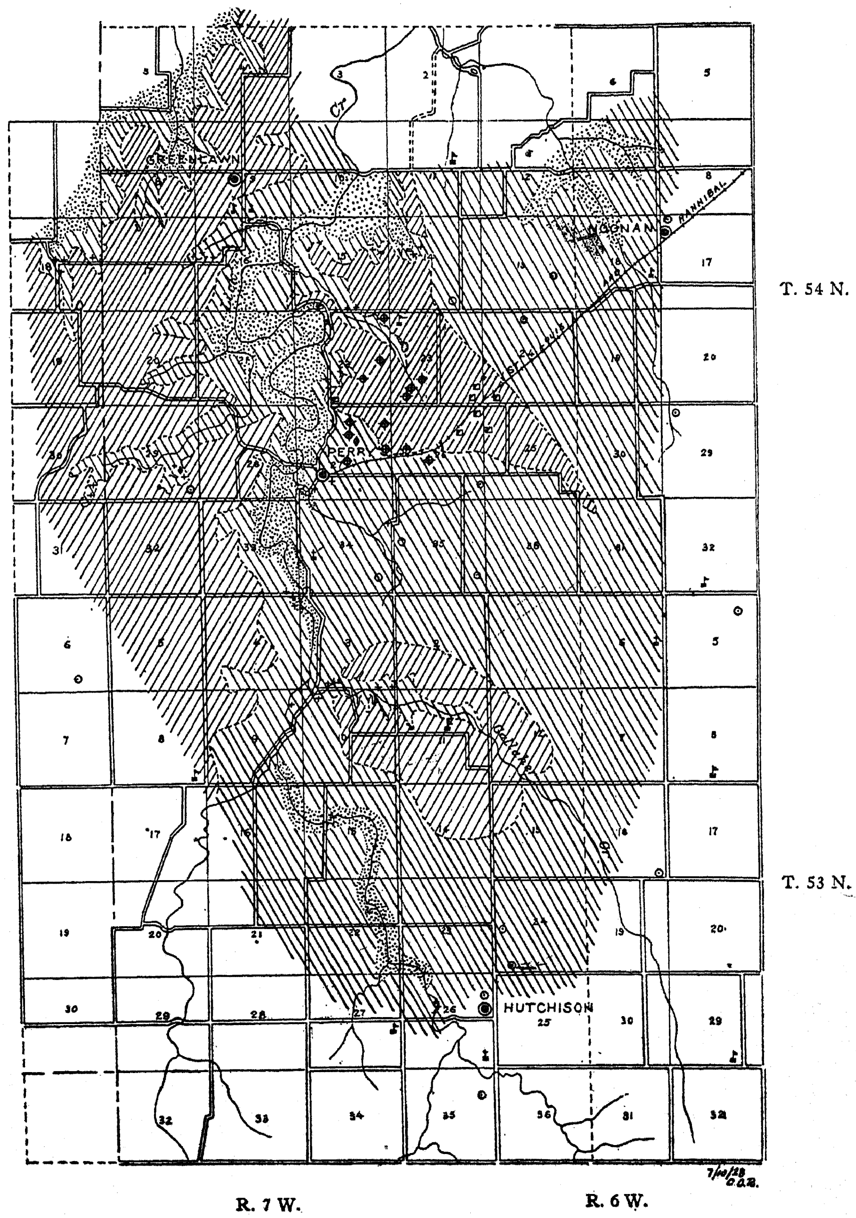
AREA IN VICINITY OF PERRY, RALLS CO., MO.,

by

H. S. McQueen

LEGEND

- Indicates rocks and glacial clays overlying 22-26 inch coal. Also indicates areas underlain by this coal.
- Approximate belt of outcrop of 22-26 inch coal.
- Rocks underlying 22-26 inch coal. In general outlines area underlain by Cheltenham fire clay.
- Burlington limestone.
- Observed outcrop of Cheltenham plastic fire clay.
- Observed outcrop of flint fire clay.
- Slope and shaft mines.
- Deep wells. No coal reported.
- Diamond drill holes



Boone County:

1. In the synclinal area east of Columbia from the Edwards-Conley Brick Company plant, NE¼ SW¼ sec. 8, T. 48 N., R. 12 W., northeast along Hinkson Creek to a point near area of coal strip in SW¼ NW¼ sec. 26, T. 49 N., R. 12 W.
2. Area of flint fire clay outcrop, Turner farm, sec. 17, T. 48 N., R. 12 W., Boone County.

Callaway County:

1. In the ridge area between Youngs Creek and Middle River centering around the common corner of Ts. 46 and 47 N., R. 9 and 10 W.
2. The area northwest of Fulton contiguous to Stinson Creek.
3. The area extending south from U. S. Highway 40 through the extreme east part of T 48 N., R. 9 W., the extreme west part of T 48, R. 9 W., and northwest part of T. 47 N., R. 8 W.
4. The Bachelor locality in T. 49 N., R. 8 W.
5. The Shamrock locality in T. 49 N., R. 7 W.

Lincoln County:

1. In the Whiteside locality additional sink-hole type deposits may be expected in the locality shown on Plate XV.
2. In the ridge area, southeast of Olney and lying between Lead Creek on the north and Cuivre River on the south, pocket-like deposits of flint clay should occur.

Monroe County:

1. In the Goss locality shown on Plate XIV.
2. In T. 55 N., R. 8 W., in the vicinity of Clapper and Stoutsville.

Montgomery County:

1. Around the margins of the Cheltenham formation in T. 49 N., R. 6 W.
2. Around and back from the margins of the Cheltenham as outlined, from Middletown to Gamma to Buell to the vicinity of Bellflower.
3. North and east of New Florence, T. 48 N., R. 5 W.

Pike County:

1. In the vicinity of Gazette, T. 51 N., R. 4 W.
2. In areas marginal to the Cheltenham clay as outlined on the accompanying map small deposits of flint clay may be expected.

Ralls County:

1. The area north and east of Perry, designated on Plate XVII as underlain by 22-26 inch coal.
2. The area south of Perry in secs. 2, 3, 10 and 11, similiarly designated.

Warren County:

1. Pocket-like deposits of flint clay should occur north and west of Jonesburg.
2. A similar clay should be found in pockets in the uplands west and north of Warrenton.

CHAPTER III

THE SOUTHERN DISTRICT.

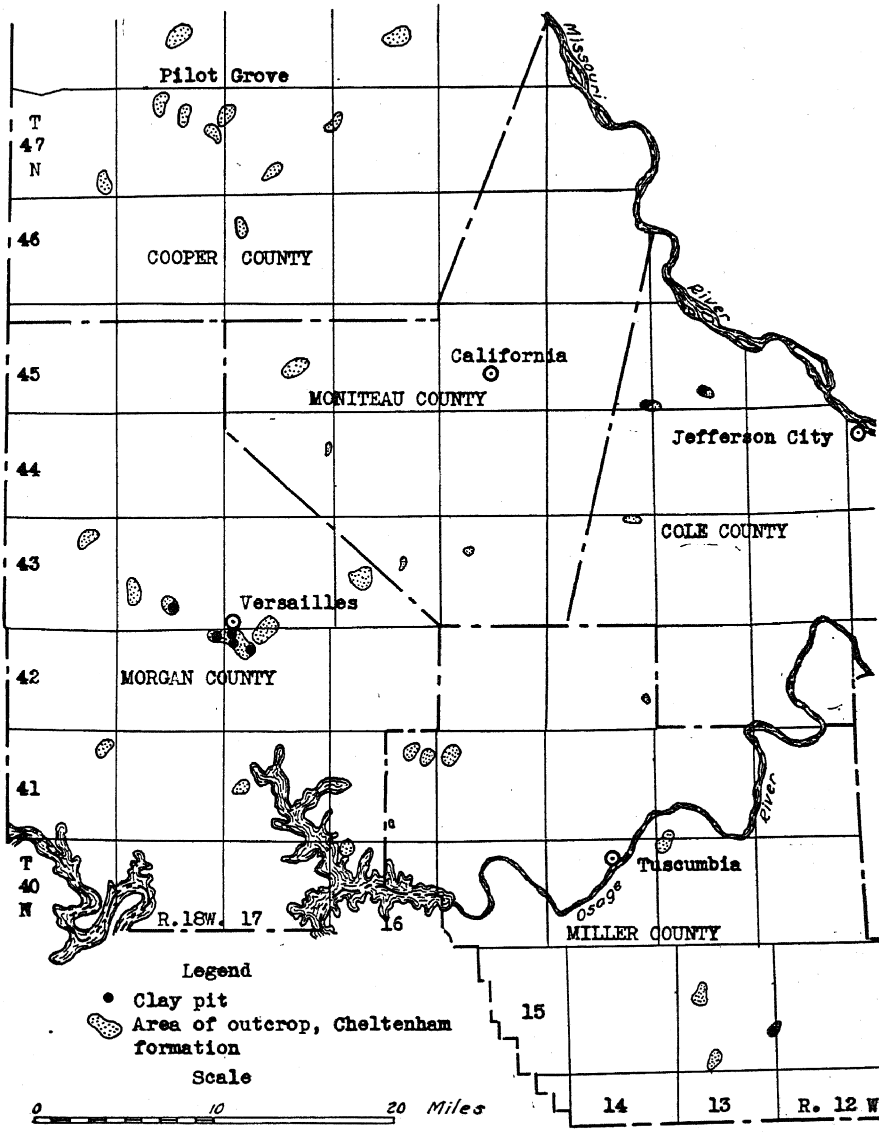
Geography. The southern district lies south of the Missouri River, and in the north central Ozark region (Fig. 1). Clay mining is the most important mineral industry and operations have been carried on in Crawford, Franklin, Gasconade, Maries, Osage and Phelps Counties. Some clay has also been found in a small related sub-district, which lies to the west in Morgan, Miller, Moniteau, and Cole Counties.

This district is served by an excellent system of State and Federal highways, the most important ones being shown on the map accompanying this report. A large tonnage of clay is hauled annually by truck from the southern district to fire brick plants in the northern district.

Three railroads serve the district and important shipping points are located on them. The southern edge of the district is traversed by the St. Louis-San Francisco (Frisco) Railroad, and shipping points are Rolla and St. James in Phelps County, and Cuba and Hofflins in Crawford County. The Chicago Rock Island and Pacific Railroad (Rock Island Lines) traverses the central portion of the district from east to west and the more important clay shipping points on it are Belle, Maries County; Bland, Canaan, Owensville, and Rosebud, Gasconade County; and Gerald and Leslie, Franklin County. The Missouri Pacific Lines skirt the northern boundary of the southern district and a large tonnage of clay is shipped over it annually from Hermann, Gasconade County. Some clay has also been shipped from Hermann by barge on the Missouri River.

There are no fire-brick plants in the southern district. One plant devoted to the grinding of flint fire clay is located at Owensville. Many years ago a plant for calcining flint fire clay was erected east of Gerald, Franklin County, on the Rock Island Railroad, but it has not been operated for many years.

In addition to the counties mentioned above, there is a small sub-district in which flint and semi-flint clays occur in the same manner as in the southern district, in sink-hole type deposits usually lined with sandstone. This sub-district lies west of the main district, the Osage River separating the two. The clays are known to occur in Cole, Miller, Moniteau, and Morgan, and possibly Cooper and Pettis Counties.



Map showing outliers of Cheltenham clay and location of pits in Morgan, Miller, Moniteau, and adjoining counties.

In this sub-district the deposits appear to be comparatively small in size and on the average shallower in depth than in the main district, which lies to the east. No diaspore clay has been found nor has the writer ever noted the presence of burley clay. The flint fire clays are exactly similar in physical and chemical composition, and the mode of occurrence, a similar topography, and similar general geologic relationships attest to the close connection with the main district. It seems obvious that it was a part of the latter, but has been separated from it by subsequent geological events.

A number of deposits have been worked and at one time the clay was processed in a fire-brick plant at Versailles, Morgan County. The location of the known deposits and the general area in which they occur are indicated on the accompanying map (Pl. XVIII).

The southern district lies in that portion of the north central Ozark region underlain by the Graydon formation, which is the basal formation of the Pennsylvanian period. This formation, or the members thereof, as shown by the blue color on the accompanying map (in pocket) is rather widespread throughout portions of the following counties: Crawford, Franklin, Gasconade, Maries, Osage, and Phelps Counties. The main area measures about 50 miles in a north-south direction and about 67 miles in an east-west direction. In addition small areas containing local and comparatively small deposits of fire clays are found in Cole and Morgan Counties and other counties mentioned.

In the southern district the clays are flint fire clay, burley, and diaspore clays with small amounts of semi-plastic and plastic clay, all of which occur in inverted cone-like, sink-hole type deposits of varying size and depth. Sandstone of the Graydon formation lines the deposits in part and forms the "rim rock". The aluminous burley and diaspore clays do not occur in all the deposits, and where found appear to be a gradational product resulting from the alteration of flint fire clay through the chemical action of circulating ground water. The sink-hole type deposits form "natural leaching pots" for such a process of alteration.

Topography.. The southern district lies in the north central portion of the Ozark region. The topography is characterized by deeply intrenched, meandering major streams, with narrow divides or broad uplands between them. The master streams of the district are the Gasconade and Bourbeuse Rivers, the former cutting through the northwest portion and the latter through the southern portion of the district.

The Missouri River bounds the northern limits, the Meramec River the southern limits, and the Osage River the extreme northwestern limits of the district, separating it from the small sub-district previously described. The topography would be classed as rough in the areas adjacent to the master streams. The upland areas, however, are gently rolling, the area north and east of Vichy, Maries County, being a characteristic example. The topographic relief measures approximately 700 feet. The highest elevation, nearly 1200 feet is found near Rolla, Phelps County, while the lowest elevation, approximately 500 feet is found in the Missouri River valley near Hermann, Gasconade County.

The area is almost completely covered by up-to-date topographic maps (Pl. I). These have been prepared by the United States Geological Survey in cooperation with the Missouri Geological Survey. The available topographic maps may be obtained from either agency. It is planned to continue the topographic mapping program until this important area is completely covered by up-to-date quadrangles.

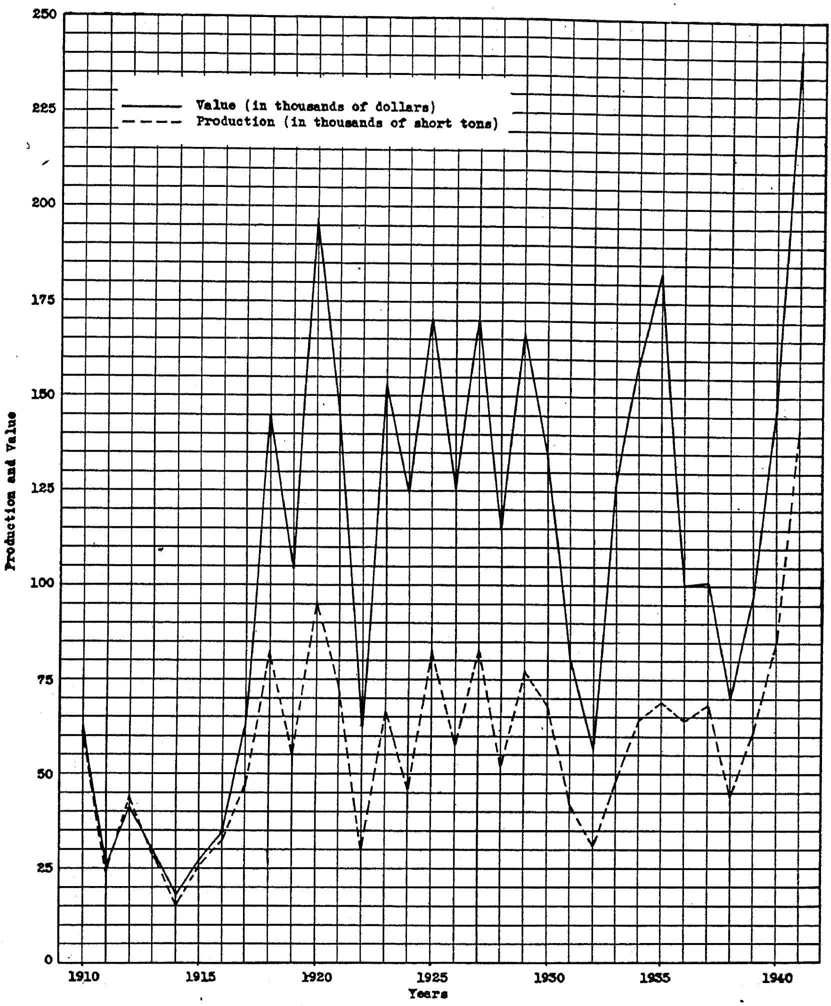
PRODUCTION OF CLAYS.

Although flint fire clay[1] was first mined in the southern district in 1882, the records covering the annual total tonnage and value do not appear to be available before 1910. Since that time the Missouri Geological Survey, in cooperation, at different periods, with either the United States Geological Survey or the United States Bureau of Mines, has collected the statistics of production. The first figures available for the annual output of flint fire clay are for the year 1910.

The history of the use of diaspore and the first production of the material have been described elsewhere in this report, and it appears to have been well known by 1918. However, the first production figures were not reported until 1922.

Table 9 presents the statistics of production insofar as the figures are available. It contains some interesting figures, which

[1]Wheeler, H. A., Clay Deposits of Missouri, Mo. Geol. Survey, Vol. 12, 1st Ser., p. 228, 1896.



Curves showing production and value of flint fire clay, southern district, 1910-1941.

are further summarized graphically in Plates XIX and XX. The increased use of flint fire clay during the latter stages of the first World War is reflected as was the stimulated production during 1928 and 1929. The demand for all types of clays is also reflected by the figures for 1940 and 1941, the increased production being directly related to the demand for fire brick used in the many industries now wholly devoted to the war effort. It is believed the current year, 1942, will be marked by the highest production figures in the history of the area. Certainly there has never been a time when the demand for the clays was greater, or the search for new pits more intensive. Plate XX also reflects the strides made by ceramists in perfecting refractories made of diaspore clay, and it also reflects, in the increased figures of production, the acceptance of such refractories by various industries.

TABLE 9.

Production of Flint Fire Clay and Diaspore Clay, 1910-1941.

	Flint fire clay		*Diaspore clay*	
Year	*Short tons*	*Value*	*Short tons*	*Value*
1910	61,674	$62,808		
1911	23,530	24,653		
1912	43,600	41,170		
1913	29,070	29,547		
1914	16,265	17,995		
1915	26,364	26,800		
1916	32,521	34,966		
1917	47,053	63,005		
1918	82,701	144,578		
1919	56,321	104,186		
1920	95,817	197,418		
1921	72,738	146,113		
1922	30,205	63,342	14,396	$55,980
1923	67,135	152,662	10,507	51,595
1924	46,049	124,163	9,131	45,548
1925	82,852	170,637	15,115	100,052
1926	57,815	125,827	15,983	71,978
1927	82,752	170,455	37,620	204,443
1928	51,818	115,465	30,126	149,430
1929	76,707	166,876	67,171	323,181
1930	68,400	135,565	40,258	183,060
1931	42,110	80,709	19,341	98,078
1932	30,772	56,655	5,726	32,597
1933	47,701	127,037	11,804	53,342
1934	63,653	158,278	19,659	100,788
1935	68,955	183,498	23,243	104,197
1936	64,048	100,392	33,580	150,353
1937	68,541	100,769	49,062	242,641
1938	43,810	69,919	33,055	149,656
1939	61,400	97,269	40,050	173,037
1940	84,726	147,637	33,862	153,079
1941	140,612	242,457	78,884	402,913
Total	1,867,715	$3,482,851	588,573	$2,845,948

With the increased demand in 1942 for flint, burley, and diaspore clay, the production is reasonably expected to exceed the record breaking figures of 1941. In this connection it should be remembered that the present rate of consumption greatly exceeds the present rate of discovery and as a result reserve supplies are being mined. If this situation continues, then it becomes evident that prospecting must be accelerated, and that it must be conducted on a different and probably more detailed and systematic basis. Consequently the cost will be increased, and finally the ultimate cost of mining the various clays will be, likewise.

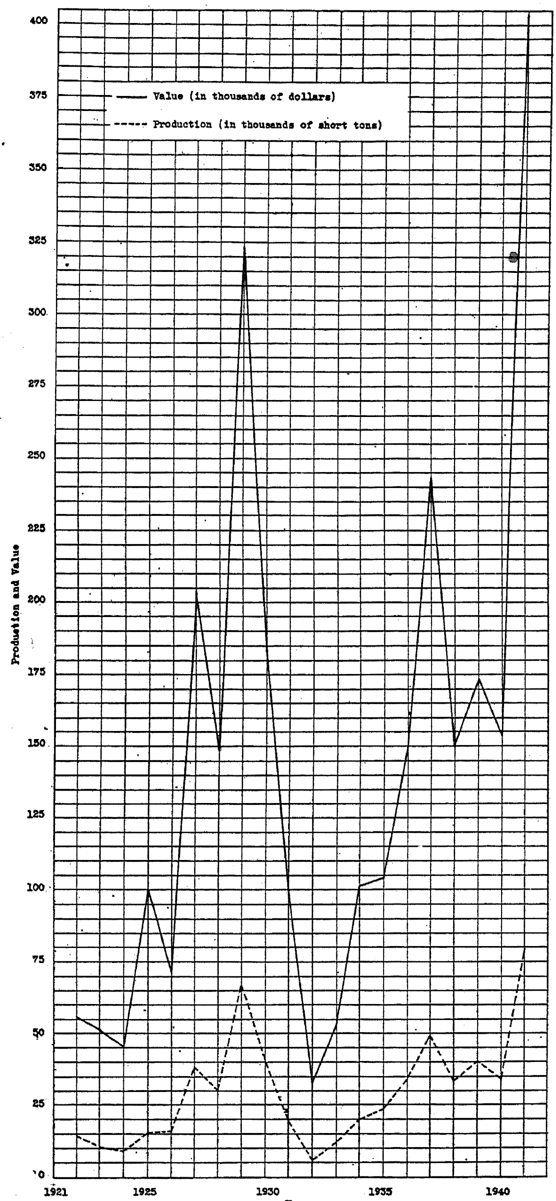
Table 10, page 125, also presents the production of flint and diaspore clay in the counties making up the southern district. These figures are presented along with the number of pits of record found in each county and the type of clay found in them. These tables might reflect, in a very general way, the number of pits that might be discovered in each county in the future.

GEOLOGY OF THE SOUTHERN DISTRICT.

STRATIGRAPHY.

Introduction. The clays in this district are also found in the lower part of the Cherokee group of the Pennsylvanian system, and although differing in mode of occurrence, they may be correlated on the basis of geologic position and character of certain clays with the Cheltenham clay formation of the northern district, and with the same clay in the St. Louis area. The basal member of the Cherokee group of this district is the Graydon formation, a widespread chert conglomerate and sandstone, which rests upon the bevelled edges of a number of pre-Pennsylvanian formations. The normally overlying Cheltenham clay formation, however, is less widely distributed and its occurrence is limited to pocket-like or sink-hole type deposits, which in effect are remnants of the once more extensive and blanket-like deposit.

Pre-Pennsylvanian Formations. The rocks beneath the Pennsylvanian formations consist of a series of dolomite, chert, sandstone, limestone, shale, and quartzite and range in age from the Cambrian to and including the Mississippian. The contact of the Pennsylvanian and the oldest formations is in the south part, and with the youngest formations in the north



Curves showing production and value of diaspore clay, 1922-1941.

TABLE 10.

TABULATION OF POTENTIAL CLAY AREAS, NUMBER AND KIND OF PITS DISCOVERED TO DATE, AND TOTAL PRODUCTION REPORTED TO 1941, BY COUNTIES.

County	Number of square miles underlain by Penn-sylvanian formations*	Number of flint fire clay pits	Number of pits containing diaspore and burley clay in addition to flint fire clay	Total number of pits known to writer	Percentage of diaspore and burley clays to total number of pits	Total production of diaspore, 1922-1941		Total production of flint fire clay, 1910-1941	
						Tonnage	Value	Tonnage	Value
Crawford	65.7	8	13	21	60.4	1,230	$5,365	9,202	$17,560
Franklin	90.5	48	11	59	22.9	24,127	94,896	214,818	425,369
Gasconade	207.1	234	153	387	42.1	377,948	1,744,268	1,461,546	2,700,212
Maries	95.4	34	37	71	52.1	113,416	498,564	69,303	133,833
Osage	110.0	101	82	183	44.8	33,090	196,015	36,494	88,929
Phelps	57.5	17	13	30	43.8	42,148	179,002	76,434	117,051
Totals	623.0*	442	309	751	41.4	591,959	$2,718,110	1,867,797	$3,482,954

*Determined by planimeter, from map of east central Missouri, which accompanies this report.

part of the district (Pl. III and IV). The following formations are present in ascending order ranging in age from the oldest to the youngest:

Cambrian System:
- Bonneterre dolomite
- Davis formation
- Derby-Doe Run dolomite

Ozarkian System:
- Potosi dolomite
- Eminence dolomite
- Van Buren dolomite with Gunter member at base
- Gasconade dolomite

Canadian System:
- Roubidoux formation
- Jefferson City formation
- Cotter formation

Devonian System:
- Grand Tower quartzite
- Callaway limestone

Mississippian System:
- Burlington (?) and other (?) formations

These formations have been described in detail in several publications[2,3,4,5,6] of the Missouri Geological Survey or the Missouri Bureau of Geology and Mines as it was formerly designated. The distribution of the pre-Pennsylvanian is shown on the State Geological Map,[7] either as formations or combined with other formations to form a single unit. The use of that map is suggested in any regional consideration of the geology.

Cambrian System. The Upper Cambrian rocks appear to be restricted to one locality, that one being near Wesco, southern Crawford County, in the extreme southern portion of this

[2]Lee, Wallace, The geology of the Rolla quadrangle, Mo. Bureau of Geology and Mines, Vol. 12, 2nd Ser., 1913.

[3]Dake, C. L., The sand and gravel resources, Vol. 15, 2nd Ser., 1918.

[4]Weller, Stuart and St. Clair, Stuart, The geology of Ste. Genevieve County, Vol. 22, 2nd Ser., 1928.

[5]Dake, C. L., The geology of the Potosi and Edge Hill quadrangles, Vol. 23, 2nd Ser., 1930.

[6]Bridge, Josiah, The geology of the Eminence and Cardareva quadrangles, Vol. 24, 2nd Ser., 1930.

[7]State Geological Map, Missouri Geological Survey, 1939.

district. Hughes,[8] as the result of a study of a complexly folded and faulted area in sections 17, 18, 19, and 20, T. 36 N., R. 4 W., has determined the presence of the Bonneterre dolomite and the Davis shale at the surface. Representatives of the Derby dolomite, which overlies the Davis and the succeeding Doe Run dolomite are possibly present also.

The Bonneterre is represented by gray, finely crystalline, non-cherty dolomite. Green shale is locally present, and sand is an important constituent in the basal beds. The thickness of the formation as determined by drill records is usually about 300 feet. The highly disturbed condition of the formation, however, precludes any measurements in the Wesco area.

The Davis formation consists of greenish gray shale interbedded with dolomite, sandy dolomite, and locally sandstone. Exposures are not particularly good and measurements of the thickness in the Wesco area are impossible. Deep wells within the district show the thickness to be approximately 200 feet.

Two formations, the Derby and Doe Run, of upper Cambrian age follow the Davis. They may outcrop in the Wesco area, but if so, they were not recognized by Hughes. Deep wells within the district show these formations to have a combined thickness of about 60 feet.

Ozarkian System. In 1911, E. O. Ulrich[9] revised the Paleozoic systems and separated a number of formations from the Upper Cambrian of former definition and placed them in a system to which he applied the term Ozarkian. The formations in ascending order may be described as follows:

The Potosi formation is composed of gray to brown dolomite. It is usually finely crystalline, and often compact. It carries a striking type of drusy chert, which is contained in this formation alone. Hence, it readily identifies the formation in areas of outcrop.

The thickness of the Potosi dolomite, as determined from the records of deep wells drilled in the southern district, is 250 to 300 feet. It may be noted that this formation yields comparatively large supplies of water to wells within the dis-

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[8]Hughes, V. H., Reconnaissance work, Crawford County: Mo. Bur. Geol. and Mines, 46th Bien. Rep't., pp. 48-54, 1911.

[9]Ulrich, E. O., Revision of the Paleozoic Systems. Geol. Soc., Amer., Bull. 22, pp. 281-680, 1911.

trict and it is now becoming, almost without exception, the objective formation where a material quantity of water is desired.

The Eminence formation succeeds the Potosi and it too is composed dominantly of dolomite, which ranges from white to gray and blue in color. The dolomite is usually finely crystalline. Chert is also an important constituent of this formation and several types are present. Green shale is not uncommon to the formation and lenses or thin beds of sandstone have been observed locally. The Eminence outcrops in the southern and southeastern margins of the southern districts. The full thickness is probably exposed only locally, but as determined from deep well records ranges from 150 to 300 feet.

The comparative solubility of the Eminence dolomite is indicated by the presence of a large number of caves and caverns, as well as numerous springs, Big Spring near Van Buren, Carter County being a fine example. It is believed that the sink-hole type fire-clay deposits of the southern district and similar type deposits of hematite, found in the central Ozark region were formed to a considerable extent by the collapse of the overlying rocks into caverns in the Eminence formation, formed by the dissolving action of ground water.

The Eminence is overlain by the Van Buren formation. It consists of light colored, finely crystalline, or fine-grained, argillaceous dolomite. Chert is a very common constituent. The base of the formation is sometimes marked by sandstone or sandy dolomite, to which the name Gunter member is given. The total thickness of the Van Buren will not exceed 100 feet.

The overlying Gasconade formation is also composed of dolomite, with chert again being a common constituent. The latter is concentrated in the lower portion of the formation, the upper portion being usually marked by an extremely low chert content. The upper part is also marked by dolomite of a comparatively high solubility as manifested by numerous caves and springs, some of which are of considerable size; Meramec Springs near St. James, Phelps County, is an excellent example. It is believed that some of the clay filled sink-hole structures may owe their origin to the collapse of caverns in the upper part of the Gasconade. The thickness of the Gasconade formation is about 200 feet. It is exposed in many of the deeper valleys of the southern district.

Canadian System. The Canadian system was a name proposed also by E. O. Ulrich[10] for certain formations, which had previously been placed in the Ordovician system. The formations present in the southern district in ascending order may be described as follows:

The Roubidoux formation, at the base consists of dolomite, chert, and sandstone. Some of the members of the formation are persistent over wide areas. This is particularly true of a sandstone member in the middle of the formation. It forms the rim rock of many of the filled sink-hole type iron ore deposits, which occur within the extreme southern portion or immediately south of this district. The dolomite of the Roubidoux formation is usually finely crystalline. The chert is of various types, with blue, gray and white being the usual color. The sandstone members are usually fine-grained, with the grains being further marked by an angularity due to secondary enlargement. The formation is widely exposed in many of the valleys, and locally in some of the upland areas, in the extreme southern portion of the area. The thickness is variable, but on the average will be about 135 feet.

The formation overlying the Roubidoux is the Jefferson City. It is composed mainly of dolomite, a large proportion of which is very argillaceous, and light gray or buff colored. This type is known in the Ozark region as cotton rock. The Jefferson City formation also contains near the base a persistent bed of dolomite, which weathers with a pitted surface. It is known locally as the pitted dolomite or the quarry ledge. It forms a valuable and reliable key bed in surface mapping. Chert is also present, and green shale and sandstone are not uncommon to this formation. The Graydon member at the base of the Cherokee group is in contact with the Jefferson City formation over a wide area. The thickness of the formation is variable due to the fact it is overlapped by the Graydon member, but increases from south to north, where the maximum thickness of approximately 300 feet is reached.

In some localities in the extreme northern portion of the district the Jefferson City formation is succeeded by the Cotter dolomite, also of Canadian age. In such cases the Pennsylvanian Graydon conglomerate is in contact with it. The Cotter is similar in its composition to the Jefferson City, the earthy

[10] Op. cit., p. 647.

cotton rock type of dolomite being again common. Chert, green shale, and sandstone also are contained in this formation. The Cotter dolomite is limited in thickness in this district to less than 100 feet.

Intervening between the Jefferson City or the Cotter dolomite, as the case may be, and the Pennsylvanian formations is an unconformity of considerable magnitude. It constitutes one of the great overlaps of the geologic column of Missouri, and is an example of the regional magnitude of the Pennsylvanian overlap in other areas of structural elevation similar to the Ozark uplift. As the result of this southward overlap many of the intervening formations which are present in the geologic column in the northern district are absent.

Ordovician System. In this district the Kimmswick, Decorah, and Plattin formations have been cut out and only the St. Peter sandstone and the Joachim dolomite are present, and these are known to occur to any extent only in the Frene Creek locality where excellent exposures of the St. Peter may be observed on Highway 19, just south of Hermann, Gasconade County.

Devonian System. The Devonian system, which is well developed in the northern district is also involved in the overlap mentioned. That it was once deposited in the area, is attested by an occurrence of Middle Devonian quartzite near Rolla, which has been described by Bridge,[11] who suggests a correlation with the Grand Tower formation of Ste. Genevieve and Perry Counties, Missouri. Fossiliferous Devonian limestone is known to occur in a cut on U. S. Highway No. 63, near the center of the west line, NW¼ SW¼ sec. 3, T. 39 N., R. 8 W., north of Vichy, Maries County. It is believed to be an outlier of the Callaway limestone. That the Devonian, Grand Tower formation was probably widespread in this district, but was subsequently almost completely removed by erosion is indicated by the many occurrences of boulders of Devonian quartzite in the basal Pennsylvanian, Graydon formation. The first suggestion of the age of such boulders was made by E. O. Ulrich,[12] during the course of a field trip in 1931.

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[11]Bridge, Josiah, and Charles, B. E., A Devonian outlier near the crest of the Ozark uplift; Jour. Geol., Vol. 30, No. 6, pp. 450-453, 1922.

[12]Personal communication.

Mississippian System. The Mississippian system[13] also was present over most, if not all, of the southern district, but now, like the Devonian, it has been removed by erosion after deposition, until only remnants or outliers chiefly of residual Osage group chert may be found. Whether or not the complete section of the Mississippian was deposited is a matter of conjecture. In view of rather thick sections in western, northern, and eastern Missouri it seems likely that a considerable portion of the Mississippian section was deposited and subsequently removed by erosion in the period prior to the deposition of the succeeding Pennsylvanian rocks.

PENNSYLVANIAN SYSTEM.

CHEROKEE GROUP.

The rocks of the Pennsylvanian system identified in the southern district belong to the Cherokee and Henrietta groups. The Cherokee, in which the fire clays are found is composed of several formations, which in ascending order are:

1. Unnamed formation, sandstone and shale, pockety in nature and possibly representing some of the oldest Pennsylvanian sediments known in the State.
2. Graydon formation, basal chert conglomerate and sandstone; overlaps No. 1, is widely distributed; and forms the "'rim rock" of the clay deposits of this district.
3. Cheltenham clay formation, which contains flint and semi-flint clay, plastic clay, burley, and diaspore clay; local representatives of the Loutre and Tebo formations may be present also and, in this report, are included in it.
4. Lagonda (?) shale, or plastic clay, locally present if at all.

UNNAMED FORMATION.

The earliest deposits of the Cherokee formation in this district are hard, black shale and hard, fine grained sandstone, the latter being marked by laminae of black shale and carbonaceous matter. It is further characterized by

[13]Lee, Wallace, The geology of the Rolla quadrangle: Mo. Bur. Geol. and Mines, Vol. XII, 2nd Ser., pp. 41-42, 1913.

fragments of mother of coal. The only deposit observed to date in the southern district is located in C SE¼ sec. 12, T. 39 N., R. 10 W., 5 miles southwest of Vienna, Maries County, where a shaft has been sunk in the hope of developing a deposit of coal, the presence of which had been suggested by fragmental coaly material included in sandstone. The sandstone occupies a sink-hole type deposit, and in elevation is now some distance below the normal base of the Pennsylvanian in this area. A representative of the black shale is believed to have been encountered in the city well at Bland, SW¼ SE¼ sec. 7, T. 41 N., 6 W., between 285 and 305 feet. Here it is 220 feet below the base of the younger, and overlying Pennsylvanian Graydon formation and it is believed to have been an early deposit in an existing cavern. In mode of occurrence it is similar to the Green well at Mexico which has been described on page 32. A chimmey-like deposit of grayish black Pennsylvanian plastic clay shale, probably of the same age, is well exposed between Vichy and Vienna on U. S. Highway 63, a short distance southeast of the bridge over the Gasconade River, and at or near the section line between sec. 1, T. 39 N., R. 9 W., and sec. 6, T. 39 N., R. 8 W., Maries County. Here the shale is in contact with distorted beds of yellow argillaceous dolomite of the Jefferson City formation, the contact being sharp and almost vertical.

The sandstone and dark shale are similar to rocks found in the lower Cherokee in one locality to the west of the northern district, and more commonly on the western flank of the Ozark uplift. Similar rocks have been described in Vernon County, southwestern Missouri, by Greene and Pond,[14] who applied to them the name Dederick member of the Cherokee "formation". Sandstone and related dark-colored shale and thin seams of coal are also known to occur in the basal part of the Cherokee group in the Forest City basin of northwestern Missouri where they have been described by McQueen and Greene.[15] These deposits reach a total known thickness of 275 to 300 feet. The occurrence of the deposits show that earlier Cherokee sediments were deposited in this area, and with local exceptions were subsequently eroded. Of these sediments, the

[14]Greene, F. C. and Pond, W. F., The geology of Vernon County, Mo. Bur. of Geol. and Mines, Vol. XIX, 2nd Ser., p. 40, 1926.

[15]McQueen, H. S. and Greene, F. C., The geology of northwestern Missouri: Mo. Geol. Sur., and Water Resources, Vol. XXV, 2nd Ser., p. 23, 1938.

field by Ulrich[18] in 1931 following a study of a splendid exposure of the basal Pennsylvanian conglomerate in deep cuts along U. S. Highway 50 in the Cave Hill locality, NE¼ NW¼ sec. 14, T. 43 N., R. 6 W., east of Mount Sterling, Gasconade County. Devonian quartzite had previously been described, however, by Bridge[19] and Charles as occurring in a place near Rolla, Phelps County.

Residual fossiliferous chert[20] derived from outliers, or isolated remnants of the Osage group of the Mississippian system are also present in the conglomerate. Variegated siliceous shales are also common to the basal member and occur as lenses associated with other material. The basal conglomerate may be observed at many places in the district, but it is probably best exposed in the extreme southern portion. What is probably one of the finest exposures may be seen in the cut into the Forbes pit, NW¼ NE¼ NW¼, sec. 35, T. 38 N., R. 8 W., just north of Rolla, Phelps County (P. XXI, A). Here the contact of the basal conglomerate and the overlying sandstone is sharp and clearly observable. The basal conglomerate is also well exposed at the junction of U. S. Highways 63 and 66 at the north edge of Rolla, where the relation to the underlying Jefferson City dolomite may be observed. Additional exposures are found east on Highway 66 toward St. James and north on U. S. Highway 63 toward Vichy. Excellent exposures may also be studied along the St. Louis-San Francisco Railroad between Rolla and St. James and particularly between the northeastern portion of Rolla and the Rolla Municipal Airport, some 2 miles east. In the latter localities the relation of the basal chert conglomerate to the underlying Jefferson City dolomite is again demonstrated.

Excellent exposures of the Graydon chert conglomerate and sandstone may also be observed in the Cave Hill locality on U. S. Highway 50, east of the village of Mount Sterling, particularly in the road cuts in the NE¼ sec. 15, and in cuts along the north line of sec. 14, and the south line of sec. 11, T. 43 N., R. 6 W., Gasconade County (Pl. XXI, B). The jumbled nature of the exposures suggests they represent the bottoms of sink hole-type deposits.

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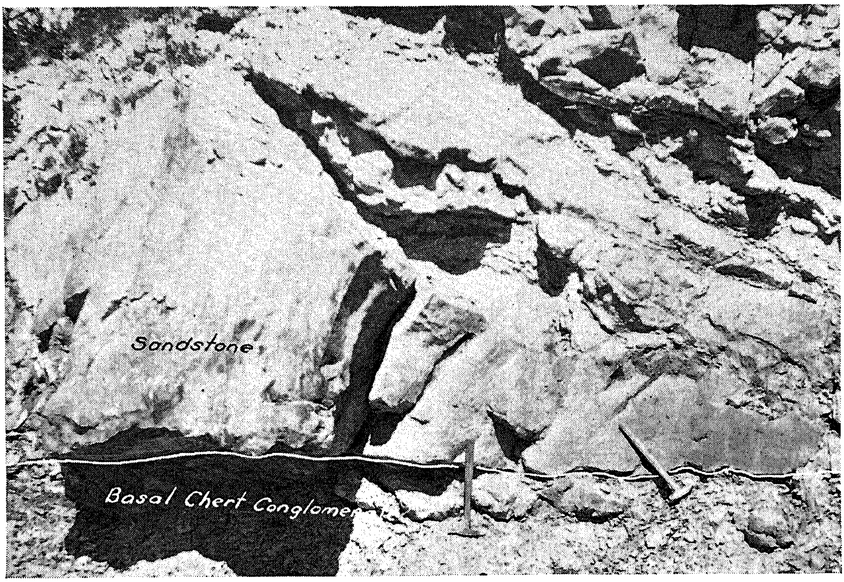
[18]Oral communication.

[19]Bridge, Josiah and Charles, B. E., A Devonian outlier near the crest of the Ozark Uplift: Jour. Geol., Vol. 30, No. 6, pp. 450-453, 1922.

[20]Lee, Wallace, The geology of the Rolla quadrangle, Mo. Bur. Geol. and Mines, Vol. XII, 2nd Ser., pp. 41-42, 1913.



A. Contact of basal chert conglomerate and massive sandstone, Graydon formation. Forbes pit, NW ¼ sec. 35, T. 38 N., R. 8 W., Phelps County.

B. Jumbled mass of sandstone and chert, Graydon formation. U. S. Highway 50, secs. 11 and 14, T. 43 N., R. 6 W., Gasconade County. Probably represents bottom of sink-type deposit.

The thickness of the basal conglomerate is highly variable, due to the fact it rests upon an uneven surface developed upon the older, underlying rocks. The full thickness has not been observed, but it probably reaches a maximum of 125 feet. Deep wells in the area furnish general information on this subject, but due to the highly variable nature of the conglomerate, it is often difficult to separate it in a study of well cuttings or samples from the sandstone or clay so closely associated with it.

Immediately overlying the basal conglomerate in most localities and possibly a gradational phase of it, is a massive sandstone, the "rim rock" of the sink-hole type clay deposits. The contact of the two is sharp locally, but on the other hand it may reasonably be a graditional one. The sandstone is usually fine grained, and often soft or friable, although in many instances it has been recemented until it is hard and quartzitic. The grains are fine to medium and angular (in part due to secondary enlargement) to rounded. The latter type is usually frosted. No attempt has been made to study in detail the characteristics of the sandstone. These no doubt vary from south to north, for the character of the sandstone would vary with the formations weathered in the pre-Cherokee interval and from which it was derived. In the direction indicated the formations composed dominantly of sandstone that could reasonably contribute a material quantity of sand to the sandstone under discussion would be the Roubidoux, St. Peter, and the early Pennsylvanian sandstones. The last two are now represented only by local deposits previously described.

The thickness of the sandstone is variable. It ranges from possibly 20 to as much as 75 feet. The variations in thickness may have been due to irregularities in the surface of the underlying dolomite, and pre-existing sink holes may have been a factor in this regard also. Erosion, following deposition may also have been a factor.

The sandstone member is important in that it forms the rim rock of the sink-hole type deposits. It is a guide in prospecting, and inclined or dipping exposures are significant and usually indicate the presence of a pit. It is also a useful guide in drilling, both in prospecting and in the detailed drilling of a pit, for it is the limiting factor in the horizontal and vertical extent of the clay.

The sandstone is equally important from the standpoint of outlining the flint fire clay and diaspore clay producing area. Together with the basal conglomerate it "holds up" the upland area of the southern or Ozark district and forms locally a low but definite escarpment around its margin.

The sandstone occupies a position in the Graydon section similar to the sandstone developed at the top of that member in the northern district. Although the sandstone is thicker in the southern district the two are probably correlatives and were deposited at approximately the same time.

THE CHELTENHAM FORMATION.

Name. The clays of the southern district occur in sink-hole type deposits and present a different problem in geological interpretation. Within these sink type structures all of the clays known to this district may occur, often as irregular masses, which grade from one to another in comparatively short distances. In other deposits a definite sequence or succession of beds of clay can be measured, but so far the writer has not been able to correlate the strata in one deposit with the strata in another except in a very general way.

As the result of a critical analysis of the geologic relations however, it is not difficult to establish the age of the clays in this district. They also occur in the Cheltenham formation. Because of the many problems presented by the mode of occurrence, the individual members of that formation cannot be specifically identified, however, in the sink-hole type deposits. Therefore the same method of treatment employed in the description of the Cheltenham clay members in the northern district cannot be applied in the southern district. In the latter, the answer appears to be in the individual description of each clay, but insofar as the mode of occurrence, distribution and thickness are concerned, in treating the clays as a whole. In connection with the preparation of this report the idea has been obtained, however, that the three members of the northern district might be represented in the southern district in a general way and the following statements may therefore be of interest.

Lower member. In the northern district this member is represented by semi-flint and flint fire clays, which occur in comparatively small and shallow sink-hole type deposits. In the southern district, the writer believes this member is represented by deposits of flint, burley, and diaspore clay, which occur in comparatively larger and deeper sink-hole type deposits. Just as leaching has affected the clays of this member in the northern district, so has more complete and thorough leaching affected the clays in the southern district. This has been accomplished chiefly because the sink-hole type structure was larger and more open at the bottom. Thus a greater area for the more rapid downward passage of meteoric water was afforded. Recent studies have indicated a sharp contact between what is generally interpreted as this member and what is possibly the succeeding middle member. These studies also suggest that the diaspore and burley clay were formed, to some extent at least, prior to the deposition of the succeeding middle member, just as the flint and semi-flint clays of the lower member in the northern district were formed prior to the deposition of the overlying semi-plastic middle clay member.

Two classic examples of the sharp contact of two obviously different clay zones may be cited. In the west side of the Klossner deposit, sec. 15, T. 44 N., R. 5 W., in the south portion of the village of Swiss, which is being operated for the A. P. Green Fire Brick Company, there occurs beneath dark colored flint fire clay and in sharp and striking contrast to it, a very hard, fine grained, rock or flint-like type, high alumina clay. The attention of the writer was first called to the latter clay by Ben K. Miller, Mining Superintendent, A. P. Green Fire Brick Company, Mexico, Missouri, who reported it to contain 71 per cent alumina. A sample was collected by the writer and the alumina content was checked as the following analysis will show.

Chemical Analysis of High Alumina Clay, Klossner Pit.
R. T. Rolufs, Analyst.

Constituent	*Percent*
Silica (SiO_2)	7.64
Alumina (Al_2O_3)	72.12
Ferric Oxide (Fe_2O_3)	1.65
Titania (TiO_2)	3.06
Lime (CaO)	0.22
Magnesia (MgO)	0.09
Soda (Na_2O)	0.13
Potash (K_2O)	0.97
Sulphur (S)	0.02
Phosphorus Pent-Oxide (P_2O_5)	0.032
Moisture (H_2O, −110 °C)	0.14
Ignition Loss (H_2O, +110° C)	14.33
	100.402

Samples of the clay were also submitted to Dr. Paul G. Herold, who obtained by X-ray analysis, a distinctly different diffraction pattern than that exhibited by the usual high grade, or high alumina diaspore clay found in Missouri. Further investigations by Herold, the results of which are described by him in Chapters V and VI of this report, have suggested the material represents a clay mineral, which he classifies as boehmite,[21] a mono-hydrate of alumina, closely related to diaspore, but differing from it in manner of crystallization. This mineral is reported to occur with the Ayrshire (Scotland) fire clays, and in the Pyreenean (Ariege) bauxites.

In the General Refractories Company, Kallmeyer pit, NW¼ sec. 35, T. 45 N., R. 6 W., near Stolpe, Gasconade County, a seven-foot bed of high grade diaspore clay, the top of which is marked by the same hard, fine-grained, almost flint-like high alumina clay, approximately one foot in thickness, is present beneath a considerable interval composed of several coal beds and dark carbonaceous flint fire clay (Pl. XXII, A). The contact and contrast between the two is striking. The hard, fine grained clay similar to that occurring in the Klossner pit has also been identified by Dr. Herold as boehmite. The occurrences mentioned suggest that the process of alteration, the enrichment of alumina, the removal of silica, took place during a period of weathering following the deposition of the lower member.

Middle member. The middle member of the Cheltenham as developed in north Missouri cannot be specifically recognized in the southern district. There is a suggestion, however, that the light colored semi-plastic clay of the northern district and the massive, uniform, homogeneous white, hard flint fire clay of the southern district are correlatives. In the latter, however, dark, colored, carbonaceous flint fire clay is also not uncommon. In many instances it is associated with beds of coal. Although seams of coal are not common to the middle member in the northern district, they may be present in the southern district. The foregoing statement is not intended to preclude the possible presence of burley and diaspore clay for they may be present also in this member.

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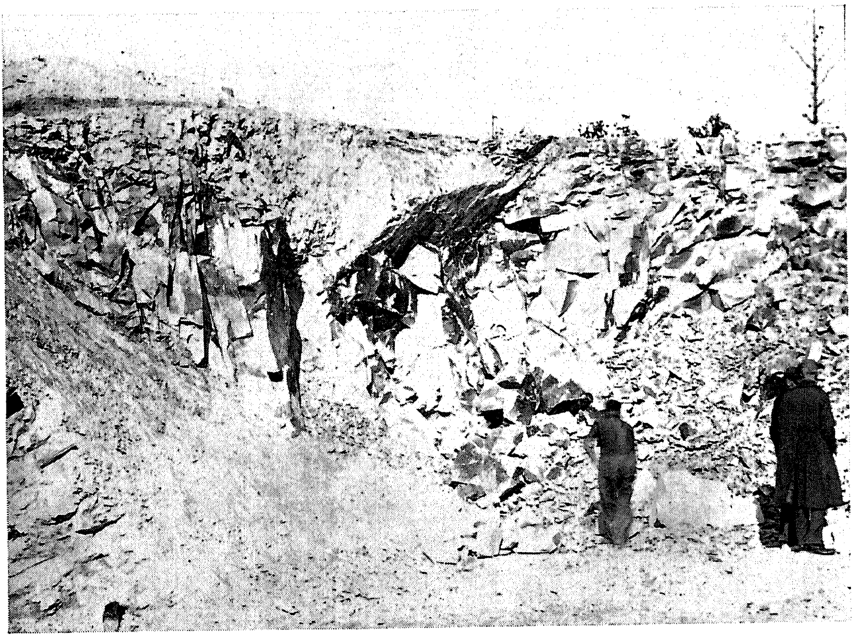
[21]DeLapparent, J., Boehmite and diaspore in Ayrshire (Scotland) fireclays, Compt. Rend. 199, pp. 1629-31, 1934.

A. Contact of dark carbonaceous flint fire clay and coal with high grade diaspore clay and hard fine-grained boehmite. Kallmeyer pit, NW ¼ sec. 35, T. 45N., R. 6W., Gasconade County.



B. Hard, white, massive flint fire clay. Note jointing and brecciation in center and smooth slickenside surface to left. Forbes pit, NW ¼ sec. 35, T. 38N., R. 8W., Phelps County.

Upper member. This member also cannot be specifically recognized in this district. There are, however, certain deposits which contain a dark colored, soft-type of flint fire clay, which may be a counterpart of the dark gray plastic clay of the northern district. An example of such clay may be observed in the Henneke pit in sec. 24, T. 42 N., R. 5 W., southeast of Owensville, Gasconade County.

Post-Cheltenham clays. In any consideration of the clays of the southern district, it would be advisable to keep in mind that clays, other than those of the Cheltenham, might be present in the sink-hole type deposits. In the northern district, clays, chiefly plastic in nature and of the underclay type, have been described as occurring in the Loutre, Tebo, and Bevier formations. Although these formations have not been specifically identified in the southern district, they may well be represented in certain deposits by dark-colored semi-flint and flint clays, and by the coal beds associated with them.

The final analysis of the detailed stratigraphy of the Chelenham and related formations in the southern district cannot be made at this time. The foregoing descriptions may serve, however, to provoke thought in that direction and finally to lead to the solution of the general problem and a better understanding of the clays.

Mode of Occurrence.

The one feature that characterizes the flint and diaspore clay deposits of the southern district or north central Ozark region is the occurrence in sink-hole type structures circled in part at least by a sandstone "rim rock", which outlines the deposit (Pls. XXIII, A and B). The deposits have resulted from the collapse of caves and caverns formed by the work of ground water percolating through the relatively soluble dolomites, chiefly those which constitute the Ozarkian Eminence and Gasconade formations. It is in these formations that the larger springs and caves of the Ozark region are known to occur.

As the roof of the caverns, of which the Pennsylvanian conglomerate, sandstone, clay, shale, and limestone were a part, became too heavy and was no longer able to support its own weight, it caved into the caverns thus formed. That these caverns were dissolved out of the dolomites mentioned, is indicated by the existing caves and springs in them, and by the fact that such formations as the intervening Roubidoux, Jefferson City, and Cotter dolomites rarely, if ever, exhibit the results of the work of solution on a sufficiently large scale as that required by the size of the larger sink-hole type clay deposit. Following the period of collapse the entire area has been subjected to erosion and the pits now present are simply existing remnants of what is considered to have been a once wide-spread clay deposit.

The shape of the sink-like structure is variable. In surface plan the deposits range from circular or nearly so to elliptical. In vertical plan an inverted cone-shape type is common, or on the other hand the deposits may be basin, cylindrical or chimney-like. The axis of the cone-shaped pits may be vertical to the surface of the ground, or may be inclined to it at various angles. Many of the cylindrical-shaped deposits are likewise inclined.

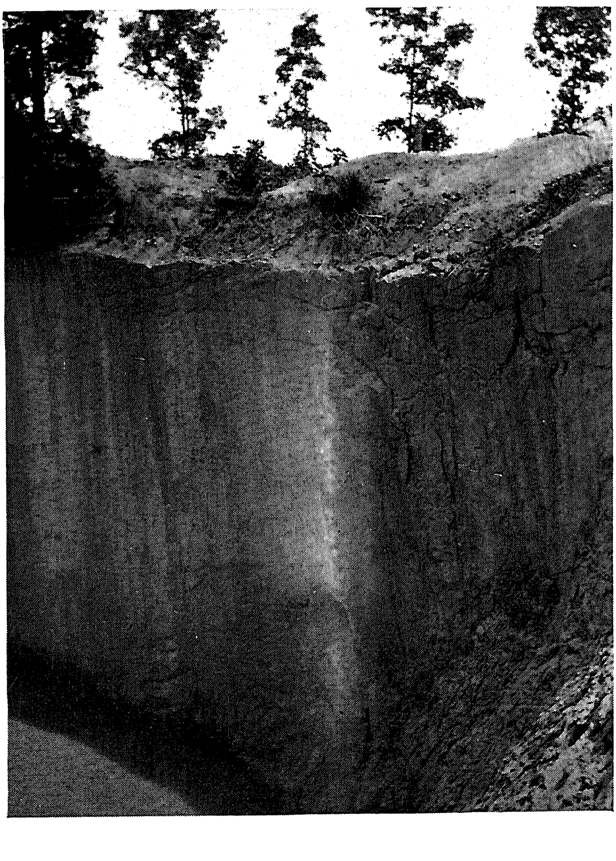
Bowl-shaped deposits are not uncommon and the surface dimensions are considerably larger than the depth. As a general rule it may be said that many of the bowl-shaped deposits contain only flint fire clay. Exceptions to this rule may be noted, however, in fact the largest deposit in the district, the Aufderheide, NE¼ NE¼ sec. 36, T. 43 N., R. 6 W., Gasconade County, measured 800 x 500 x 30 feet and contained a comparatively large tonnage of diaspore and related plastic clay.

The deposits, in size, are likewise variable. As a rule the surface dimensions are greater than the depth but not necessarily so. The pits range in size from comparatively small ones, of only a few feet in diameter and depth, to large ones, the Aufderheide pit above mentioned being the largest. Pits 150 x 150 feet and up to 250 x 250 feet with depths ranging from 25 to 150 feet are not uncommon. The average deposit would probably measure 100 x 75 x 60 feet.

There appears to be no rule regarding the occurrence of the deposits in relation to size or shape, as small deposits occur in the same general area as large ones. However, it does appear that in some instances a given area is marked by more large deposits than small, or the contrary may be true.

The Rosebud area of Gasconade County is characterized by the comparatively large size of the pits, the bulk of which contain flint fire clay. A number of large pits have been found also in the Goerlisch ridge area north of Owensville,

A. View of sandstone "rim Rock". Korff pit, SW ¼ SE ¼ sec. 17, T. 42 N., R. 4 W., Gasconade County.



B. Near view of "rim rock", Korff pit.

Gasconade County, where comparatively large tonnages of diaspore clay have been found, the Fornberg, NW¼ SW¼ sec. 30, T. 43 N., R. 5 W., and the Aufderheide, NE¼ NE¼ sec. 36, T. 43 N., R. 6 W., being notable examples.

A number of large pits also characterize the Swiss area, T. 44 N., R. 5 W., Gasconade County, the Fleutsch pit, SW¼ SE¼ sec. 16, T. 44 N., R. 5 W., being one with more than the average amount of diaspore. A number of large pits have also been found in Mint Hill locality, in the western portion of T. 44 N., R. 7 W., and the eastern portion of T. 44 N., R. 8 W., Osage County.

On the other hand a number of areas in which the pits or deposits are comparatively small have been found. The area immediately adjacent to the Cuba fault, in the vicinity of Canaan, T. 41 N., R. 6 W., Gasconade County, being an example. Deposits in the immediate vicinity of Gerald, T. 42 N., R. 4 W., Gasconade County, are also examples. Small deposits are the general rule in the Drake locality, T. 43 N., R. 5 W., Gasconade County, and in the northeastern part of T. 43 N., R. 8 W., Osage County.

The reason for localization of the areas of comparatively large and small deposits appears to be related to the regional geologic structure, which will be discussed in full in a later chapter. In this connection it may be repeated that the smaller deposits appear to occur in areas crossed by regional anticlines (upfolds in the rocks), whereas the larger deposits and the ones containing the most diaspore occur in areas crossed by regional synclines (downfolds).

In some instances isolated deposits of these clays have been found in areas wholly underlain by the older rocks (Cotter, Jefferson City, and possibly Roubidoux?), or they have been found in the deeper valleys some distance below the upland surface previously described. Such deposits simply represent the remnants or roots of deeper deposits, remaining after detachment from the usual locale of occurrence by erosion. Examples of such deposits are the Lamb, SE¼ SE¼ sec. 8, T. 44 N., R. 7 W., south of Aud Post Office, Osage County, where the country rock appears to be the Cotter or Jefferson City formation, and the Henry Froelker deposit, NE¼ NW¼ sec. 9, T. 42 N., R. 3 W., Franklin County, about four miles east of Gerald. Here the country rock is dolomite of the Jefferson City formation and the deposit is in a valley.

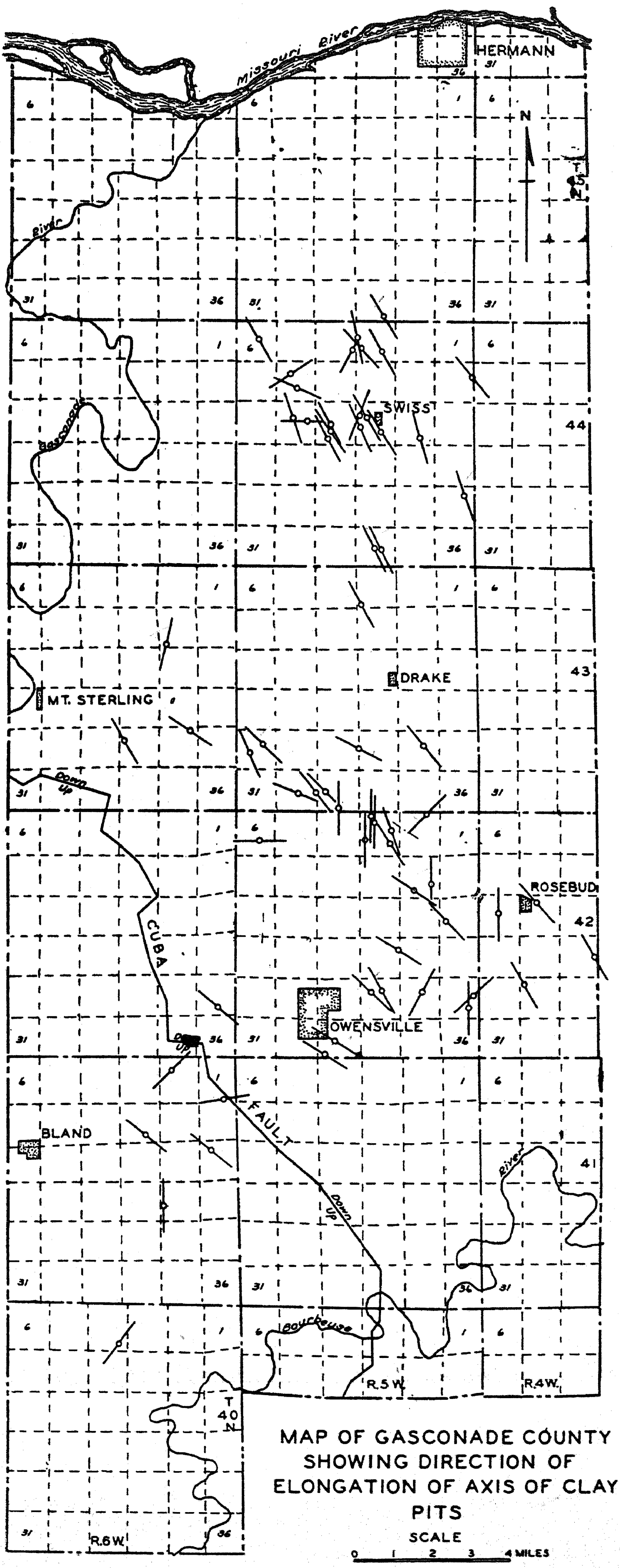
One of the most interesting features of the deposits is the surface plan, which as previously pointed out, ranges from circular, or near so, to elliptical. The latter appears to be an alignment parallel to the major folding and faulting in the district. In connection with the preparation of the original map, and in the revision, which has resulted in the current edition, Garland B. Gott and the writer studied this problem and found an axis of elongation in 82 individual deposits. This number probably does not represent the total by any means. Of this number 52 had axes elongated in a northwest-southeast direction and approximately parallel to the Cuba-Mt. Sterling fault; 18 were elongated from northeast to southwest; 8 were elongated in a north and south direction; 4 were elongated in an east and west direction. In this area the strike of the major folding and faulting is N. 10° to 40° W., to which the longer axis of the majority of these pits is approximately parallel (Pl. XXIV).

The elongation in a northeast-southwest direction coincides with the general alignment of a series of folds, one of which, the Kruegers Ford anticline, is described in the section devoted to the structure of the southern district. This alignment is also parallel to that strike in some localities of the Leasburg fault, a prominent structural feature, which also is described later.

The alignment of the axes of the deposits is a reflection of the joint pattern and possibly faulting also. In the periods of folding and faulting, which the district has undergone, accompanying joints or fissures were formed in the rocks. Ground water migrating along such planes, attacked the more soluble dolomites and they were enlarged. With continued solution, and with the development of underground streams carrying abrasive materials, enlargement proceeded until large and small caverns were formed. As the caverns increased in size, and as the roof of each was no longer able to support its own weight, it collapsed or subsided and at the surface is now reflected by the filled sink-hole type deposits of fire clay, and iron ore.[22]

This subsidence followed in most cases the direction of the joint plane or related structure along which solution pro-

[22]Crane, Guy W., Iron ores of Missouri: Mo. Bur. Geol. and Mines, Vol. X, 2nd Ser. 1912.



MAP OF GASCONADE COUNTY SHOWING DIRECTION OF ELONGATION OF AXIS OF CLAY PITS ceeded. The circular, or nearly circular, and cylindrical shaped deposits, may reflect the work of solution at the intersection of two joint planes. A further study of the direction of joint planes is urged as the information gained might well be useful in prospecting.

There is no set rule for the occurrence of the clays in the pits or deposits in the southern district, with but one exception. All of them contain flint fire clay, but not all of them contain burley or diaspore clays, by any means. The statistics presented in Table 10 will be of interest in this connection. It would appear that the ratio of the occurrence of diaspore and burley to flint fire clay alone is approximately 4 to 6, or 4 diaspore-burley pits in each ten recorded on the accompanying map.

The occurrence of the clays within an individual deposit is highly variable. In the shallower, bowl-shaped deposits, the occurrence of flint fire clay is the general rule, but there are exceptions. In the deep cylindrical or cone-shaped type of deposit, burley and diaspore clays are found, with but few exceptions. There is also no set rule for the position of the clays within the deposits. Diaspore and burley clay may occur at the surface, in the center of the pit, or at the sides; or these clays may occur some distance beneath the surface, and be overlain by other clays. The diaspore and burley may occur as seams or beds interbedded with other clays, or as irregular masses of indefinite shape and varying size. It would appear, however, that in a number of instances the aluminous burley and diaspore clays are quite often found in that portion of the deposit adjacent to the part of the rim rock marked by steepest dip. This may mean that they occur in that portion of the pit in which the original clays were most highly fractured or brecciated during the subsidence of the deposit. Consequently circulating ground water may have had a greater and more rapid access to this zone, and leaching was more easily attained and completed. In this case, as will be proved in the discussion of the origin of the clays, the change was from flint fire clay to and through burley to diaspore clay. On the other hand, the diaspore and burley clays may have been formed prior to slumping into the sinks. This suggestion has been made by Ben K. Miller[23] and according to him would account

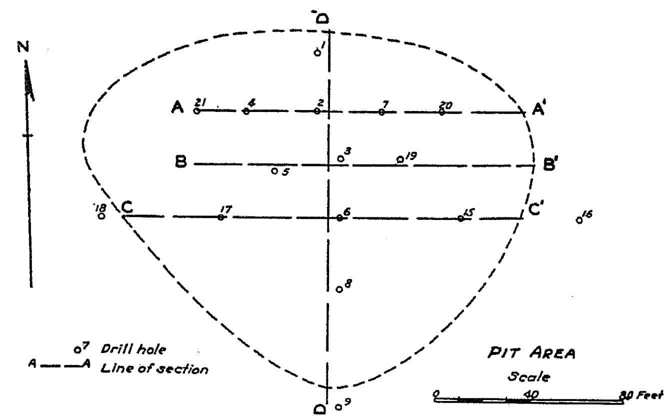
[23]Oral communication.

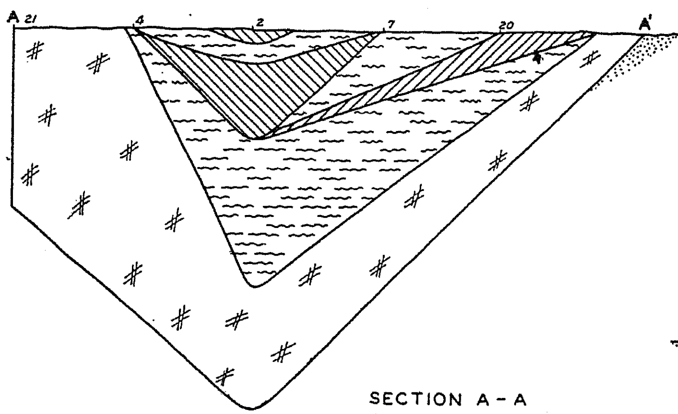
for certain erratic conditions pertaining to the occurrence of the clays, the gradations between them and the impurities which are sometimes more heavily concentrated locally than the average. The writer believes that it will be well to consider that alteration may have gone on before and after subsidence, and a combination of the two would possibly achieve the final alteration of the clays.

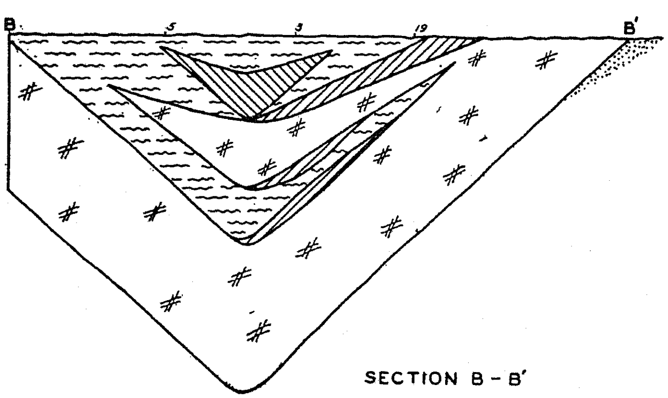
Much could be written about the occurrence of the clays in the individual deposits, their variations, and their gradation. In this connection cross sections of typical deposits are given (Pls. XXV and XXVI), as well as several photographs. Within a clay mass the change from flint to diaspore may be sharp or on the other hand the gradation may be imperceptible. Likewise, gradations from flint to burley clay and from burley clay to diaspore clay may be gradual or abrupt. The accompanying Plates XXVII, A and B, and XXVIII, A and B, indicate some of the gradations observed during the field work. Much could be said about such changes, but they would all simply be variations of a general principle that the diaspore and burley clays are alteration products of flint clay, the medium being downward circulating ground water, charged with organic and carbonic acids and the alkaline carbonates.

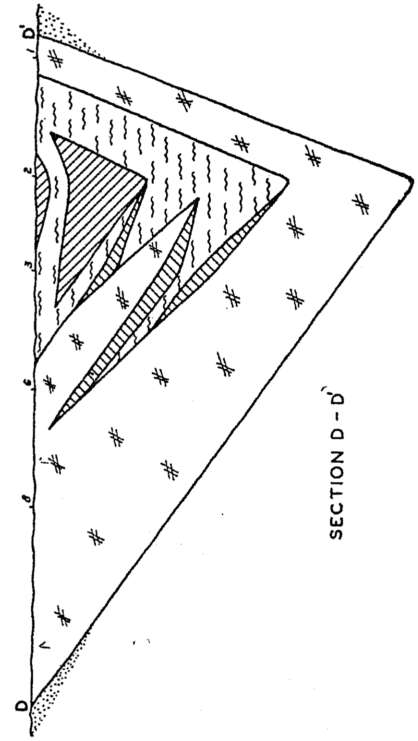
Structurally the clays exhibit minor features that reflect the subsidence of the mass into the sink-like deposits. In those assymetrical deposits with steep rim rocks, the adjacent clays likewise exhibit steep dips. They reflect a dip corresponding to that of the rim rock on the side of low dip also. A feature noted in many pits is evidence of drag, or reverse dip, in the beds of clay adjacent to the steeply dipping rim rock. Although the normal dip is toward the structural center of the pit, a reverse dip toward the rim rock is often apparent. The writer believes this results from lateral compression developed as the mass of clay subsides into the sink, and is brought about by the slumping of a mass into a space of smaller dimensions.

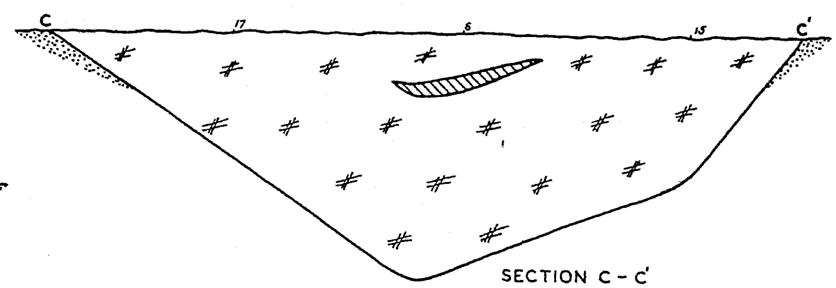
Splendid examples of drag or reverse dip were observable in the massive diaspore clay in the Wallace or "Red" pit; in the Forbes pit, NW¼ NE¼ NW¼, sec. 35, T. 37 N., R. 8 W., near Rolla; in a pit of the General Refractories Company, SW¼ SE¼ SW¼ sec. 32, T. 42 N., R. 3 W., Franklin County; in the Matthews pit, SE¼ SE¼ sec. 22, T. 41 N., R. 7 W., near Belle, Maries County; the Plattner pit, SW¼ SE¼ sec. 14, T.

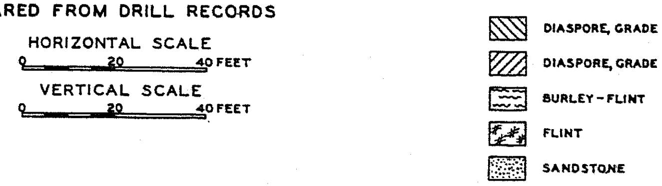












CROSS SECTIONS OF SHOCKLEY PIT
NE 1/4 SEC. 26, T. 41 N., R. 7 W., MARIES CO.
PREPARED FROM DRILL RECORDS

44 N., R. 5 W., Gasconade County; and the Boesch deposit, NW¼ NE¼ sec. 10, T. 44 N., R. 5 W., Gasconade County. Many others could be named.

Distinct bedding planes are often observable in the various clays. Classic examples of bedding were observable at one time in the Forbes pit near Rolla, NW¼ NE¼ NW¼ sec. 35, T. 37 N., R. 8 W., and the John Holt pit, NE¼ sec. 30, T. 40 N., R. 5 W., near Owensville (Pl. XXVIII, A), where the following section was measured:

Section Measured in Holt Pit.

	Thickness	
	Feet	*Inches*
Burley, low grade, blue in color, with dark brown oolites and pisolites of crystalline diaspore clay in a hard shaly flint clay matrix	3	
Flint fire clay, black	0	6
Flint fire clay, hard, blue grading downward into gray flint. In basal part are large nodules of high grade, dense, soft light gray diaspore clay with the outer surface stained with iron	2	0
Diaspore clay, light gray, hard, fine grained to porous	1	8
Burley and flint fire clay. In main composed of very hard gray flint clay. The burley clay is softer and particularly well defined in a 6 inch seam 9 to 12 inches below base of No. 4	6	4
Diaspore clay, oolitic, brown, soft	0	6
Flint fire clay, dark gray, hard, dense, varies in thickness from 6″ to 1″	1	
Diaspore, or very light grade burley clay, very oolitic, gray, soft	2	0
Flint fire clay, gray, hard, slightly oolitic, there is no perceptible break between No.'s 8 and 9	0	5
Diaspore, gray, hard, slightly porous, with few local streaks of burley clay near top	8	0

Bedding is particularly observable in those deposits having seams of coal or beds of dark colored clay interbedded with lighter colored ones.

Faulting is not uncommon and is present especially in those pits with steeply dipping rim rocks. The faulting in the Forbes pit at Rolla (Pl. XXIX, A) is particularly conspicuous, and again marks the movement or subsidence of the mass into the sink-like structure. Faulting within the clays is also evident, and while displacement along the planes cannot be everywhere measured, the beautifully developed slickensided surfaces are mute evidence of the downward movement of the clay. Such planes of movement are inclined always toward the deep part or structural center of a pit, a feature previously described as also occurring in the northern district (Pl. XXIX, B).

Jointing in the clays is perhaps the most obvious and omnipresent structural feature. In fact, jointing is so well developed in some deposits that all evidence of bedding is completely obliterated (Pls. XXX, A and B). The jointing may be vertical, or inclined either at a high or a low angle. It may be widely spaced or the planes may be so close together that the clay mass is fractured into small pieces. This is particularly true in those deep deposits having a steeply dipping sandstone rim rock. In some deposits the jointing, when viewed in ground plan, is arranged concentrically and corresponds to the shape of the deposit as outlined by the sandstone rim rock. Jointing is less in evidence in those deposits that are shallow and basin-like in character, and in which downward movement or subsidence is believed to have been at a minimum. The jointing and brecciation of the clay and the faulting have played important roles in the development of the burley and diaspore clays, for without such features, ground water could not have circulated downward through the clays and carried out of the containing sink-type structures the water soluble constituents, and finally brought about the aluminization of the clay.

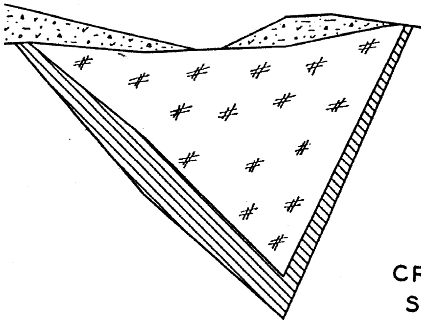
Areal distribution: On the accompanying map (in pocket) the area in which clay deposits may be reasonably expected has been outlined. The Graydon formation has been used for this purpose. In a north south direction the southern district measures about 50 miles, and in an east-west direction about 67 miles.

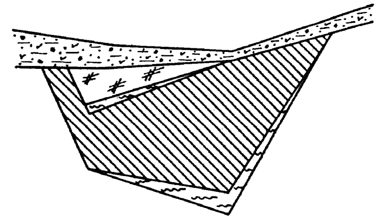
Within this area, however, the Graydon formation is not everywhere present and, as shown on the map, continuously underlies about 600 square miles. There are isolated deposits, the area of which, if added to that figure, would result in raising it.

The clays as mentioned occur in comparatively small deposits of varying size within the area outlined on the map. Therefore it may be said that the areal distribution of the Cheltenham formation is limited to sink-hole type deposits distributed over an area of some 600 square miles, which is underlain by the closely associated Graydon formation.

Thickness. In any deposit as complex structurally and containing as many different types of clays as the sink-hole type deposits under discussion, it is difficult to measure the true thickness of the clay.

Drill hole records are not always reliable, for some deposits upon being opened for development have been found to





CROSS SECTIONS OF ROBERTS-APEL PIT
SE 1/4 SEC. 27, T. 45 N., R. 6 W., GASCONADE CO.
PREPARED FROM DRILL RECORDS

HORIZONTAL AND VERTICAL SCALES

0 20 40 FEET

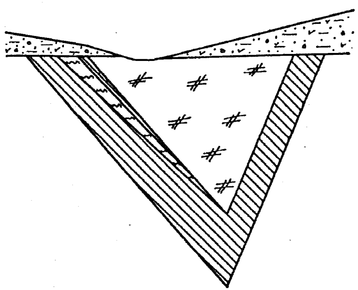
LEGEND

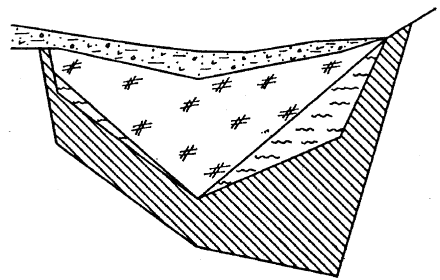
DIASPORE, GRADE I

BURLEY

FLINT

OVERBURDEN





be marked by steeply dipping clays, hence the thickness revealed by vertical drill holes was exaggerated. In other instances, the clays may have been so intensely folded in subsiding into the sink structure, that a duplication of beds may have resulted. It appears, however, that the Cheltenham clay in the southern district greatly exceeds the maximum known thickness that can be established for the northern district. For the latter, a maximum figure of approximately 90 feet has been previously given. The thickness in the southern district will probably exceed that figure considerably. If the diaspore clay is confined chiefly to the lower member of the Cheltenham formation, as previously suggested, then a thickness for that member of 100 feet or possibly more might be attained. A thickness of 75 feet or more might be attained by the hard white flint clay that seems to occur in so many deposits. The thickness of the upper member, if present, and the thicknesses of any clays associated with the formations younger than the Cheltenham, if present also, are not known. The writer believes that a total thickness exceeding 200 feet could be compiled. It should be recalled, however, that such a thickness is probably never attained in a single deposit but in some of the deeper ones, in which the subsidence, as reflected by nearly horizontal bedding planes, has been vertical, that figure may be approached.

Topography. The individual deposits of clay do not appear to influence the topography to the extent that any prominent surface features can be used to detect their presence, with the possible exception of locally protruding masses of rim rock. The general geologic relations to the topography, however, are probably a more striking feature, and one that has been helpful in prospecting. The formations of the Cherokee group in the north central Ozark district cap the characteristic uplands, and have been instrumental not only in their formation, but also, instrumental in preserving them in the periods of erosion that the area has undergone since the deposition of the clay.

The basal chert conglomerate and the associated overlying sandstones have been particularly important in this connection. Locally, they form low escarpments around the margins of the uplands and form the "breaks", so-called by the clay prospector. The "breaks" have been walked or "hunted" for clay and many deposits have been found, either from outcrops of clay in place, from "float" material weathered from an outcrop, or from exposures of sandstone "rim rock".

The elevation of the base of the Graydon formation, hence the position of the "breaks", is lower with respect to sea level from south to north. In the vicinity of Rolla the elevation is approximately 1150 feet, at Belle 915 feet, and at Linn, Osage County, it is 875 feet. The dip is well shown on the north-south geologic cross section, Plate V. Similar data when used in conjunction with topographic maps might be useful in prospecting.

Character of the clays: Any description of the clays should properly be prefaced by a description of the relation of the clays to the underlying Graydon chert conglomerate and sandstone. In nearly every pit examined by the writer, the clay in contact with this formation is flint fire clay. Local exceptions of plastic clay of no great thickness or extent might be noted, however.

As a general rule, a zone of sandy clay separates the sandstone of the rim rock from the merchantable clay. In fact, the sandstone appears at times to grade into a very clayey sandstone, thence into a sandy clay, and finally into the merchantable flint fire clay. This gradation is perhaps not as real as would first appear. In the writer's opinion, it simply represents the reworking of the sandstone by the water in which the clay was deposited. The contained sand grains are very similar to those contained in the underlying sandstone and are generally medium in size, rounded, and lightly frosted. Some of the grains are etched and a watery or limpid appearance is common to the outer surface. The zone of sandy clay is variable in thickness, but nowhere does it exceed a few feet in thickness.

Another feature that characterizes the basal portion of the clay, and particularly at or near the contact with the sandstone, is the presence of variegated colors, red, maroon, purple, blue, green, and buff being the more common ones. These colors appear as large irregular masses, in fact, they may be of considerable extent around the walls of a deposit. On the other hand, these colors may be represented by areas of mottling, that is, in some of the larger areas they appear to have been leached out, thus causing irregular, or sometimes symmetrical, spots or blotches in the white or light colored clay.

View of east face of John Holt pit showing arrangement of clays. NE ¼ sec. 30, T. 40 N., R. 5 W., Gasconade County.

View of north face near "rim rock" showing relation and irregular contact of high grade diaspore clay to oolitic flint fire clay, Forbes pit, NW ¼ sec. 35, T. 38 N., R. 8 W., Phelps County.

There has been considerable speculation regarding this mottling. In most instances it appears to be due to the presence of iron, although manganese and organic matter may be contributors also. Is the coloring primary, that is, deposited with the clay, or has it been introduced into the clay at a later date? The writer favors the former theory. Although much could be written on the subject, it does not appear to be of great consequence except that these clays when found in prospecting (either in studying outcrops or in drilling) might serve as a clue to a deposit. In conjunction with an outcrop of sandstone rim rock, they would indicate the direction in which prospecting could be undertaken most advantageously.

The variegated colors and the sandy clay described above are similar in every respect to the same features so often observed in the northern district. There the clay is most often sandy, and most often discolored at the base of the middle member of the Cheltenham formation. Whether or not the same horizon is indicated in the southern region cannot be determined. However, that is a point to keep in mind in connection with a better understanding of the clays.

In all of the deposits in the southern district the dominant clay is flint fire clay. Lesser amounts of burley, diaspore, and plastic clays are found and they will be discussed in the order given. Each clay will be considered on the basis of physical properties, mineralogical and chemical composition. In addition firing behavior tests have been made on several typical samples and the results are discussed by Herold in chapter V.

In view of the close relation and the gradation of the clays from one to another in an individual pit, it is apparent that they are closely related with respect to origin. Therefore a chapter pertaining to that subject also will be found in this report.

Flint Fire Clay: This type of clay is unique. It is characterized by its hardness, a lack of plasticity, a smooth texture, and a habit of breaking with a conchoidal or shell-like fracture and with sharp splintery edges. In this property it resembles flint or chert, hence the name. It is further characterized by spalling into somewhat concentric fragments much like that of an onion. Such pieces often can be broken down until only one very small, almost rounded fragment remains.

This spalling or slacking becomes quite evident with prolonged weathering, and is more pronounced in some types of flint clay than in others.

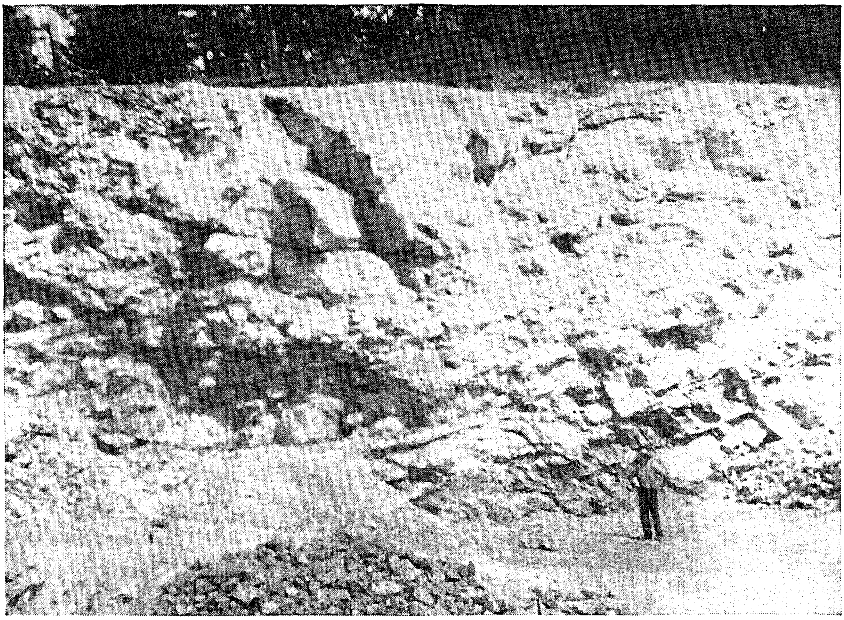
Several types or grades of flint clay, according to certain physical properties, are recognized in the district. The so-called No. 1 grade or "pop corn" flint fire clay is homogeneous, massive, extremely hard, pure white, and has a conchoidal fracture, and sharp splintery edges as pronounced characteristics. This clay represents a member of the Cheltenham formation, possibly the middle one. Another type is the "soft flint", which seemingly has more plasticity, is not as hard, and shows a greater tendency to complete slacking. It appears to the writer to be a flint fire clay that may represent an entirely different member of the formation, or it may represent a weathering phenomena.

The term "plastic flint" has sometimes been applied to this type of clay also. "Mottled flint" is the term given to flint fire clay with differential coloring, blue or gray and white mottling being not uncommon. This clay might be best described as "conglomeratic". It consists of light or dark colored fragments, sometimes angular, but at other times fairly well rounded and cemented with dark or light colored clay. The conglomeratic appearance is best exhibited where contrasting colors are present. Such clay is common to deposits containing coal or carbonaceous clay. The dark colors are the result, of course, of impregnation by organic matter.

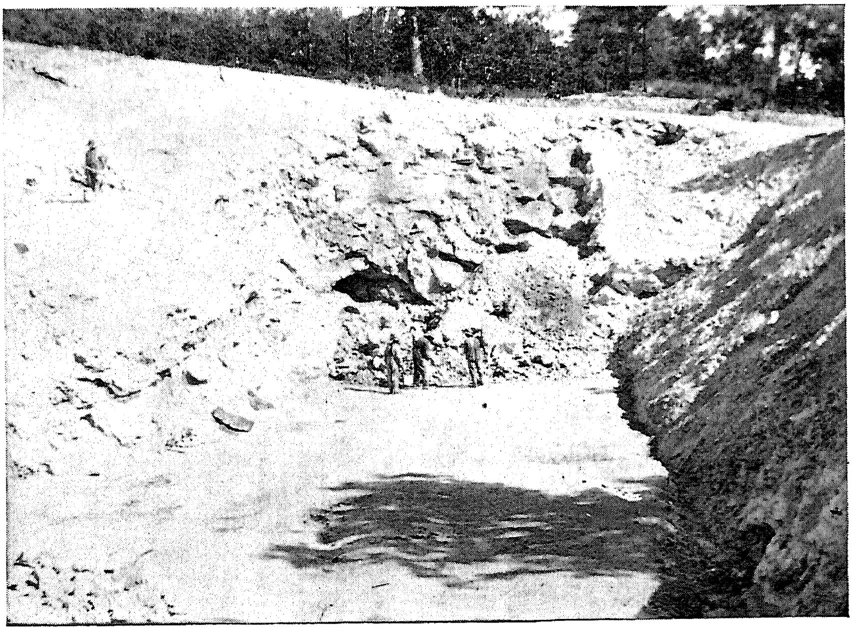
Such clays are of the flint type and are seemingly uniform in composition and physical make up despite the conglomeratic appearance.

Many excellent examples of this type of clay have been noted. A current one, and perhaps the best exhibit in the district, is present in the General Refractories Company, Kallmeyer pit, NW¼ sec. 35, T. 45 N., R. 6 W., near Stolpe, where 20 feet or more of this clay is associated with coal.

To the writer the conglomeratic type of flint clay suggests the deposition of light or dark colored clays in shallow water. They were then exposed to weathering, dried and cracked into fragments and then reworked in the next body of water which invaded the locality. Other clay sediments were carried in and were deposited, and served to cement the fragments into a mass. Later this mass was altered from probably a plastic or semi-plastic state to flint fire clay.



A. View showing bedding in John Holt pit, NE ¼ sec. 30, T. 40 N., R. 5 W., Gasconade County.



B. Same deposit as above. In lower right hand corner is the steeply dipping sandstone "rim rock". Massive bed at base to left of men is diaspore clay.

"Burley flint" is the name also applied to flint fire clay having included small oolites, pisolites or even nodules of the mineral kaolinite or halloysite. As these features become more aluminous and are made up dominantly of the mineral diaspore, the term burley clay is applied.

The flint fire clays exhibit a wide range of colors. White is the common color, and the color of the most desirable clay. Organic matter is a coloring agent and various shades of gray and blue and black are common. Iron likewise is a coloring agent and its presence is indicated by buff and many shades of red from light to dark maroon, light and dark purple, and various shades of green. The clay as previously mentioned is usually marked near the edges of the deposits or sinks by the colors just mentioned, particularly those for which iron is the coloring agent.

The flint fire clays are marked by a comparatively high fusion or melting point. This property depends to a large extent upon the chemical composition, and chiefly the presence or absence of various fluxes. Although it is difficult to choose between the flint fire clay from deposits south of the Missouri River and from those north of the Missouri River, it does seem as if the former are harder, have a slightly higher alumina content and a higher fusion point. This difference may be related to the origin and formation of the clays.

The mineralogy of the flint fire clays does not seem to be particularly complex. An early study of flint fire clay was made by Galpin[24] and later an excellent summary was given by Somers,[25] who reported this type of clay to be composed dominantly of the mineral kaolinite, with hydromica and colloidal matter being common. Diaspore oolites were also found in some specimens, and occasionally, nodules of diaspore of some size are found in the flint fire clay. These nodules occurred commonly in seam No. 3 of the section measured in the John Holt pit, NE¼ sec. 30, T. 42 N., R. 5 W., where they measured up to 4 x 4 x 2 inches in size. A chemical analysis showed these nodules to be high in alumina, the following being a typical one:

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[24]Galpin, S. L., Studies of flint clays and their associates, Jour. Amer. Ceram., Soc., Trans., Vol. 14, pp. 330-331, 1912.

[25]Ries, H., and others, High grade clays of the eastern United States, U. S. Geol. Survey Bull. 708, p. 294, 1922.

Chemical Analysis of Diaspore Nodule in Flint Clay
H. W. Mundt, Analyst

Constituent	*Percent*
Ignition Loss (H_2O,+110° C)	14.13
Moisture (H_2O,−110° C)	0.16
Silica (SiO_2)	6.53
Alumina (Al_2O_3)	77.88
Iron (Fe_2O_3)	0.52
Titania (TiO_2)	1.19
Lime (CaO)	0.14
Magnesia (MgO)	0.04
Total	100.59

Somers[26] also reports the presence of halloysite, rutile, zircon, and tourmaline.

Allen[27] has more recently contributed an excellent paper on the mineralogy of flint fire clay, which he reports to be "composed mainly of the hydrous aluminum silicates, halloysite and kaolinite."[28] According to Allen[29] the halloysite occurs as large areas of isotropic material. Recently, however, Allen[30] has informed the writer that John W. Gruner believes the isotropic material is microscopic kaolinite rather than halloysite. The X-ray patterns of typical specimens of flint fire clay were reported, however, by Paul F. Kerr[31] "as those of halloysite with some microscopic kaolinite". More information on this subject has been obtained as the result of X-ray studies by Dr. Paul G. Herold. These are reported in chapter VI. Quartz, in the form of small to medium-sized grains of sand, is sometimes present but more commonly in the clay immediately adjacent to the rim rock. A number of other minerals have been noted in rare instances. Barite (barium sulphate) and selenite (calcium sulphate) sometimes occur in the joint planes. Pyrite, and marcasite, sulphides of iron, and their oxidation products are sometimes present. Chalcopyrite, a copper iron sulphide, has been noted also. An unusual occurrence of small flat flakes of native copper, associated with fragments of coaly material in flint fire clay in the Mason-Rohrer pit near Belle, Maries County, has been described.[32]

26Idem., p. 294.

27Allen, V. T., Mineral composition and origin of Missouri flint and diaspore clays, Mo. Geol. Survey & Water Resources, 58th Biennial Rept. App. IV, 1935.

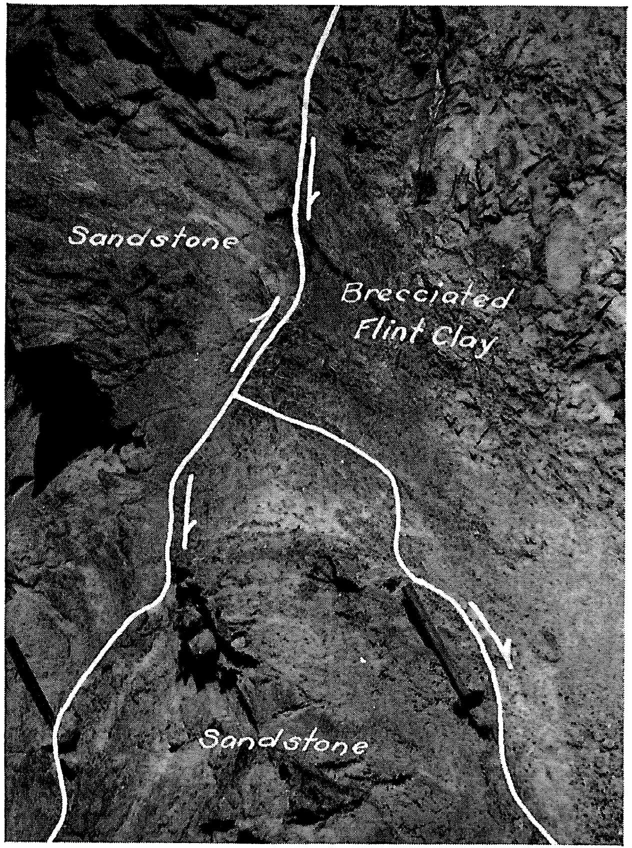
28Idem. p. 7.

29Idem. p. 7.

30Allen, V. T., written communication, Sept. 21, 1942.

31Idem. p. 9.

32McQueen, H. S., Mineral production of Missouri, Mo. Bur. Geol. and Mines, 55th Biennial Rept., p. 55, 1929.



A. View of brecciated flint fire clay faulted into sharp contact with Graydon "rim rock" sandstone. Note downward splitting of fault, north wall Forbes pit, Phelps County.

B. Slickensided surfaces in flint and burley clay, Forbes pit.

The occurrence of a rare mineral in the flint fire clays has recently been determined by Dr. Oliver R. Grawe, who has generously supplied the following description.

METATORBERNITE IN MISSOURI FLINT FIRE CLAY.

By Oliver R. Grawe

In 1940 J. G. Grohskopf of the Missouri Geological Survey obtained from Mr. Edward Sassman, Mining Superintendent, The General Refractories Company, Owensville, Missouri, a specimen of flint fire clay, on the surface of which, were tiny green scales of a mineral not previously observed in the fire clays of Missouri. The specimen was identified by the writer as metatorbernite, a hydrated copper uranyl phosphate, $Cu\ (UO_2)_2 (PO_4)_2 \cdot 8\ H_2O$, and on March 22, 1941 he visited the pit from which the mineral was obtained. This pit is one of the typical sink structures common to central Missouri. It is on land owned by Eliza Gelauf in the NW¼ SW¼ SW¼ sec. 32, T. 42 N., R. 3 W., about 5½ miles southeast of Gerald, Franklin County.

The mineral occurs as very thin apple green plates, square or octagonal in outline, and about one to two millimeters on edge. The plates are soft, have a distinct pearly luster, and a refractive index of 1.626 in the square section. They yielded distinct tests for copper, uranium, and the phosphate ion, and distinctly fogged a photographic film on which they were placed, indicating their radioactivity.

The mineral was observed to occur chiefly on spheroidal masses of bad clay, so-called "sore spots" about 20 feet beneath the surface, and was associated with barite, a small amount of chalcopyrite, and limonite. It undoubtedly is secondary and is chiefly of interest because of its radioactivity. A determination of the age of this mineral might throw some light on the time at which some mineralization took place in Missouri. So far as the writer is aware, this is the first radio active mineral to be described from the State.

* * * * * * * *

The chemical composition of flint fire clay is remarkably uniform. That it is an hydrous aluminum silicate is best shown by the chemical analyses presented in Table 11. In connection with the present report many analyses of flint fire clay, made in the chemical laboratory of the Missouri Geological Survey, have been studied. An average of these analyses has shown the following composition:

Constituent	*Percent*
Alumina (Al_2O_3)	38
Silica (SiO_2)	43
Ignition Loss	13

In addition to the foregoing, iron is present in varying amounts and also titania up to approximately two per cent. Calcium and magnesium, as oxides, and sodium and potassium are usually present in very small amounts. Phosphorus and sulphur are probably present in very small amounts.

Flint fire clay is used chiefly in the manufacture of high grade fire brick and refractories. It has also been used in the manufacture of zinc retorts. A considerable tonnage is also used annually by the rubber industry as a compounding ingredient and in the manufacture of chemicals. The results of a firing behavior test on a sample of hard, fine-grained, homogeneous, white flint fire clay, the "pop-corn" variety of the southern district, Sample No. 10 of the table of analyses, is presented in chapter V.

Burley clay. This term is applied to those clays containing rounded particles or lumps ranging in size from small oolite or shot-like particles to small nodules, the latter often being an inch in size. To these particles the name "burls" was given locally, and the term has been so persistently used that it is now universally recognized and accepted. The term is a misnomer, however, and is losely applied to those clays which range from a "burley" or "rough flint" on one end to diaspore or high alumina clay on the other. Hence it may refer to an hydrous aluminum silicate containing a minimum of approximately 45% alumina, or it may refer to an hydrated oxide of alumina containing as much as 60% alumina. The gradation or chemical range of this clay is believed to be directly related to its origin, as will be discussed more fully in the chapter devoted to the origin of the clays. The burley clay is believed to be the gradational product in the change of flint fire clay, an hydrous aluminum silicate, to an hydrated oxide of alumina, diaspore clay, through leaching by ground water. The physical properties of burley clay are difficult to describe. It may look like flint fire clay with a few included

A. Vertical jointing in flint fire clay, Fisher pit, north of St. James, Phelps County.

B. Steeply inclined and jointed flint fire clay, Forbes pit, north of Rolla, Phelps County.

TABLE 11.

CHEMICAL ANALYSES OF FLINT FIRE CLAYS, SOUTHERN DISTRICT.

Sample No.	1	2	3	4	5	6	7	8	9	10
Ignition Loss (H_2O, + 110° C.)...	13.16%	13.81%	11.75%	13.40%	12.31%	12.96%	13.19%	14.00%	13.80%	13.19%
Moisture (H_2O, — 110° C.)......	2.13	0.66	1.23	0.63	0.93	0.70	0.49	ND	ND	0.43
Silica (SiO_2)....................	39.99	44.28	42.18	43.70	43.50	41.67	44.99	44.36	43.67	43.32
Alumina (Al_2O_3)................	38.20	36.94	40.50	39.65	37.92	38.22	37.37	36.64	38.87	38.18
Ferric Oxide (Fe_2O_3).............	2.42	1.19	0.91	0.79	3.79	3.26	4.52	1.77	0.44	1.56
Titania (TiO_2)...................	2.15	0.53	0.59	0.27	0.24	0.27	0.32	2.14	2.64	1.58
Lime (CaO)....................	0.36	0.78	1.09	0.65	0.52	0.77	0.32	0.35	0.02	0.39
Magnesia (MgO)................	0.60	1.07	0.27	0.12	0.52	1.22	0.32	0.12	0.14	0.11
Soda (Na_2O)....................	ND	0.38	0.07	0.20	0.07	1.21	0.00	ND	0.34	0.08
Potash (K_2O)	ND	0.44	1.36	0.26	0.38	0.12	0.98	ND	0.10	0.49
Phosphorus Pentoxide (P_2O_5).....	ND	None	0.26	0.33	0.10	0.05	0.20	ND	ND	0.098
Sulphurous Oxide (SO_3)..........	ND	None	Tr	Tr	Tr	0.41	Tr	ND	ND	0.02
Totals.....................	99.01	100.08	100.26	100.00	100.32	100.86	99.88	99.38	100.02	99.548

ND. Not determined.

Sample No. 1—White, smooth, hard flint fire clay, Bullington pit, NE ¼ sec. 9, T. 41 N., R. 5 W., Gasconade County.
Sample No. 2—White, hard, flint fire clay, Johnson pit, near Anaconda, Franklin County.
Sample No. 3—Flint fire clay, McCurdy pit near Owensville, Gasconade County.
Sample No. 4—Hard flint fire clay, Wacker pit.
Sample No. 5—Flint fire clay, iron stained, Frank Parting pit, NW ¼ SE ¼ sec. 15, T. 43 N., R. 9 W., Osage County.
Sample No. 6—Flint fire clay, Curtat pit, SE ¼ SE ¼ sec. 14, T. 44 N., R. 8 W., Osage County.
Sample No. 7—Oolitic flint clay, Oscheskey pit, NE ¼ NW ¼ sec. 14, T. 44 N., R. 7 W., Osage County.
Sample No. 8—White flint Clay, J. F. Bacon pit, SW ¼ sec. 35, T. 41 N , R. 3 W., Franklin County.
Sample No. 9—White flint clay, W. S. Dickey pit, Versailles, Morgan County.
Sample No. 10—Hard, white, hard "pop corn". flint fire clay, General Refractories Company, Pieuch pit No. 2, SW ¼ sec. 11, T. 42 N., R. 5 W., near Owensville Gasconade County.

round "burls" or it may resemble more closely the rough textured diaspore clay. The firing behavior of the clay is likewise variable.

The minerals common to the other clays are likewise found in burley clay. Allen[33] reports, "The most conspicuous difference between burley clay and diaspore clay revealed by petrographic examination is that the number of diaspore oolites is less and many of these are smaller in burley clay than in diaspore clay."

Allen[34] also reports the presence of gibbsite, and an isotropic material that suggests an intermediate stage between halloysite and cliachite. Allen[35] also reports the results of X-ray studies by Dr. Paul F. Kerr, who found patterns "similar to those of bauxite with fine kaolinite or halloysite". Further X-ray data are given in chapter VI.

TABLE 12.

Chemical Analyses of Burley Clay
H. W. Mundt, Analyst

Sample No.	1	2	3	4	5	6
Ignition Loss (H_2O,+110°C.)	12.34%	13.38%	12.08%	13.18%	13.27%	12.00%
Moisture (H_2O,−110°C.)	1.16	0.52	0.65	.92	0.30	1.64
Silica (SiO_2)	22.96	23.50	23.94	32.60	32.48	41.09
Alumina (Al_2O_3)	58.51	55.53	53.57	48.26	46.53	41.14
Ferric Oxide (Fe_2O_3)	0.63	0.75	0.51	0.49	0.38	1.47
Titania (TiO_2)	2.10	3.58	3.08	2.25	2.38	1.50
Lime (CaO)	0.40	0.22	0.53	0.28	0.69	0.26
Magnesia (MgO)	0.98	0.38	0.14	1.62	0.66	0.12
Soda (Na_2O)	0.65	ND	3.46	0.61	2.08	0.19
Potash (K_2O)	1.67	ND	2.33	0.54	1.39	0.40
Totals	101.40	97.86	100.29	100.75	100.16	99.81

ND Not determined.

Sample No. 1. Burley clay, Brown pit, NW¼ Sec. 25, T. 42 N., R. 4 W., 5 miles southeast of Owensville, Gasconade County.

Sample No. 2. Burley clay, Travis pit, NE¼ SE¼ Sec. 29, T. 41 N., R. 7 W., Maries County.

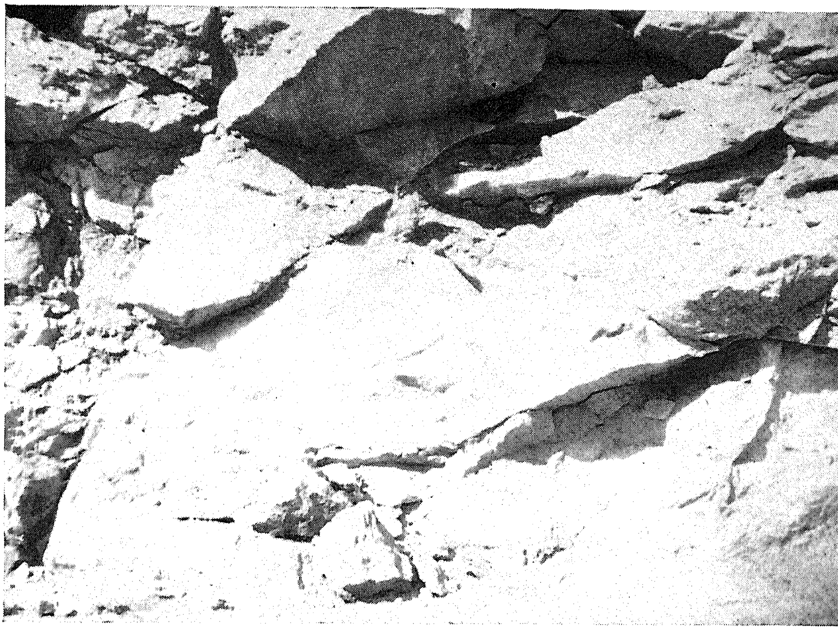
Sample No. 3. Burley clay, with high alkali content, Travis pit, NE¼ SE¼ Sec. 29, T. 41 N., R. 7 W., Maries County.

Sample No. 4. Burley clay, Kahle pit, SW¼ Sec. 22, T. 44 N., R. 5 W., near Swiss, Gasconade County.

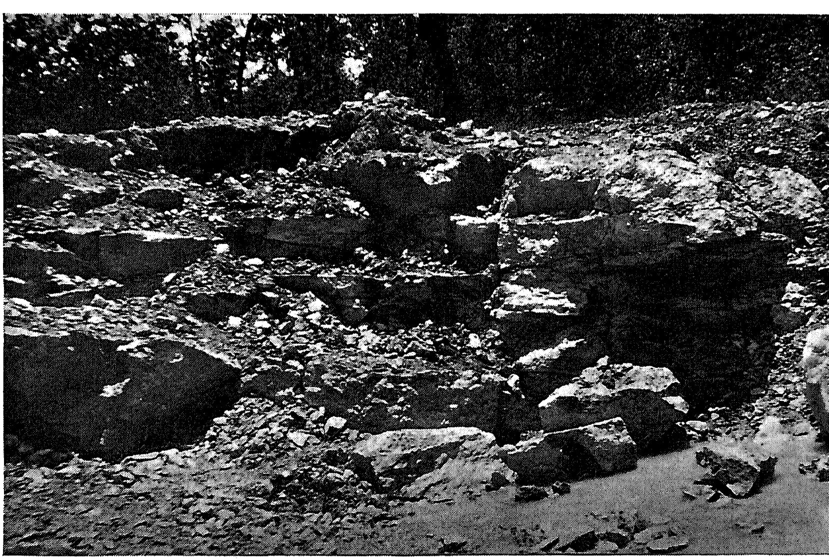
Sample No. 5. Burley clay, Sassman pit, NW¼ NE¼ Sec. 32, T. 42 N., R. 5 W., Gasconade County.

Sample No. 6. Burley-flint clay, Fitzgerald pit, Bland, Gasconade County.

[33]Idem. p. 13.
[34]Idem. p. 13.
[35]Idem. p. 14.



A. Massive face of high grade porous diaspore clay, Forbes pit, Phelps County. Smooth face extreme upper center is a slickensided surface.



B. Hard rock-like, finely porous high grade diaspore clay interbedded with thin seams of soft "talcum powder" clay. Aufderheide pit, Gasconade County.

The chemical composition is no exception as to the variability of this clay, and as shown by Table 12, covers the range of increase in alumina and the decrease in silica from flint clay to diaspore clay. In some instances, the burley clay appears to have a higher content of fluxes, particularly alkalies, than the other clays. The reason for this is not fully understood. It may represent the cessation of the leaching cycle for some reason, and the resultant concentration of the soluble constituents. As the burley clays are the intermediate leaching product, the concentration in them of the soluble impurities could reasonably be greatest.

Diaspore clay. This high alumina clay is found in commercial quantities only in Missouri. The occurrence is confined solely to the southern district, with a few exceptions in the extreme southern portion of the northern district. In those exceptions in the northern district, the sink-hole sandstone-lined type of deposit and the same general geologic relations that have been described in the southern district, are found. Such occurrence suggests the close relationship and a further general correlation of the districts, and further establishes the idea that sandstone-lined sink-hole type deposits alone contain the higher alumina clays.

The diaspore clay as defined in the district consists of two grades. The No. 1 diaspore carries more than 70 per cent alumina. No. 2 diaspore carries 60 to 70 per cent alumina. In some instances a grade known as number two diaspore has been used to designate those clays containing 65 to 70 per cent alumina, and in such instances a third grade or No. 3 diaspore, containing 60 to 65 per cent alumina has also been designated. In this connection it might be mentioned that different classifications of burley clay are used, and in some cases overlap the above grades, particularly the one used locally as No. 3. The figures given above, however, are believed to be in more common usage, and the burley grade usually is designated for those rough-textured clays falling below 60 per cent alumina.

The diaspore clay occurs in several forms or varieties, none of which appears to determine or govern the alumina content. A common form is a porous, spongy or ashy, rough-textured mass (Pl. XXXI, A). In some instances the clay is only finely porous, in others it is more coarsely so and then greatly resembles the texture of the usual run of commercial lightbread.

Another variety of diaspore clay is the so-called mealy type. It too, is porous, but it is chiefly characterized by being much softer, and "mealy". This type, however, appears to become harder upon long exposure to weathering. On the other hand the diaspore clay may be oolitic, that is made up of small shot-like particles, up to possibly one-eighth of an inch in diameter. Pisolites or larger rounded particles, and even small nodules composed of a mass of diaspore crystals have been noted. They are, however, more common to the burley clay grade.

Another variety is a hard, rock-like type of diaspore clay that may be slightly oolitic, or may even be marked by extremely fine pores. In exposure in a pit face, this type when viewed from a distance often resembles thin bedded, jointed limestone. In addition, what may be a related and peculiar, very hard, rock-like type of high alumina clay, which closely resembles flint fire clay, but which has an apparently greater density, has been reported in previous pages as having been recently discovered in the Klossner pit, sec. 15, T. 44 N., R. 5 W., at Swiss, Gasconade County. This clay was first called to the writer's attention by Ben K. Miller, Mining Superintendent, A. P. Green Fire Brick Company, who reported an alumina content of approximately 71 percent. Subsequent X-ray studies by Herold have suggested the clay mineral is boehmite, a monohydrate of alumina closely related to diaspore, but different from it in crystallization. The occurrence of boehmite,[36] has been reported in Ayrshire (Scotland) fire clays by De Lapparent. A more detailed discussion of the results of X-ray studies of this clay is given by Herold in chapter VI.

In the mode of occurrence, it is interesting to note that in the Klossner pit, sec. 15, T. 44 N., R. 5 W., in the south portion of the village of Swiss, Gasconade County and on the east side of State Highway No. 19, this type of clay occurs as a bed, the thickness of which could not be precisely determined. However, it probably does not exceed a few feet. The clay was dipping rather steeply. Overlying this clay unconformably

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[36]De Lapparent, J., Boehmite and diaspore in Ayrshire (Scotland) fire clays, Compte Rende, 199, pp. 1629-31, 1934.

and showing a lesser degree of dip, was dark colored carbonaceous flint fire clay.

The same general relations exist in the Kallmeyer pit, operated by the General Refractories Company in the NW¼ sec. 35, T. 45 N., R. 6 W., near Stolpe, Gasconade County. Here the hard high alumina clay, again boehmite, according to X-ray analysis, forms a cap about one foot thick of a seven foot bed of diaspore clay. The overlying material again is hard, dark-colored carbonaceous flint fire clay, containing thin lenses and beds of cannel and sub-bituminous coal.

In the Harbison-Walker Refractories Company, Aufderheide pit, NE¼ NE¼ sec. 36, T. 43 N., R. 6 W., Gasconade County, a similar hard, fine-grained, rock-like "diaspore" clay was obtained. This clay also had a high alumina content. Again, it occurred as thin bedded material associated with a peculiar soft type of plastic clay (Pl. XXXI, B).

The occurrence of such clays in the manner described suggests weathering or laterization along an unconformity, and the formation of a high alumina clay prior to the sinking into a pit and prior to the deposition of the overlying clays. In the case of the Klossner pit discordance in bedding is indicated between the two clay zones. Similar relations are suggested by the Kallmeyer pit, also. It has, however, not been developed fully, therefore the relations are not perfectly clear.

The Aufderheide pit was a shallow one, some 30 feet deep, it did not exhibit steep dips, in fact was more suggestive of a shallow basin type deposit than of a sink-hole type deposit resulting from subsidence. Additional comments on this subject will be found also in the chapter devoted to the origin of the clays.

Diaspore clay is found in a fairly wide range of colors. It may be light, and in the case of some very low, or almost iron free varieties, it is almost white. Light and dark gray are also common colors. The presence of iron oxide is a determining factor in the color, and imparts to the clay colors ranging from buff to light brown to various shades of red. There is produced in the district for special purposes, a variety of high iron bearing clay to which the term "red diaspore" is given.

Mineralogically, and physically, the diaspore clay is found to be composed of two fractions, a hydrated aluminum oxide, and a complex aluminous titanium silicate. Early work by

H. W. Mundt and the writer showed that the two fractions could be separated in the laboratory and, as will be shown later, the separate fractions are vastly different in chemical composition.

The presence of the mineral diaspore in the Missouri clays was probably first reported by Wherry.[37] At or about the same time, the high alumina content and the nature of the clay had been determined and reported upon by Buehler.[38] Subsequently the identification was verified microscopically by Somers[39] and more recently the mineralogy of this clay has been considered by Allen,[40] who reports "the optical and X-ray data are in agreement that diaspore is the characteristic mineral making up 85 to 90 percent of diaspore clay."

Less is known regarding the mineralogy of the fine fraction obtained in a mechanical separation of high grade diaspore clay. The chemical composition is that of a complex aluminum silicate with a comparatively high percentage of titania. Allen[41] states that optically "the fine material is partly isotropic and partly opaque and the mineral cliachite (Al_2O_3 nH_2O) is most closely related to the optical properties exhibited by the fine isotropic material." Allen[42] has also considered in detail the comparatively high titania content and has concluded that it is due to the presence of leucoxene, which according to Coil,[43] as quoted by Allen, is an amorphous, hydrous titanium oxide. Allen further states: "All avenues of approach converge towards leucoxene as being the titanium mineral, which accounts for the major portion of the titania in analyses of Missouri diaspore clay." It would appear, therefore, that this clay was an aluminum silicate carrying leucoxene. In recent months the discovery of a new high alumina mineral, boehmite through X-ray analysis as reported in previous pages, has resulted in added interest and will lead no doubt to a more careful examination of the harder and heavier,

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[37]Wherry, E. T., Diasporite in Missouri: Am. Miner., Vol. 2, p. 144, 1917.

[38]Buehler, H. A., Mo. Bur. Geol. and Mines, Bien. Rept. State Geologist, 50th General Assembly, pp. 17-20, 1919.

[39]Ries, H., and others, High grade clays of the eastern United States: U. S. Geol. Survey Bull. 708, p. 299, 1922.

[40]Allen, V. T., Mineral composition and origin of Missouri flint and diaspore Clays, Mo. Geol. Survey and Water Resources, 58th Bien. Rept., p. 10, 1935.

[41]Idem. p. 11.

[42]Idem. p. 13.

[43]Coil, Fay, Chemical composition of Leucoxene in the Permian of Oklahoma: Am. Min., Vol. 18, pp. 62-65, 1933.

Idem. p. 12.

fine-grained clays, which in the past may have been shipped to some extent as flint fire clay. The nature of this clay is such that it is most amenable to study by X-ray analysis. The results thus obtained by Herold are discussed in chapter VI.

At this point it would be advisable to mention the diaspore clay with a high iron oxide content, which occurs either as the oxide thoroughly disseminated throughout the mass or as rythmically arranged bands of dark brown colored iron oxide. This form of iron oxide is known as "iron-band" diaspore. In every instance the diaspore associated with this type of ore is of the highest quality, high in alumina and low in silica. Invariably it is of the porous, ashy, rough-textured type, and the banding, ranging in thickness from a thin line to an inch or more is the direct replacement of diaspore clay by iron oxide. The iron band diaspore varies in shape from nodules to rectangular blocks and in size from small pieces to very large ones. There is no question, but what the iron band is a direct replacement of the diaspore possibly by iron carbonate, which has been subsequently oxidized. A discussion of the mode of origin will be found in the chapter of this report devoted to the origin of the clays.

In this connection it is interesting to note the presence of siderite, or iron carbonate, associated with a diaspore clay in the Camp Ground pit near the center of the south line, sec. 30, T. 39 N., R. 7 W., near Vichy, Maries County, and in the Mueller pit N½ SW¼ sec. 5, T. 44 N., R. 5 E., Gasconade County. In both pits large rock like masses of diaspore clay impregnated with iron carbonate were found. The following chemical analysis was furnished by P. E. O'Rourke.[44]

Chemical Analysis of "Hard Sample" from Camp Ground Pit. Waring and Williams, Analysts

Constituent	*Percent*
Ignition Loss, other than Carbon Dioxide (CO_2)	17.18
Carbon Dioxide (CO_2)	5.10
Silica (SiO_2)	2.68
Ferrous Oxide (FeO)	8.33
Ferric Oxide (Fe_2O_3)	19.34
Alumina (Al_2O_3)	42.05
Titania (TiO_2)	2.32
Lime (CaO)	0.03
Magnesia (MgO)	2.12
Na_2O	0.73
Undetermined	0.12
Total	100.00

[44]Written communication dated Sept. 17, 1942.

These occurrences at once suggested that the iron originally occurred as the carbonate, siderite, which was disseminated or arranged in bands in the diaspore clay. The origin of the high iron diaspore of the district is at once suggested, for with the oxidation of the iron-carbonate mineral siderite ($FeCO_3$), the iron oxide (FeO) would be left behind. Both forms of iron-oxide are present, the iron-bands being the most common. A splendid example of this type was present at the Wallace or "Red" mine, NE¼ sec. 29, T. 41 N., R. 7 W., not far from the southern limits of the town of Belle, Maries County. A deep uniformly red clay containing small particles of limonite also occurred in this pit.

In this connection it is interesting to record the occurrence of calcium carbonate in diaspore clay. In the Mueller pit, SW¼ NW¼ sec. 5, T. 44 N., R. 5 W., west of Swiss, Gasconade County, there occurs a dense, hard rock-like mass which, upon analysis, shows the following composition:

CHEMICAL ANALYSIS OF DIASPORE CONTAINING CALCITE

R. T. ROLUFS, *Analyst*

Silica (SiO_2)	5.84%
Alumina (Al_2O_3)	42.30
Ferric Oxide (Fe_2O_3)	3.03
Titania (TiO_2)	1.68
Lime (CaO)	20.69
Magnesia (MgO)	0.16
Sulphur	0.025
Phosphorus (P_2O_5)	0.05
Soda (Na_2O)	0.27
Potash (K_2O)	1.32
Moisture	0.12
Ignition Loss	24.16
Total	99.645

Upon weathering the calcium carbonate is dissolved out leaving boulders of high grade, open-textured, very porous diaspore clay. Calcium carbonate occurs as calcite, and when viewed in mass it resembles fine-grained to slightly crystalline limestone. The calcite is considered to be secondary, and was possibly derived from the break down of the limestone of the Henrietta group and redeposited in the porous diaspore.

Many chemical analyses of diaspore clay are available for study. Table 13 presents a series of analyses of specially collected samples of diaspore clay. These were collected for the purpose of having complete chemical analyses made, and also, for the purpose of having the firing behavior of each sample determined. In addition analyses of the heavy fraction are also available and two of these are presented in Table 14. They substantiate, by the high alumina content and the chemically combined water or loss on ignition, that the mineralogical determination of the mineral diaspore as the dominant constituent of this clay is correct.

The results of the firing behavior tests are given in Chapter V. A series of analyses of the number one and number two grades of diaspore are given in Table 13. These are presented to show the variation in chemical composition.

TABLE 13.

Chemical Analyses of Diaspore Clay.

H. W. Mundt, Analyst

Sample No.	1	2	3	4	5	6
Ignition Loss (H_2O,+110°C.)	13.74%	14.20%	14.42%	13.57%	13.15%	13.52%
Moisture (H_2O,−110°C.)	0.18	0.36	0.36			0.78
Silica (SiO_2)	4.50	3.89	4.56	12.59	12.30	15.60
Alumina (Al_2O_3)	75.62	76.21	76.15	68.32	67.76	64.46
Ferric Oxide (Fe_2O_3)	1.08	0.98	0.70	1.29	0.69	0.42
Titania (TiO_2)	4.00	3.52	2.75	2.04	3.04	2.60
Lime (CaO)	Trace	0.08	0.16	1.85	1.85	0.92
Magnesia (MgO)	0.39	0.06	0.30	0.15	0.18	1.52
Soda (Na_2O)	ND	0.79	0.33	1.34	0.74	0.37
Potash (K_2O)	ND	0.24	Tr.	0.19	0.40	0.81
Totals	99.51	100.33	99.73	101.34	100.11	101.00

ND Not determined.

Sample No. 1. Diaspore clay, No. 1 grade, weathered boulder from surface of Aufderheide pit, NE¼ NE¼ Sec. 36, T. 43 N., R. 6 W., Gasconade County.

Sample No. 2. Diaspore clay, No. 1 grade, Travis pit, NE¼ SE¼ Sec. 29, T. 41 N., R. 7 W., Maries County.

Sample No. 3. Diaspore clay, Decker and Lacy pit, NE¼ Sec. 15, T. 41 N., R. 6 W., Gasconade County.

Sample No. 4. Diaspore clay, No. 2 grade, Wettling pit, SW¼ NW¼ Sec. 16, T. 44 N., R. 5 W., Gasconade County.

Sample No. 5. Diaspore clay, No. 2 grade, Fleutsch pit, SW¼ SE¼ Sec. 16, T. 44 N., R. 5 W., Gasconade County.

Sample No. 6 Diaspore clay, No. 2 grade, Stoltz (Mueller) pit, NW¼ Sec. 6. T. 42 N., R. 2 W., 1 mile west of Beaufort, Franklin County.

In addition to iron, the occurrence of which has been described, the other chief impurity in diaspore clay is titania. This constituent has previously been described in the section devoted to the mineralogy of the diaspore clay, and its occurrence will again be indicated in the discussion of the light or plastic clay fraction obtained in a mechanical breakdown of diaspore clay. The occurrence of titania, at times in appreciable amounts, is believed to be significant however, especially in connection with the solution of the problem of the origin of the clays. In the flint clays the titania content will vary from one to about two percent. If these clays were altered, it would be expected that the titania content would be concentrated for the titania bearing minerals are generally considered to be stable in the zone of weathering. The increases as revealed by the analyses of the diaspore clays are believed to be significant in this connection.

Other impurities are calcium and magnesium oxides. These constituents, insofar as the writer knows are never present in diaspore clay, or in fact in any of the clays in large amounts. There is a possibility, however, that should be considered in connection with the chemical composition, and that is the presence of limestone, either as a capping or as nodules in green shale in the structural centers of some of the larger pits of the district. Such occurrences have been described in the chapter devoted to the stratigraphy of the Fort Scott formation in the southern district. The breakdown of such limestone in the zone of surface weathering and the transportation of the calcium (lime) oxide by downward circulating waters, and its precipitation in the clays of the pits, would be accomplished without difficulty and with determental effect upon the clays involved. The calcite bearing material previously described is an example.

The writer recalls that the Fornberg pit, NW¼ SW¼ sec. 30, T. 43 N., R. 5 W., Gasconade County, one of the largest ones in the district, was once looked upon unfavorably because the clays were reported to be high in lime. This occurrence may have resulted as mentioned above, or conceivably could have resulted from scraping or chipping of the limestone cap, or from the introduction of small nodules of limestone contained in the associated green shale, during the drilling of the pit. The limestone and shale are well developed and form a mass in what appears to be the structural center of this deposit. Clays with a high lime content should be carefully considered before the pit containing them is rejected.

TABLE 14.

Chemical Analyses of Oolitic Fractions of Diaspore Clay.
H. W. Mundt, Analyst.

Sample No.	1	2
Ignition Loss (H_2O,+110° C.)	14.86%	14.73%
Moisture (H_2O,−110° C.)	0.08	.01
Silica (SiO_2)	2.14	2.46
Alumina (Al_2O_3)	79.04	81.29
Ferric Oxide (Fe_2O_3)	0.70	0.69
Titania (TiO_2)	2.92	1.95
Lime (CaO)	0.24	0.20
Magnesia (MgO)	0.28	0.00
Totals	100.26	100.03

Sample No. 1 Oolitic portion of No. 1 diaspore clay, Leach pit, SE¼ SE¼ sec. 22, T. 42 N., R. 7 W., Maries County.

Sample No. 2 Oolitic portion of No. 1 diaspore clay, John Holt pit, NE¼ sec. 30, T. 40 N., R. 5 W., Gasconade County.

Occasionally diaspore clay is reported to have a high alkali content, and in some cases a clay marked by small white spots, which give a mottled appearance, has been rejected. All such clay, however, is not comparatively high in alkali content and there are, no doubt, waste piles of such clay throughout the district that could be utilized. In any event a comparatively high alkali content is of no importance in the case of high alumina-low silica diaspore clay of high fusibility. Studies by H. W. Mundt suggest that the alkali content of the diaspore clay is concentrated in the fine or plastic clay binder, which makes up 10 percent or more of the diaspore clay. There has been a suggestion that a high alkali content will be present in diaspore clay at or near the bottom of the pit. This is not always true. However, a high alkali content is suggestive that leaching action was stopped and either the alkalies concentrated locally or that leaching had not been completed to the stage of almost entire removal.

The chemical composition of the heavy and light fractions that comprise the diaspore clay, obtained through mechanical fractionation, has been revealed as the result of an exhaustive series of analyses by H. W. Mundt, formerly chemist, Missouri Geological Survey.

The following experimental work was undertaken by him. A sample of No. 1 grade diaspore clay was broken with a wooden mallet and disintegrated in a ball mill for two hours. The sample was then run through a blunger for two hours and washed by decantation with a resultant separation of a heavy or coarse fraction and a light or fine fraction. The following fractions were thus obtained from a treatment of a No. 1 grade diaspore clay from the Leach or Matthews pit, SE¼ SE¼ sec. 22, T. 41 N., R. 7 W., Maries County.

No. of Fraction	*Material*	*Percent of original sample*
1	Coarse separate retained on 100 mesh screen......	50
2	Material passing through 100 mesh screen........	40.6
3	Fines screened from No. 2........................	9.4
	Total	100.00

In addition a sample of fraction number 3 was passed through a specific gravity solution and that portion, which floated at specific gravity 2.95, but sank at 2.82, was recovered for chemical analysis. The samples above described were analyzed with the results being given in Table 15.

TABLE 15.

Chemical Analyses of Diaspore Clay Fractions, Leach or Matthews Pit. H. W. Mundt, Analyst.

Sample No.	1	2	3	4
Ignition Loss (H_2O,+100° C.)	13.74%	14.44%	14.37%	10.10%
Moisture (H_2O,−100° C.)	0.17	0.08	0.07	0.57
Silica (SiO_2)	6.85	4.91	5.29	27.17
Alumina (Al_2O_3)	73.67	76.27	76.22	41.05
Ferric Oxide (Fe_2O_3)	0.61	0.56	0.70	2.07
Titania (TiO_2)	3.90	3.03	2.87	10.91
Lime (CaO)	0.20	0.52	0.68	1.02
Magnesia (MgO)	0.38	0.56	0.46	0.90
Totals	99.52	100.37	100.66	93.79

Sample No. 1 Diaspore clay, No. 1 grade.

Sample No. 2 Coarse or heavy fraction obtained from No. 1, 50 percent of original sample by weight.

Sample No. 3 Coarse or heavy fraction through 100 mesh 40.6 percent of heavy separate.

Sample No. 4 Fine or light material, 9.4 percent of original sample.

From the foregoing analyses it becomes apparent that the coarse material contains the highest percentage of the mineral diaspore, hence the highest percentage of alumina. The fine fraction is much lower in alumina, higher in silica, and also contains a much higher titania content. The fines obtained by washing and the same fraction obtained by separation in a specific gravity solution are of markedly similar composition. A concentration of lime and magnesia in the fine fractions will be noted. There is also a suggestion in the unbalanced analysis of the fines of a concentration of the alkalies.

A similar study was made of a sample of No. 1 diaspore from the John Holt pit sec. 30, T. 42 N., R. 5 W., Gasconade County. The fractions were separated by washing only. The chemical analyses are given in Table 16.

TABLE 16.

Chemical Analysis of Diaspore Clay Fractions, Holt Pit.
H. W. Mundt, Analyst.

Sample No.	1	2	3
Loss on Ignition (H_2O,+100° C.)	14.06%	14.73%	12.04%
Moisture (H_2O,−100° C.)	0.12	0.01	0.24
Silica (SiO_2)	5.67	2.10	17.74
Alumina (Al_2O_3)	73.86	80.45	54.14
Ferric Oxide (Fe_2O_3)	1.26	0.83	1.44
Titania (TiO_2)	3.81	1.95	10.77
Lime (CaO)	0.48	0.22	0.56
Magnesia (MgO)	0.32	0.28	0.62
Totals	99.58	100.57	96.85

Sample No. 1 No. 1 grade diaspore clay.

Sample No. 2 Coarse material, not sized, obtained by crushing, and washing of No. 1, 74.2 percent of original sample by weight.

Sample No. 3 Fine material, obtained as in sample No. 2, 25.8 percent of original sample.

A sample of low grade diaspore, or more specifically burley clay from the Travis pit, NE¼ SE¼, sec. 29, T. 41 N., R. 7 W., Maries County, was also fractionated by crushing and washing and the results of chemical analyses of the original material and the fractions are given in Table 17.

TABLE 17.

Chemical Analyses of Diaspore (Burley) Clay Fractions, Travis Pit

H. W. Mundt, Analyst.

Sample No.	1	2	3	4
Ignition Loss (H_2O,+110°C.)	13.38%	13.77%	13.90%	13.27%
Moisture (H_2O,−110°C.)	0.52	0.64	0.41	0.37
Silica (SiO_2)	23.50	20.49	30.80	30.09
Alumina (Al_2O_3)	55.53	60.43	46.70	47.66
Ferric Oxide (Fe_2O_3)	0.75	0.81	1.06	1.07
Titania (TiO_2)	3.58	3.21	3.94	4.34
Lime (CaO)	0.22	0.28	0.28	0.27
Magnesia (MgO)	0.38	0.40	0.40	0.33
Totals	97.86	100.03	97.49	97.40

Sample No. 1 No. 3 diaspore (burley) clay.

Sample No. 2 Coarse fraction obtained after crushing and washing of sample No. 1, 64.5 percent of original sample by weight.

Sample No. 3 Fine fraction as in No. 2, 35.5 percent of original sample by weight.

Sample No. 4 Fine fraction recovered by separation through specific gravity solution, float at 2.82, sink at 2.70.

Similar treatment was given by Mundt to a sample of burley clay from the Travis pit. Chemical analyses of the original material and the washed fractions thereof are given in Table 18.

TABLE 18.

Chemical Analyses of Burley Clay Fractions, Travis Pit.

H. W. Mundt, Analyst.

Sample No.	1	2	3
Ignition Loss (H_2O, 110° C.)	13.39%	13.90%	13.25%
Moisture (H_2O,−110° C.)	0.39	0.16	0.33
Silica (SiO_2)	33.38	27.22	38.53
Alumina (Al_2O_3)	47.81	54.83	40.27
Ferric Oxide (Fe_2O_3)	0.79	0.75	0.99
Titania (TiO_2)	3.02	2.67	3.44
Lime (CaO)	0.24	0.20	0.22
Magnesia (MgO)	0.36	0.32	0.36
Totals	99.38	100.05	97.29

Sample No. 1 Burley clay.

Sample No. 2 Heavy, fraction obtained by crushing and washing of sample No. 1, 47.7 percent of original sample by weight.

Sample No. 3 Light fraction, as in No. 2, 52.3 percent of original by weight.

Allen[45] has also considered the nature of the plastic clay that bonds the oolitic portion of diaspore clay and published two interesting analyses as follows:

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[45]Allen, V. T., Mineral composition flint and diaspore clays, Mo. Geol. Survey, 58th Bien. Report, State Geologist, App. IV, p. 11, 1935.

TABLE 19.

Chemical Analyses of Plastic Clay, Separated from Diaspore Clay

R. T. Rolufs, Analyst.

Sample No.	7	8
Silica (SiO_2)	14.18%	22.14%
Alumina (Al_2O_3)	54.98	30.78
Ferric Oxide (Fe_2O_3)	1.56	1.56
Titania (TiO_2)	13.74	24.22
Lime (CaO)	.70	.60
Magnesia (MgO)	.02	.03
Soda (Na_2O)	.20	ND
Potash (K_2O)	1.64	ND
Moisture (H_2O, −110° C.)	0.45	0.90
Ignition Loss (H_2O, +110° C.)	12.98	14.00
Totals	100.45	94.23

ND Not determined.

Sample No. 7 Fine separate from diaspore clay, Forbes pit, NW¼ sec. 35, T. 38 N., R. 8 W., Phelps County. Separated by V. T. Allen, analyzed by R. T. Rolufs.

Sample No. 8 Fine separate from diaspore clay passing through filter paper, Forbes pit, NW¼ sec. 35, T. 38 N., R. 8 W., Phelps County. Separated by V. T. Allen, analyzed by R. T. Rolufs.

Diaspore clay is used in the manufacture of super refractories and particularly for those uses where high temperatures are encountered for sustained periods. It is also used where various types of slags are in contact at high temperatures and a notable success has been attained in the use of liners manufactured from diaspore clay for rotary cement kilns. Much ceramic research work has been done on diaspore clay, in order to bring refractories made from it to the present state of development. One of the chief difficulties encountered was in curing the shrinkage, particularly after the refractory was placed in service.

Diaspore clay has also been used in the manufacture of certain types of high alumina cement, the iron-band type being utilized chiefly for this purpose. Although previously rejected for refractory manufacture, there has been in recent years some use of this type clay for this purpose. Diaspore clay was also used at one time for the manufacture of abrasives, and various grades from the white to the red iron-bearing types were used. A low silica ore was required for this purpose.

The possibilities of using diaspore clay in the manufacture of aluminum has been considered since the material was first discovered. The tonnage of material available at present does not seem to be sufficiently large to warrant establishing a large scale plant. Further, the diaspore clay is not suitable for treatment by the methods now used in processing bauxite. Another factor to be considered in this connection is the variability in alumina content and the range in composition from an aluminum silicate to an hydrated oxide, which would present not only a problem in large scale mining operations, but an even more acute problem in processing. These problems might reasonably be eliminated, however, by intensive prospecting to build up a reserve tonnage and by research work in connection with processing the clay.

Plastic clay. Three types of plastic clay are associated with the non-plastic flint fire clay and the aluminous burley and diaspore clays. One, a fairly common type, has the characteristic physical properties of flint fire clay except that it is softer, and is more plastic. In reality this clay, although mined and shipped as a plastic clay, is a semi-flint clay. It is known in the district as "bond" or "soft" or "plastic" flint clay. It appears to be a product formed in the weathering of flint fire clay, and apparently results from prolonged exposure to surface water. On the other hand it may represent the alteration and partial purification of possibly the upper member of the Cheltenham clay, or the remnant of a clay of an overlying formation. Local masses are found in some pits and no explanations other than those given may be offered at this time for the occurrence. Probably the best example is the clay now being mined by the A. P. Green Fire Brick Company from the Henneke pit, sec. 24, T. 42 N., R. 5 W., southeast of Owensville, Gasconade County. An analysis is given in Table 20.

Another and less common type of plastic clay is fine-grained, soft, usually white in color, which seems to be associated only with diaspore clay. A considerable tonnage of this material occurred in the Aufderheide pit, NE¼ NE¼ sec. 36, T. 43 N., R. 6 W., where it was interbedded with diaspore clay. The following is the section exposed. It represents the view given in Plate XXXI, B.

Section Measured in Aufderheide Pit.

	Thickness Feet	Thickness Inches
Diaspore clay, hard fine grained	2	0
Clay, plastic, white	1	0
Diaspore, as above	0	8
Clay, plastic, white, slightly oolitic	0	4 to 6
Diaspore, as above	1	4
Clay, plastic, as above, top only exposed	0	4

This clay is possibly a decomposition product and represents a stage in the alteration of an unknown type of clay to diaspore clay. The clay, according to H. W. Mundt[46] has the comparatively high fusion point of cone (PCE) 36, 3290° F. The chemical composition is indicated by the analysis in Table 20.

The third type of plastic clay is a gray, tough, rubbery unctuous, highly plastic material, which occurs commonly filling joint planes in the other clays. "Hog hide" was the name in vogue for this clay a number of years ago. The material is discarded as waste. Roots of present day plants are usually found near the surface in this clay. A chemical analysis of this type of clay is given in Table 20.

TABLE 20.

Chemical Analyses of Plastic Clays, Southern District.

H. W. Mundt, Analyst.

Sample No.	1	2	3
Loss on Ignition	13.57%	13.16%	12.09%
Silica (SiO_2)	33.59	40.13	43.40
Alumina (Al_2O_3)	48.55	38.54	3721
Iron (Fe_2O_3)	0.68	2.28	1.65
Titania (TiO_2)	2.52	2.15	1.68
Lime (CaO)	0.06	0.34	.46
Magnesia (MgO)	0.22	0.32	.36
Sodium (Na_2O)	0.80	ND	.56
Potassium (K_2O)	0.64	ND	1.94
Sulphur (S)	...	...	.012
Phosphorus Pentoxide (P_2O^5)	...	...	.14
Total	100.63	99.05	99.502

No. 1 Soft white plastic bond clay. Aufderheide pit, NE¼ NE¼ sec. 36, T. 43 N., R. 6 W., Gasconade County.

No. 2 Bond clay ("Hoghide") filling joint planes in flint clay, Travis pit, NE¼ SE¼ sec. 29, T. 41 N., R. 7 W., Maries County.

No. 3 Soft flint or "plastic" flint clay, Henneke pit, sec. 24, T. 42 N., R. 5 W., Gasconade County.

The soft flint or bond or plastic flint clays described above have been used as a bonding medium in the manufacture of fire brick. A quantity of the soft plastic clay, of which the material in the Aufderheide pit is an example, is reported to have been used for the same purpose. It appears to be of local extent, however, and the available tonnage is not large.

The writer recently observed the occurrence of a plastic clay between the surface residuum and the underlying flint fire clay, in the Bueker pit, NE¼ SE¼ sec. 25, T. 43 N., R. 5

[46]Unpublished notes.

W., Gasconade County. Here the clay again is tough, rubbery, and highly plastic and not unlike the "hog hide type". Fairly well rounded chert pebbles up to one inch in diameter seemed to occur in the clay, although they may have been pressed into it from the overlying gravels during stripping operations. An analysis of this clay has been given elsewhere. This clay may be representative of the Lagonda formation where it will be again discussed.

Coal. Associated with the various clays in many pits are lenses or beds of sub-bituminous to bituminous coal. In a few instances, at least, cannel coal is present also, but only in one instance have the two been observed in the same pit. The thickest coal deposit known to the writer was the Johnson pit located on the south side of U. S. Highway 66 about midway between Stanton and St. Clair, NW¼ sec. 9, T. 41 N., R. 1 W., Franklin County. Although the coal was reported to be of fantastic thickness, observations made underground during mining operations indicated it was a lens, some 12 feet or more in thickness, which had dropped or moved from a horizontal to a nearly vertical position during the formation of the containing sink-hole structure. Because the coal lens extended downward from the surface to a depth of 190 feet, it was erroneously credited with a thickness of that amount. An end of the lens was observed by the writer in the bottom of the underground workings. Here the clay beneath the coal was dark gray and almost black at the coal contact. The clay over the coal was also flint fire clay, very dark in the basal few inches, but grading upward into light colored clay. The overlap of the coal by the upper clay was quite obvious in the deeper workings.

The coal in other deposits is also lenticular and in some instances is completely pinched out near the margin of the deposit, or conversely, it thickens toward the center or lowest part structurally of the sink-hole type deposits. In other instances the coal grades laterally into very dark clays, or very clayey coals.

What is believed to be one of the finest examples of the occurrence of coal with the clays of the southern district, may now be observed in the General Refractories Company, Kallmeyer pit, NW¼ sec. 35, T. 45 N., R. 6 W., Gasconade County. Here a fairly thick section containing dark, carbonaceous, and light and dark "conglomeratic" flint fire clay is interbedded with sub-bituminous and cannel coal. Beneath this series is high grade diaspore clay with a thin capping of the newly discovered clay mineral boehmite. The upper coal and clay zone permitted the measurement of the following section from top to bottom:

Section Measured in Kallmeyer Pit.

	Thickness	
	Feet	*Inches*
Clay, flint, gray	1	0
Coal, sub-bituminous, lenticular, from zero to	0	6
Clay, flint, dark	1	0
Coal, cannel, lenticular	5	0
Clay, flint, gray	1	3
Coal, sub-bituminous, lenticular	1	6
Clay, flint, dark	2	0
Coal, cannel	1	6
Clay, flint, dark	4	6
Diaspore clay, the upper part of which is composed of boehmite	7	0

The Sitterman pit, SE¼ SW¼ sec. 3, T. 42 N., R. 3 W., west of Leslie, Franklin County, furnished an excellent example for observation. Here the following section was measured.

	Thickness in feet
1. Flint fire clay, gray, hard	12
2. Flint fire clay, gray, grading downward into black	6
3. Coal, semi-bituminous, light in weight, bright satin-like luster, grades into a brownish gray flint fire clay, which in turn grades, near the edge of the pit into gray flint clay	3
4. Flint fire clay, very black almost an impure coal, exposed	8

The Tomnitz pit, NE¼ SE¼ sec. 17, T. 42 N., R. 5 W., also contained coal. Although the relations are poorly exposed, and the individual strata on one limb of the deposit were steeply inclined, the following generalized section was measured.

	Thickness	
	Feet	*Inches*
1. Flint fire clay	..	
2. Flint fire clay, light gray, fine-grained	3	
3. Clay, brown, soft, with fragments of flint fire clay	0	2
4. Coal, cannel type, grading laterally into brown, highly plastic muck-like clay	3	0
5. Clay, black, soft	1+	(?)

Coal has been observed in many other pits, some of them, in addition to the foregoing, being listed on next page.

Name of Pit	*County*	*Location*
Ellison-Barnett	Crawford	NW¼ SW¼ sec. 11, T. 39 N., R. 4 W.
Morre	Gasconade	SE¼ sec. 34, T. 44 N., R. 5. W.
Moha	Gasconade	NE¼ sec. 17, T. 42 N., R. 4 W.
Linneman	Gasconade	SW¼ SE¼ sec. 17, T. 44 N., R. 5 W.
Lamb	Osage	SE¼ SE¼ sec. 8, T. 44 N., 7 W.
Morre or Brink	Gasconade	SW¼ SE¼ sec. 3, T. 44 N., R. 5 W.

Thicker deposits of cannel and sub-bituminous coal, occurring in pocket-like deposits, are known to occur in the Miller,[47] Moniteau,[48] and Morgan[49] Counties sub-district (Pl. XVIII) and possibly are related in age to the coals of this district. Certainly the flint clays of the two areas have much in common with regard to composition and occurrence.

No correlation of the coal found in these pits is practicable at this time. In the northern district the Tebo coal is present in many localities and is not far above the top of the Cheltenham clay formation and may be represented, in part, by the coals of the southern district. The Bevier coal may be likewise represented. On the other hand, thin discontinuous seams of coal, as well as dark colored, coaly clay and clayey coal are found in the Cheltenham clays of the northern district and are probably of approximately the same age as the coals in the southern district. The coals may well be related to that portion of the lower Cherokee group in which occurs the Montserrat coal of Johnson County,[50] the Mammoth and Jordan coals of Henry County,[51] and the Eureka coal of Randolph and Macon[52] Counties. In any event the coals are local in character and distribution and, as shown by the foregoing sections, they sometimes change laterally and quickly into clays.

The coals are significant in that they demonstrate that conditions approaching the tropical were present. The climate was warm to hot, the rainfall was excessive, and the general conditions were therefore suitable for the development of a heavy, rank, luxuriant growth of early plants. The water in which they grew was warm, and probably brackish. With the decay of the rank, abundant plant life, it was gradually

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[47]Ball, Sydney and Smith, A. F., The geology of Miller county, Mo. Bur. Geol. and Mines, Vol. 1, 2nd ser., p. 90, 1903.

[48]Van Horn, F. B., Geology of Moniteau county, Mo. Bur. Geol. and Mines, Vol. III, 2nd ser., pp. 78-79, 1905.

[49]Marbut, C. F., The geology of Morgan county, Mo. Bur. Geol. and Mines, Vol. VII, 2nd ser., pp. 51-57, 1907.

[50]Hinds, Henry and Greene, F. C., The stratigraphy of the Pennsylvanian series in Missouri, Mo. Bureau of Geol. and Mines, Vol. XIII, 2nd ser., p. 49.

[51]Idem. p. 47.

[52]Idem. p. 52.

converted into coal. Whether the coal was developed in place, or washed into the localities of present occurrence, is a matter that cannot be specifically settled at this time. The presence of plant roots suggests that in some localities the coal was formed in the bog in which the plants flourished. In other instances, particularly where sharp lateral gradations into clay have been noted, it seems likely that the coaly material was washed in, or transported and deposited as such.

A recent paper by Keller[53] has described the finding in the Morre pit north of Drake, Gasconade County, of a specimen of diaspore clay (No. 2 grade) filling a cavity formerly occupied by wood. An analysis of a specimen of this clay furnished through the courtesy of Keller, has been made by R. T. Rolufs, with the following results:

Chemical Analysis of Diaspore Clay, Morre Pit.

Constituent	*Percent*
Ignition Loss (H_2O, +110° C.)	13.10
Moisture (H_2O, −110° C.)	0.14
Silica SiO_2)	15.78
Alumina (Al_2O_3)	64.75
Ferric Oxide (Fe_2O_3)	1.56
Titania (TiO_2)	2.47
Lime (CaO)	0.07
Magnesia (MgO)	0.18
Soda (Na_2O)	0.77
Potash (K_2O)	2.03
Total	100.85

Similar material has been observed by the writer in the Felix Malan pit in the SE¼ NE¼ NW¼ sec. 31, T. 44 N., R. 7 W., Osage County. These two occurrences are suggestive of transportation and deposition of the wood, but in each case conversion to coal was not accomplished. The coal, with its associated organic acids may have contributed to the origin of the present clays. This will be discussed later.

Post-Cheltenham formations: In the southern district the record of the formations overlying the Cheltenham is obscure (Pl. V). Representatives of the Loutre and Tebo formations may or may not be present as gray or dark colored semiflint clays, or as some of the beds of coal previously reported. A specific identification of them is impossible, however, in the sink-hole type deposits.

[53]Keller, W. D., Diaspore clay cast of fossil wood in a Missouri diaspore pit. Amer. Mineralogist, Vol. 23, No. 7, July, 1938, pp. 461-463.

The phosphate bearing shale and limestone of the Ardmore formation and the members of the Bevier formation have also not been identified, although further work may result in the correlation of one or more of the coals with the coal of this formation.

If the formations were deposited in the Ozark region, they have been removed except as indicated. That these formations thin in a southerly direction is indicated by some of the sections studied near Fulton, Callaway County. In any event the clays of this district had an opportunity to be further leached in the period of geologic history represented by the formations mentioned.

Lagonda formation: Although the presence or absence of the Lagonda shale is of no great economic significance insofar as the clay deposits are concerned, either case does constitute a chapter in the sequence of historical events that marked the geology of both districts, hence steps necessary and incident to the formation of the clays. As mentioned in the section describing the Lagonda shale in the northern district, there is a possibility that it is also represented in the southern one by a very unctuous tough, rubbery fine-grained, highly plastic, gray clay, which apparently is of no great thickness.

The best exposure of such a clay was noted by the writer during the stripping of the Bueker pit, NE cor., SE¼ sec 25, T. 43 N., R. 6 W., which apparently constitutes with the adjacent Fornberg pit, NW cor., SW¼ sec. 30, T. 43 N., R. 5 W., one of the largest sink-hole type deposits of the southern district. The latter contained a remnant of the Fort Scott member in the structural center of the pit.

Another exposure of a somewhat similar clay is poorly presented in the northern portion of the stripped area in the Willoughby pit, SW¼ NE¼ SE¼, sec. 30, T. 41 N., R. 7 W., near Belle, Maries County.

The similarity of this material to a gray plastic clay, which fills joints and crevices in the flint fire clay and the burley and diaspore clays, has been noted elsewhere in this report, where analyses showing the composition are also given. A comparison with similar material in what is without question the Lagonda shale is also given in that section. Similar clay no doubt occurs elsewhere, but as it would be removed in stripping operations, the record of it would not have been preserved for subsequent observation. In the event this clay is correctly correlated with the Lagonda, and if it rests upon the Cheltenham as the writer believes, then the magnitude of the unconformity is indicated. The significance of this "break" and the unconformity between the Lagonda and the Fort Scott are discussed in detail in the description of the latter.

HENRIETTA GROUP.

Fort Scott formation: The occurrence of fossiliferous Pensylvanian limestones in a few localities in the north central Ozark region has long been of interest to geologists working in the area. These limestones have been found to date, without exception, in the structural centers of sink-hole type clay deposits. These deposits are always larger in surface dimensions and also deeper than the general average.

As the result of earlier field work in the southern district, Hall[54] concluded that the limestones were representatives of the Fort Scott formation. Later, however, Greene[55] suggested the limestones might represent the Ardmore formation. The correct determination of the age of the limestone is important in any consideration of the clays and the historical events, which have affected them. Therefore, a restudy has been made by the present writer of the previously known and more recently discovered exposures, and the conclusion reached that the limestones and associated strata are related to the Fort Scott formation and chiefly to the upper portion. The units which make up the general section from bottom to top are as follows:

1. Sandstone, or sandy clay, may be representative of the Squirrel sandstone of the northern district.
2. Clay, red, with small boulders of iron oxide, possibly reflects the unconformity between the lower and upper Fort Scott.
3. Clay, green, calcareous, with small nodules of calcium phosphate.
4. Limestone, gray, fine grained, fossiliferous.

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[54]Hall, R. H., unpublished manuscript, The origin of the flint and diaspore clays of east central Missouri.

[55]Oral communication.

The foregoing units may be described as follows:

The presence of a very sandy clay or hard thin bedded sandstone, overlying the fire clays and separate and distinct from the Graydon sandstone "rim rock" underlying them, while not common, is known locally in the southern district. It is tentatively correlated with the Squirrel sand of the Fort Scott formation of the northern district. The stratigraphic position of the sandstone is best shown in the section measured in the SW¼ SW¼ NE¼ sec. 17, T. 41 N., R. 7 W., Osage County, northwest of Belle (Pl. V). The sandstone was not noted as such at other localities where the overlying red and green shales and limestones were observed, but with the above mentioned exception the relations are poorly exposed, or the complete sections are difficult of access. A sandstone and associated sandy clay, totalling 2½ feet in thickness and probably at this same horizon is present, however, in the center of the Kahle pit, NE¼ sec. 25, T. 44 N., R. 5 W., Gasconade County, a short distance southeast of the village of Swiss.

The Johnson pit, sec. 16, T. 39 N., R. 4 W., north of the village of Hofflins, Crawford County, is also marked by the presence of an upper sandstone, which may mark this sandstone member. In this instance, however, there is a possibility that the sandstone may be a part of the lower or rim rock sandstone, but moved out of normal position during the formation of the pit.

The sandstone appears to have been encountered in recent prospecting. The localities, however, are not available at this time. It is believed that the sandstone or sandy clay will be found in the future, in the larger and deeper deposits and particularly in those which the red and green shales and the overlying limestone are found. The presence of the sandstone is undesirable in that it presents an additional and somewhat more expensive item in the stripping of the overburden, and in prospecting it might well terminate at too shallow a depth, a hole drilled with the rotary type of auger drill. Unless other check holes were drilled close by, the presence of a clay deposit might not be revealed because of the presence of this sandstone, and the mistake made in assuming that it was the "rim rock" or Graydon sandstone, which lies below the clays.

The red clay shale zone is found overlying the above described sandstone in the southern district. It is excellently developed as to lithology in a small exposure located in the structural center of the Willoughby clay pit, SW¼ NE¼ SE¼ sec. 30, T. 41 N., R. 7 W., Maries County (Pl. V). The section is as follows:

Section in Willoughby Pit.

Number	*Lithology*	*Thickness Feet*	*Inches*
	Fort Scott Formation:		
1.	Limestone, gray, fine-grained, marked by the coral, *Chaetetes and* crinoid segments, ranges from 12 inches to	1	3
2.	Limestone, dense, poorly exposed	0	6
3.	Limestone, gray, massive, very fossiliferous, crinoid segments being common	1	0
4.	Limestone, gray, fine-grained, fossiliferous	0	4
5.	Clay, plastic, light green, with limestone in upper one to two feet; darker green in lower 3 feet, thin (⅛-¼ inch) slabs and nodules of calcium phosphate bearing a discinoid brachiopod occurs at contact	5	0
6.	Clay, red, hard, slightly oolitic to pebbly, by analysis contains 37% iron oxide; poorly exposed, but thickness appears to be approximately	3	0
7.	Clay, plastic, gray, very sandy (Squirrel?)		

The red clay shale is also exposed in the section in a northwest-southeast valley, 200 yards north of a county road, and on the west slope of a high bald knob in the SW¼ SW¼ NE¼ sec. 17, T. 41 N., R. 7 W., Osage County, one-half mile northwest of Belle. That section is as follows:

Section Measured Northwest of Belle, Osage County.

Number	*Lithology*	*Thickness Feet*	*Inches*
	Henrietta Group		
	Fort Scott Formation		
	Higginsville limestone		
1.	Covered interval to top of hill	44	
2.	Limestone, one boulder exposed	1	
3.	Covered interval	2+	
4.	Limestone, many boulders, weathers rough	0	6-9
5.	Covered interval	2	6
*6.	Limestone, one big boulder exposed	2	
7.	Covered interval, grassy slope	5	
*8.	Limestone, poorly exposed as many boulders, glauconitic	0	6-9
9.	Clay, plastic, dark green, lumpy, slick, with nodules of calcium phosphate	3	
10.	Clay, red	1	
11.	Clay, plastic, cream to buff, very sandy grading into clayey sandstone (Squirrel)	4	6
	Cherokee Group		
	Cheltenham formation		
12.	Clay flint-like, white to blue purple mottled	1	
13.	Clay, flint fire, white, purple mottled purple and dark blue..	0	6
14.	Covered interval	1	0
15.	Sandstone, occurs as boulders on local bench and may be out of place, hard, fine grained	0	9
16.	Covered interval	1	0
17.	Similar to No. 13, exposed	0	6

*6 and 8 may represent one bed, No. 8 having slumped from it.

The red clay as developed in the Willoughby pit, SW¼ NE¼ SE¼ sec. 30, T. 41 N., R. 7 W., Maries County, is high in iron oxide. It is hard, lumpy, and slightly psuedo-oolitic or pebbly and is fine and even-grained. It is more shaley in character in the section northwest of Belle, SW¼ SW¼ NE¼ sec. 17, T. 41 N., R. 7 W., but on the whole it is similar in appearance to the red clay shale of the Fort Scott member, which is developed in the Columbia area (bed No. 11, p. 98) and with which it is correlated. The red clay shale was also present in the Fornberg pit, NW¼ SW¼ sec. 30, T. 43 N., R. 5 W., Gasconade County. The red clay shale, as previously mentioned, may express an unconformity between the upper and lower members of the Fort Scott formations and a further thinning of the general interval between the overlying Higginsville limestone and the Squirrel sand, which as suggested in the discussion of the stratigraphy of the northern district, may well represent the base of the Fort Scott formation. The red shale with the associated units also serves to tie the two districts of this report together.

The chemical composition of the red clay is shown by the analyses presented in Table 21. A sample was submitted to V. T. Allen,[56] who reports that the red clay seems to contain the clay mineral illite, "but it is impregnated with hematite and contains calcite grains, both of which render the determination more difficult and less reliable."

Green clay shale overlies the red clay shale. It is plastic and soft and contains rough, irregular nodules of limestone in the upper two feet of the exposure at the Willoughby pit, SW¼ NE¼ SE¼ sec. 30, T. 41 N., R. 7 W., Maries County. In that section the lower three feet are darker green in color and more platy, the two being separated apparently by a thin (⅛ to ¼ inch), discontinuous gray and nodular phosphatic limestone, which carries discinoid brachiopods. Another excellent exposure is presented at the locality of the detailed section just presented and it was also noted at the Fornberg pit, mentioned above. In appearance and stratigraphic position these shales and the intervening limestone are probably the same as those described as numbers 8, 9 and 10, in the exposure along the south line, SE¼ SE¼ sec. 1, T. 46 N., R. 10 W., Callaway County, the section being given on page 94.

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[56]Written communication, dated Dec. 27, 1942.

The green clay shale also serves to tie the Fort Scott formation of both districts and to establish further the stratigraphic sequence. It seems remarkable to the writer that the light and dark green shale with the thin intervening nodular and discontinuous seam of limestone or calcium phosphate nodules, bearing the discinoid type of brachiopod, should be developed in exactly similar detail in both the Fulton and Belle areas, the two localities being some 40 miles apart.

What is possibly the same green shale, and thin phosphatic limestone has been observed in the Fort Scott formation by the writer, in sec. 14, T. 46 N., R. 27 W. on U. S. Highway 50, about 12 miles west of Warrensburg, Johnson County. This locality would be approximately 105 miles southwest of Fulton and 125 miles west of Belle.

The chemical composition of the green clay is indicated by the analyses given in Table 21. Mineralogically, the clay is reported by Allen[57] as follows:

"The refractory indices of the green clay are too high for kaolinite and agree with those of the sericite-like mineral from Mexico and Farber. This mineral has been named[58] illite."

TABLE 21.

Chemical Analyses of Red and Green Clay.
R. T. Rolufs, Analyst.

Sample No.	1	2	3	4
Ignition Loss (H_2O, +110° C.)	5.82%	7.93%	6.94%	6.51%
Moisture (H_2O − 110° C.)	3.33	2.58	1.00	1.99
Silica (SiO_2)	57.30	50.74	27.10	62.26
Alumina (Al_2O_3)	17.77	16.17	20.13	14.51
Ferric Oxide (Fe_2O_3)	5.98	5.98	36.92	6.24
Titania (TiO_2)	0.99	0.89	0.89	0.89
Lime (CaO)	1.19	4.92	0.51	2.49
Magnesia (MgO)	1.81	2.24	0.56	0.79
Totals	94.19	91.45	94.05	95.68

Sample No. 1. Green clay immediately below Fort Scott limestone and above the red clay. Reported to be 3 feet thick. Contains nodules of limestone. Willoughby pit, SE¼ sec. 30, T. 41 N., R. 7 W., southwest of Belle, Maries County.

Sample No. 2. Green clay, lumpy, slick plastic, 3 feet thick, underlies nodular Fort Scott limestone, SW cor., NE¼ sec. 17, T. 41 N., R. 7 W., one mile northwest of Belle. Compare with No. 1.

Sample No. 3. Red clay from measured section, Willoughby pit, SW¼ NE¼ SE¼ sec. 30, T. 41 N., R. 7 W., Maries County, 2 miles southwest of Belle.

Sample No. 4. Red clay from measured section, SW¼ cor. NE¼ sec. 17, T. 41 N., R. 7 W., Osage County, one-half mile northwest of Belle.

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[57] Written communication, dated Dec. 27, 1942.

[58] Grim, R. E., Bray, R. H., and Bradley, W. F., The mica in argillaceous sediments, Am. Min., Vol. 22, pp. 813-829. 1937.

As exhibited in the few exposures in the Ozark region the Fort Scott limestone varies from light to dark gray to dark blue. It is fine grained, compact and hard, although locally it appears to have been brecciated, probably as the result of slumping into the clay filled sink-hole type deposits. As a result, it has been recrystallized and masses and veinlets of calcite are often present. Fossils are very common.

The maximum thickness of the limestone is not known, but approximately three feet are exposed at the Willoughby pit, SW¼ NE¼ SE¼, sec. 30, T. 41 N., R. 7 W., southwest of Belle, Maries County. The presence of several horizons of boulders of limestone of different lithology in the section measured in the SW¼ SW¼ NE¼ sec. 17, T. 41 N., R. 7 W., Osage County, northwest of Belle, suggests a greater total thickness, and possibly the presence of additional beds of limestone interbedded with shale, which have not been observed elsewhere in this district. A number of comparatively thin limestones comprise the lower Fort Scott in some localities in the northern district, and reference should be made to the descriptions of the stratigraphy.

In addition to the exposures referred to, the Fort Scott limestone occurs in bouldery form in the stripping at the Fornberg pit, NW¼ SW¼ sec. 30, T. 43 N., R. 5 W., Gasconade County. It also occurs in the pit located in the center SW¼ NE¼ sec. 26, T. 43 N., R. 5 W., and Hall[59] has noted its presence near the center of the north line, SW¼ sec. 3, T. 42 N., R. 5 W., Gasconade County.

In the exposure at the Willoughby pit, SW¼ NE¼ SE¼ sec. 30, T. 41 N., R. 7 W., the uppermost bed of limestone exposed, is virtually composed of the coral Chaetetes and literally packed with other fossils also. This bed and the related limestone beds are believed to represent the Higginsville limestone of the upper Fort Scott and it is correlated with that member in the Fulton and Columbia localities.

REGIONAL GEOLOGIC STRUCTURE.

In the absence of detailed mapping, little or no information regarding the intimate or detailed structure of the district is available. Some information on this subject of a

[59]Hall, Roy H., Unpublished notes.

regional nature is available, however, and because it is believed to have some effect on the localization of the clay deposits, the following brief description is given in this report.

The dominant structural trend or grain in the Ozark region is northwest-southeast. Oriented in this direction is a series of regional anticlines and synclines, the flanks of which are often faulted. The former are upfolds, the latter downfolds in the rocks. The features have a general strike of N. 10° to 40° W. They are generally assymetrical in shape, that is, one side is marked by a steeper dip in the rocks than the other. Several of these features appear to cross the district under consideration.

The dominant and most readily observable structural features are two systems of folds and faults, both of which are shown on the accompanying clay map as faults. One follows the strike above mentioned, and has a northwest-southeast direction. It is known as the Cuba fault, and may be observed some three miles west of the town of that name in Crawford County. It strikes in the direction mentioned across the southwestern portion of Gasconade County, passing near the villages of Bem and Canaan. It crosses the Gasconade River between Cooper Hill and Mount Sterling in Gasconade County, but from that point its trace in adjoining Osage County is difficult to follow. The fault is downthrown to the northeast. Considerable drag is exhibited locally by the beds, which with the throw, results in a vertical displacement of 125 to 150 feet. In some cases at least, studies of this structural feature indicate that it is an assymetrical anticlinal fold rather than a fault. The west or upthrown side is rather broadly arched and along the axis, formations as old as the Gasconade dolomite are at the surface. The downthrown side is marked by a low broad syncline, which probably controls the occurrence of clays in the Rosebud locality of Gasconade County.

Another observable and important structural feature of the district is the Leasburg fault and related anticlinal fold. Strangely enough the strike of this structural feature departs regionally from the usual direction for the Ozark region. Locally the strike is northwest-southeast, but taken as a whole the strike is northeast-southwest. Whether or not the change in strike is along a single fault or represents intersections of more than one pattern of faults is a matter of conjecture, as insufficient work has been done and the details are unknown. The Leasburg fault, so-called from the town of that name in Crawford County is downthrown to the northwest. Together with the Cuba fault it results in a fan-shaped regional dropped block, which widens to the north. Within this dropped block is one of the large areas underlain by the Cherokee formation. The effect of the faulting is probably best shown by the geologic cross sections, Plates III and IV. Each depicts the structurally high areas adjacent to both faults, and the intervening structurally low areas between them. Many clay deposits, some of them being quite large in size, are found in the dropped block between the two faults, the deposits around Owensville and Rosebud in Gasconade County being examples.

Two other areas of faulting are known to occur in the district. Both are complex, although the details are not known. Although neither one is of great importance from the standpoint of important clay deposits, some local ones are involved and it is proper to describe them briefly. One area is situated in the St. Clair-Anaconda localities, Ts. 41 and 42 N., R. 1 W., Franklin County. It is shown on the accompanying map. The only important pit in this structural complex is the Johnson, NW¼ sec. 9, T. 41 N., R. 1 W., from which a large tonnage of coal has been mined. The deposit is discussed further in the section describing the occurrence of coal.

The other area, and an extremely complex one, is designated as the Crooked Creek. It is situated in secs. 17, 18, 19 and 20, T. 36 N., R. 4 W., Crawford County. It has been described by Hughes.[60] More recent work has indicated the structure is even more intricate than was indicated by Hughes' map. In this area (W½ sec. 18 and SW¼ sec. 21) are small deposits[61] of flint-fire clay, but their relation to the local structure is not known at this time.

In addition to the faulting described, a series of assymetrical anticlines and synclines previously mentioned appear to cross the southern district in a northwest-southeast direction, and in the opinion of the writer, play a part in the localization of certain areas where clay pits are most numerous. One of these, and an important regional anticline, is believed to strike

[60] Hughes, V. H., Reconnaissance Work, Crawford County Area, Mo. Bur. Geol. and Mines, 46th Biennial Rept. State Geol. pp. 48-52.

[61] Idem. p. 52.

from a point near Chamois, Osage County, T. 45 N., R. 7 W., southeastward through the villages of Pershing and Bay (T. 44 N., R. 5 W.) Gasconade County. Southeastward from the vicinity of Bay the suggested general trend of the feature is in the direction of Gerald, (T. 42 N., R. 4 W.) Franklin County, and thence southeastward in the general direction of the St. Clair- Anaconda faulted areas, which were described above.

Consequently, it would form one side of a triangular area, of which the other two sides are the Cuba and Leasburg faults. Thus it can be seen that the Owensville-Rosebud producing areas are within the synclinal area southwest of the regional anticline being considered. Within its limits is the area north of Owensville, marked by pits containing exposures of Fort Scott limestone and associated strata, as well as deposits of coal. The presence of both could well signify a structurally low area. Large deposits of clay are the rule, also, those of the Goerlisch ridge locality north of Owensville, being exceptionally large.

Northwestward in Osage County and between a projection of the Cuba fault and the Pershing-Bay-Gerald regional anticline is an area, again considered to be regionally synclinal and again marked by many large deposits, some of which contained unusually large proportions of diaspore clay. These center around the village of Mint Hill, Osage County in Ts. 44 N., Rs. 7 and 8 W.

Along what is believed to be the crest of the Pershing-Bay-Gerald anticline and particularly between Bay, Drake, and Gerald the ridge area is underlain by rocks comprising the Graydon formation. It appears to be thin, however, and in the area adjacent to this suggested axis, clay deposits are not numerous and those present are of comparatively shallow depth and of small surface dimension.

The same thing appears to be true immediately adjacent to the upthrown side of the Cuba fault in the vicinity of Canaan, Gasconade County, and in the area in the northeast portion of T. 43 N., R. 8 W., Osage County, along the suggested northwestward projection of the axis of that feature.

On the northeast side of the Pershing-Bay-Gerald axis is another structurally low area in which numerous pits are found. Comparatively large ones occur in this locality which centers around the town of Swiss, T. 44 N., R. 5 W., Gasconade County.

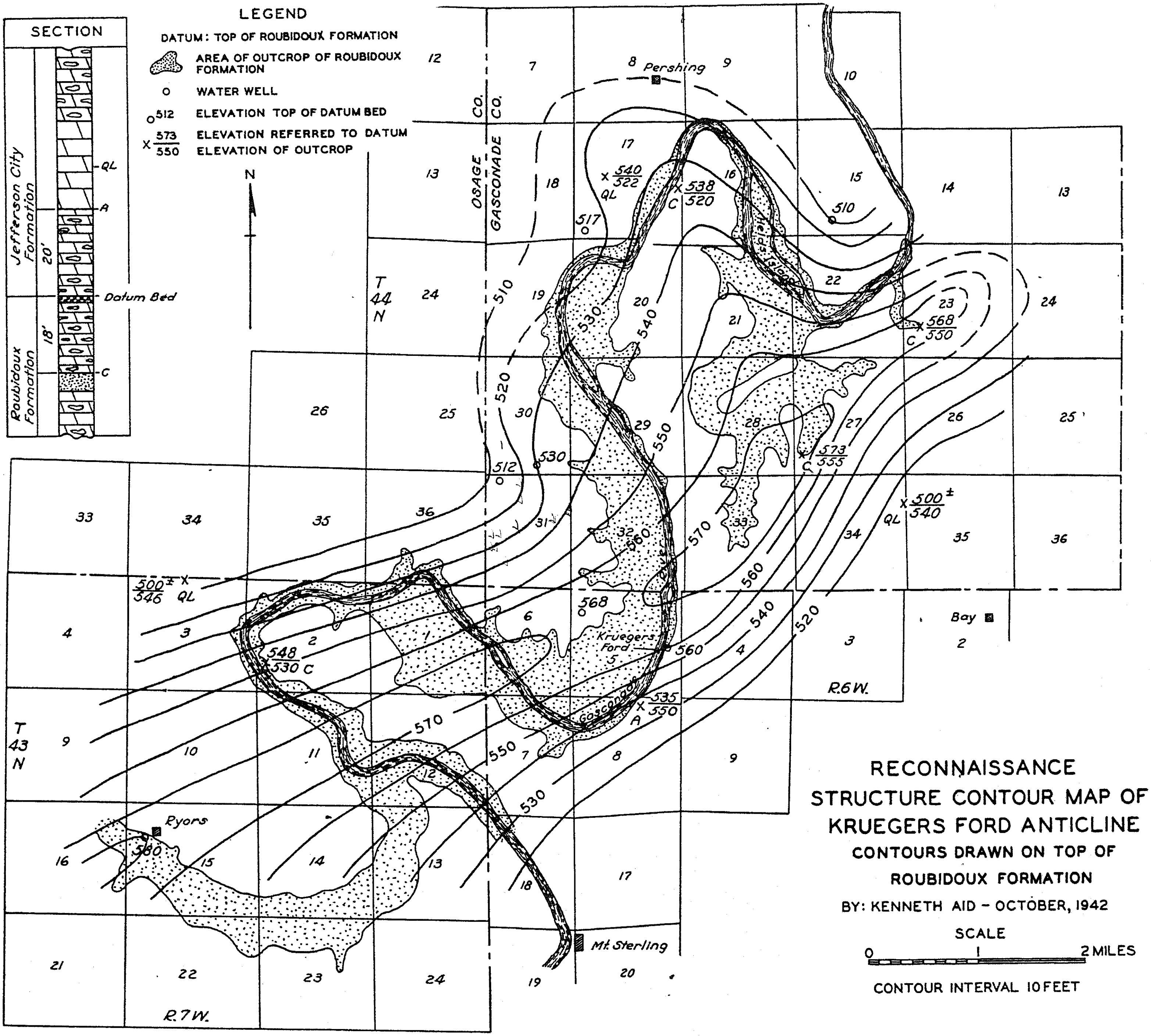
Another structurally low area lies west of the Cuba fault. The producing area centering around Belle, Maries County and Bland, Gasconade County, appears to be situated within it. Northwestward by projection, it would appear that the producing area around Linn, Osage County, might reasonably be situated in it also. To the southwest of this synclinal area, little is known about the structure. The synclinal area possibly continues, however, into the area underlain by the Cherokee, which is roughly triangular in shape from a point near Belle south to Rolla, and from Rolla east to Rosati. To this area many local names are applied such as Lanes Prairie, Vichy Upland, High Gate and Red Bird "flats." Some of the clay deposits found in this area to date are comparatively large, the Forbes pit, sec. 35, T. 37 N., R. 8 W., near Rolla, and the Bray pit, SW¼ NE¼ sec. 26, T. 40 N., R. 8 W., southwest of Lanes Prairie being excellent examples. This area is believed to be virtually undeveloped and is considered to have great possibilities.

Recent field work by Kenneth Aid has shown the presence of a pronounced anticlinal fold in the vicinity of Bay, Gasconade County, to which the name Kruegers Ford anticline is given. A map of this structural feature is given in Plate XXXII. It will be noted that the steep flank is on the southeast side, which represents a sharp reversal of the prevailing northwest dip. On the northwest side a nose plunging in that direction also may reflect, or be related to, the northwest-southeast folding previously described as present in this area.

The direction of the axis of the Kruegers Ford anticline is related somewhat to the axis of the Mexico anticline, which has been previously described in the northern district. Other parallel folds no doubt will be found in the southern district with detailed mapping.

The relation of the Kruegers Ford anticline to the occurrence of clay deposits is not known to date.. A northeastern extension of the axis, however, in combination with the northwest-southeast axis previously described as extending from Chamois to Pershing to Drake, might well account for the localization of the Swiss clay locality, in Gasconade County, which is an important one.

In connection with a consideration of the role of structure to the deposits, the direction of the axes in those deposits, which



RECONNAISSANCE STRUCTURE CONTOUR MAP OF KRUEGERS FORD ANTICLINE

CONTOURS DRAWN ON TOP OF ROUBIDOUX FORMATION

BY: KENNETH AID - OCTOBER, 1942

are elongated, have been plotted where the information was available. The map, Plate XXIV, was prepared by Garland B. Gott and covers a portion of Gasconade County. It shows the northwest elongation to be the dominant direction and suggests a close relationship between the direction of the regional structural features, and the localization of the deposits upon them or upon minor associated features. The map also shows a northeast-southwest elongation, which suggests cross folding, such as the Kruegers Ford anticline, or the development of accessory jointing associated with the regional grain. It is believed that a similar map of the entire district would be most instructive and helpful in future prospecting.

In final consideration of the structure it would be well to keep in mind in future prospecting the concept that the best producing areas, and those containing the largest deposits, appear to be situated in regional synclinal or downwarped areas. The reverse seems to be true for the regional anticlinal areas. Consequently those areas in which the basal chert conglomerate or the basal sandstone are at relatively high elevations, with respect to sea level, would seem to be less favorable than those areas where the reverse is true. In those broad flat upland areas, where exposures are not numerous, shallow churn drill holes would reveal some worth while structural information. This method and the significance of the results to be obtained will be discussed more fully in the chapter devoted to prospecting.

MINING METHODS.

After a deposit has been thoroughly prospected by drilling, and the edges determined, the entire area is stripped of overburden. In the southern district, the overburden, except in certain rare instances consists of red or yellowish residual clay, soil and gravel. Both are usually of local origin and were derived originally from the pre-Pennsylvanian rocks of the area.

The overburden, over most deposits is not thick, and the average figure probably would not exceed five feet. The removal of the overburden presents no great problem. In former years, the material was first loosened by plowing and was then removed by scrapers. More recently heavy power-drawn dirt moving equipment has been utilized, however, for this purpose, and in some instances power shovels have been employed.

The clay is loosened from the face by drilling auger holes, usually by hand, and shooting with dynamite or powder. Because of the variations in the types of clay, large scale loading operations are usually not practicable, and sorting and loading is done by hand.

In the early history of most deposits, that is, when they are of shallow depth, loading is done directly into trucks. As the depth increases and the grade becomes greater, it is common practice to employ power hoists, the boom type being the most common one (Pl. XXXIII, A). In such cases the clay is loaded into boxes, which are hoisted and dumped directly into trucks, in which the clays are hauled to a shipping point or directly to the plant of consumption.

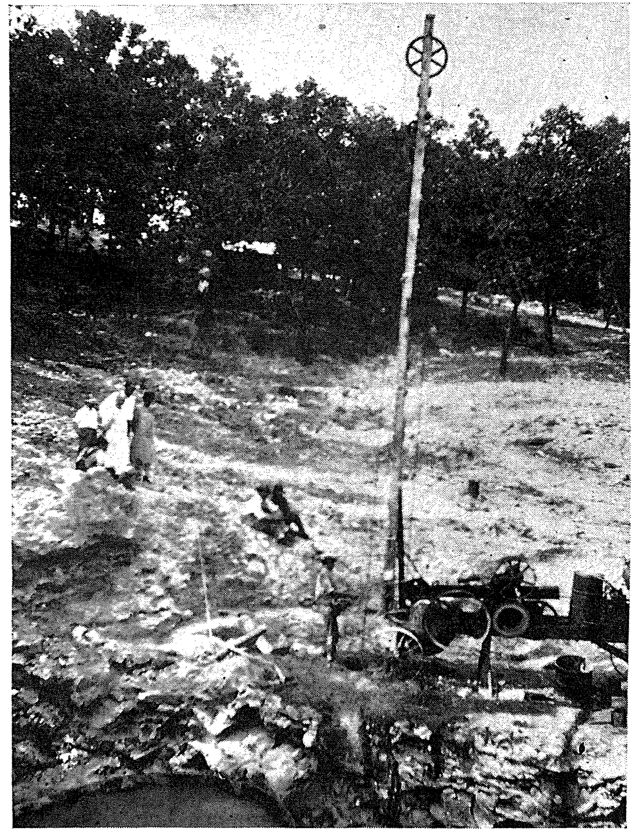
Careful grading of the clay is attempted by most operators and some thorough systems of control are employed. Most of the miners are excellent judges of clay, or become so with practice, and can grade the clay according to alumina content very satisfactorily. There are several grades of clay mined. While there is some lack of uniformity in terminology the following range is employed throughout most of the district:

	Percent Alumina
No. 1 Diaspore	+70
No. 2 Diaspore or No. 1 Burley	+60
No. 2 Burley	+50
Burley Flint	+45
Flint Fire Clay	45 and less.

The Missouri Clay Testing and Research Laboratories of the School of Mines at Rolla, make chemical analyses and physical tests. Samples are burned in the various fire brick plants and control maintained in that manner also.

In view of the pit-like character, and the depth to which some of the deposits are worked, the accumulation of surface water during periods of excessive rainfall presents a problem of drainage. This is an additional factor in the cost of producing clay. Syphons are used wherever and as long as possible, but when the pit becomes deeper small centrifugal pumps are employed. Several years ago the writer proposed a plan of draining pits by means of holes drilled through the bottom and into the "open ground" which is believed to occur in the underlying dolomite formations. The plan was prompted by the occurrence of the clays in pit-like deposits, which have

A. A type of hoist used in mining clay from deeper pits.



B. Drilling in clay pit in an attempt to drain surface water through the bottom.

been formed by the collapse of the clays into underlying caverns. It was believed that churn drill holes into the cavernous ground might reasonably be a means of draining surface water. This would possibly be true in the case of those pits located at comparatively high elevations, especially those near the "breaks" or margins of the uplands, and further situated in areas of considerable topographic relief and with a comparatively low ground water table.

With these factors in mind a test hole was started with a spudder or churn drill many years ago in a pit in Gasconade County (Pl. XXXIII, B). The water employed in drilling was lost to some extent when the hole reached the sandstone immediately below the clay, but at this point the drilling contractor lost the hole because of his failure to case it properly. The hole was never completed.

The idea, however, would appear to be worthy of consideration, in some instances at least, for natural drainage through the bottom has been reported at the Hensley pit, SE¼ NW¼ sec. 15, T. 41 N., R. 6 W., south of Canaan, Gasconade County, by Mr. Clyde Evans,[62] District Mine Superintendent, Harbison-Walker Refractories Co. It is believed that similar conditions could be obtained artifically in some pits. If so, the cost of pumping water would be eliminated.

METHODS OF PROSPECTING.

In the development of the district, the bulk of the deposits have been found from observation of some surface evidence. The chief expressions have been: (1) The presence of boulders of diaspore, as the clay is very resistant to erosion, or the presence of spalls of flint fire clay, or (2) exposures of sandstone rimrock. Combinations of the two are often present. With the discovery of a deposit it is drilled with hand-powered augers, the diameter being about one inch. These augers are made usually of twisted and tempered spring steel, the spiral portion being from one to two feet in length. The bottom of the auger is fish-tail in shape, the ends of which are kept sharpened with a file. One-half inch pipe in sections is attached to the auger. Holes have been drilled by hand to a reported depth of 200 feet. However, the rate of drilling is slow, particularly

[62]Written communication, Nov. 6, 1942.

as the hole reaches any great depth. A gin-pole, or portable derrick arrangement is employed in drilling the deeper holes.

In recent years the diamond core drill has been used to drill out a deposit, and the results of drilling have given more accurate knowledge of the character and extent of the various clays. The flint fire clays core very satisfactorily, and no particular difficulty is found in coring diaspore clay, except in some of the softer varieties where care must be exercised.

Since most of the deposits having some surface expression have been found, it has become necessary to resort to methods that will find deposits without any surface indication, and particularly those under considerable overburden. For many years the writer has insisted that certain upland areas should contain clay pits under more than average overburden, hence without any surface signs. The Lanes Prairie locality of eastern Maries County is an example, and is one that has always been so considered. A few years ago a boulder of high grade diaspore clay was found in plowing on the Bray farm, SW¼ NW¼, sec. 26, T. 40 N., R. 8 W., and subsequent prospecting revealed one of the largest deposits of the district, both as to size and tonnage of diaspore clay. Additional deposits will no doubt be found in the same general area.

In order to prospect such areas a type of spud drill has recently been employed with some success. The drill is a small portable churn drill or spudder type. The bit is hollow, with two vertical channels. The cutting edge is usually faced with some resistant surfacing material. The up and down drilling motion employed results in the clay being pushed upward into the hollow inside portion of the drill. When it has been filled, the clay thus collected can be obtained for a sample by prying it out with a small rod or similar tool inserted into the vertical slots on each side of the bit.

More recently the Parmanco drill has been employed with considerable success. This drill likewise is portable and is transported by being attached to a truck. The rotary principle is used, and the hole is sunk by means of a spiral or auger type of bit. As the hole proceeds in depth, additional short sections of the auger are added. Samples of the material being drilled are spiralled upward by the auger and are collected at the surface. The rate of drilling is very rapid, and holes up to 75 feet can be drilled in clay in a comparatively short period of time. The ease with which the drill can be moved permits the drilling of a limited area in a reasonably short time.

This type of drill will be employed successfully in prospecting those areas about which so little is known, the eastern portion of Maries County, the southwestern portion of Gasconade County, and the northeastern portion of Phelps County being examples. The rapid rate of drilling, the portability, and the fact that no water is required in drilling operations are favorable factors. This type of drill is not satisfactory for drilling sandstone, and no hole can be made in the basal sandstone member of the Cherokee, nor in the local sandstone which has been described as immediately overlying the fire clay, and as a result a pit might not be discovered. The Fort Scott limestone, which locally is found in the centers of some of the larger deposits, is reported to offer no problem in prospecting with this type of drill.

SUGGESTIONS FOR PROSPECTING.

The map accompanying this report has been designed as a guide in prospecting. Although the southern district is perhaps better known to the clay producer and to the mining and prospecting personnel of the operating companies, than it is to the writer of this report, it is believed that the map will be helpful to them. It shows the district as a whole, all of the important towns, most of the villages, the main roads, the railroads, and the important streams.

Of even greater importance is the area of blue color, which designates the area in which the fire clays will be found. Further, the deposits known to the writer are indicated with various symbols being used to designate the types of clays contained in them. For example, the pits containing diaspore or burley clay are so designated. It should be remembered that such pits also contain flint fire clay and many pits contain that type of clay alone. In that case a different symbol is used.

The distribution of the pits known to date is itself a guide in prospecting. The areas that have the greatest concentration are those in which the surface evidence has been the most prominent or prospect drilling the most intensive. When a pit is discovered, a wave of prospecting usually follows in the immediate area. This is intensified, if additional deposits are found. If no additional pits are discovered, then enthusiasm for the area wanes, and attention is turned to others of more apparent promise.

The map shows the areas in which few or no pits have been found, hence the area where prospecting might well be concentrated. The foregoing statement does not mean to imply that additional pits will not be found in the areas marked by a large number of pits, for in such areas additional ones will be found by systematic prospecting.

The use of the topographic maps previously described in connection with the map of the districts will also be helpful in prospecting. The topographic maps show all of the details of the surface, and the upland areas underlain by the Pennsylvania rocks, and the marginal areas thereof stand out in striking fashion. The Vichy area north of Rolla is a good example. The topographic maps will also be helpful in any drilling campaign. Enlarged copies of them can be used for spotting the location of each hole and for plotting also the geologic details obtained through field surveys or by drilling.

The period of finding deposits of clay from some surface expression or evidence is rapidly drawing to a close. Many deposits, marked at the surface by the dipping sandstone rimrock, or by boulders of hard, weathered diaspore clay, have been located.

One of the most helpful guides in prospecting for diaspore clay by "hunting", is found in the presence of boulders of such clay. Where the diaspore is at or near the surface in a pit, it becomes detached, and in some instances, particularly in or adjacent to ravines the boulders may be transported by running water some distance. A considerable portion of the diaspore where buried beneath other clay, is comparatively soft, and moist. Upon exposure and when dried it becomes very hard. The higher density and the general texture serve to differentiate it from certain porous types of chert, which are common to the pre-Pennsylvanian formations of the southern district. Surface boulders of diaspore clay are also marked by a veneer, consisting of a thin film of iron oxide. This is different in appearance and make up from the iron band, which, however, is also useful in prospecting.

Another test for diaspore clay and one used in both mining and prospecting for the determination of grade is the knife test. The high grade diaspore clay, being by nature an abrasive, will "take" steel, that is when the back of a knife blade is firmly rubbed over a fresh surface of diaspore clay, a dark mark will be formed on the clay surface from the abrasion of the steel in the knife. Similar marks will be left by picks, gads, and other mining tools. In this connection it should be remembered that some of the soft porous tripolitic cherts of the pre-Pennsylvanian formations will yield to the same test particularly when damp. These cherts are much lighter, however, in weight. Also the tongue adheres to such material, but much less so to diaspore and flint fire clay. Fine spalls or fragments of flint fire clay also often mark the presence of deposits under thin or no overburden at all.

The Bray pit, SW¼ NE¼ sec. 26, T. 40 N., R. 8 W., Maries County, one of the largest deposits in the Lanes Prarie locality, was found by prospect drilling following the turning up of a boulder of diaspore clay in plowing. Incidentally, the alumina content of this boulder was extremely high.

The discovery of additional deposits now appears to be a problem that is almost wholly a geological one. The area outlined on the map in blue is the geological distribution of the Pennsylvanian formations in which the clays occur. Within the area designated systematic drilling will uncover additional deposits. The successful use of one type of drill, a power auger, has been adequately demonstrated, in the drilling out of pits to determine size as well as in prospecting for new ones. The rapid rate of drilling and the compactness and portability of the unit make it well suited to this area.

Other types of drills appeal to the writer as having possibilities. A small portable rotary drill employing the usual type of bits, both fish-tail and hard rock or cone type, will be admirably suited to the shallow drilling necessary for this district. It would have certain advantages over the power auger type of drill, one being that a core of the material being drilled could be taken as desired. Hence an accurate and uncontaminated sample would be available for examination and analysis. An ordinary hard rock core head would be satisfactory for such coring. A rotary drill would also be able to penetrate any desired distance into the basal sandstone or chert conglomerate or into the underlying dolomite, and thus basic geologic information applicable to the problem of finding clay would be available. Such a drill would also be able to penetrate the upper sand, which locally is known to overlie the clay, and thus the underlying clay body would be found. The same information, but at greater expense could be obtained with a diamond drill. The chief advantage of the power auger drill over other rotary types is the fact that no water is required by the former, while sufficient water to obtain and maintain circulation is required by the latter. The cost of drilling per foot would be approximately the same in systematic and well governed operations with the added advantage of deeper drilling into the rock for geological information with the rotary drill.

The first and most obvious type of prospecting is a detailed, systematic drilling campaign in a given area, in order to determine thoroughly the presence or absence of clay deposits. In order not to miss a pit, as local and as small as the average ones, it would be advisable to drill holes from 50, and certainly not more than 100 feet apart along a previously surveyed base line. The next series of holes should be drilled parallel to the first and so arranged or staggered as to be exactly between the holes of the first line, and 50 or 100 feet from that line. A similar pattern, but with a considerably greater distance between the holes is often used by oil companies in prospecting for structure.

In such drilling it would be well to locate each hole by instrument surveys to known land corners. It would also be well to determine their surface elevation and thus to record the depth to rock, and its relative elevation. Occasional holes drilled into the rock, either by rotary or churn drilling, would serve to indicate the general structure. An anticlinal area has been suggested as one marked by small or no pits at all whereas a synclinal or downwarped area has been suggested as one marked by numerous pits, some of them being large in size, and with appreciable tonnages of diaspore clay. Hence the synclinal areas would be the ones for intensive or very detailed prospecting.

With the plotting of the data obtained by either shallow or deep drilling, in the form of cross sections, structure contour maps and geologic maps, a pattern of broad regional proportions would be rapidly established, and by projection would be helpful in pointing ahead to further areas meriting prospecting. It is obvious that the detailed drilling of large areas can result in a material capital investment, without promise of return. The drilling program as suggested in the preceding paragraphs would also be expensive, but in the long run, would be far more profitable and less expensive than a haphazard program.

In connection with the drilling program, geologic mapping in the "breaks" or around the margins of the district is also suggested. Such mapping should be undertaken in order to determine structure. The use of certain key beds, such as the sandstone members of, or the oolitic chert at the top of, the Roubidoux formation; or the pitted dolomite and its associated fossil sponge zone in the overlying Jefferson City formation, some fifty feet above the top of the Roubidoux, is recommended. Locally, at least, a thin sandstone some 140 feet above the base is present in the Jefferson City, and might serve also as a marker. The contact of the Pennsylvanian basal conglomerate and sandstone with the Jefferson City dolomite might also serve as a marker in the structural mapping. It should be borne in mind, however, that this contact is an uneven one, and much relief might be present locally.

The key horizons described would be present only in the areas of rough topography and marginal to the Pennsylvanian capped uplands, where the clay deposits are found. No outcrops will be found in the upland areas, but structural work there will be aided by plotting the outcrops and elevations of the basal Graydon conglomerate and sandstone, and the dolomite of the Jefferson City and Cotter formations as indicated by drilling. Where the Graydon members are thin and at a comparatively high elevation locally, anticlinal folding would be suggested, and the chances for the occurrence of clay deposits minimized. Thick deposits of these rocks over a fairly large area and at relatively low elevations would suggest synclinal conditions, and hence a more favorable area for detailed prospecting. In the upland areas of few or no outcrops, drilling into the rock at intervals of one mile along certain lines of cross-section would supplement the field work outlined and would add to the knowledge of the structure.

A combination and sensibly correlated program of drilling as outlined, and geological surveys as described would be helpful in setting out areas for prospecting. In the chapter of this report devoted to the structure of the southern district, what is considered to be the major structural framework of the district has been outlined. The further delineation of the structural framework by drilling and geological surveys is suggested as a means of adding to present day reserves.

In addition to the foregoing there are other methods that might be considered and used in association with the broad program, which has been suggested. Observation from the air of the southern district might well supplement surface geological work, particularly in selecting areas for detailed drilling. The months of the winter season would be most desirable for such work, because vegetation is heavy in some portions of the district. A study of aerial photographs might well be correlated with the program of aerial and ground observation.

The matter of the direction of elongation of the pits, where observable, has been described. Such a map of the entire district, and on a sufficiently large scale so as to permit the showing of the axes and size of the deposits would be helpful information in the consideration of the general structure of the area, and again might reasonably be useful in detailed prospect drilling.

Electrical resistivity surveys[63] have been employed by the Geological Survey and some of the results have been published. Exceptionally fine results were obtained in a few instances, but in most cases the deposits were not sharply defined, and it appears that in a general survey of an area of some size it would be difficult to differentiate the clay deposits from the barren areas.

The entire area has been surveyed with the magnetometer by the Missouri Geological Survey. The stations, however, were occupied at such intervals (usually one mile) that the resultant map shows only the regional structural grain. However, some of the major features described under the structure of the district are reflected. The map in general, however, is of no aid insofar as locating an individual deposit. The results of the surveys will be published shortly in the form of a map of the State.

A number of areas are considered by the writer to be favorable for intelligent and systematic prospecting. Prior to a brief description of them, it would be advisable again to state that

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[63]Farnham, F. C., and others, Geophysical prospecting, Mo. Bur. Geol. and Mines, 56th Biennial Report, State Geologist, pp. 146-151, 1931.

careful and systematic prospecting, by means of power drills of the localities in which clay pits have been worked, would be advisable. Anyone familiar with important producing localities such as the Belle, the Bland-Canaan, the Owensville, the Goerlish ridge north of Owensville, the Rosebud, the Swiss, the Linn, the Mint Hill and perhaps others, realizes that additional deposits will eventually be found.

In addition there are a number of localities in which a few scattered pits have been found. In some of them those opened have been larger than the average. Among such localities are, (1) the broad upland comprising the Lanes Prairie-Vichy-High Gate locality in eastern Maries County, (2) the upland between Rolla and Dillon, extending north to Macedonia and Light and situated chiefly in Phelps County, (3) the upland extending north from the Frisco Railroad between St. James and Rosati in Ts. 38 and 39 N., R. 6 W., in northeastern Phelps County, (4) the Safe-Vichy-High Gate locality in southeastern Maries County, (5) the upland area west of Redbird in T. 40 N., R. 6 W., Gasconade County, (6) the Goerlish ridge locality, southwest portion T. 43 N., R. 5 W., and southeast portion T. 43 N., R. 6 W., Gasconade County, (7) the upland lying south of the Rock Island Railroad between Belle and Bland, Maries, Osage, and Gasconade Counties, (8) the upland between Swiss and Stony Hill, T. 44 N., Rs. 4 and 5, Gasconade County, (9) the upland northwest and southeast of Mint Hill, Osage County, and (10), the Linn locality, chiefly T. 43 N., R. 8 W., Osage County.

In addition there are a number of areas in which few or no deposits have been found. Among the larger ones are, (1) the uplands immediately south of Hermann, T. 45 N., Rs. 4 and 5 W., Gasconade County, (2) the locality between Gerald, Leslie, and Campbellton, chiefly in Ts. 43 and 44 N., Rs. 2 and 3 W., Franklin County, (3) the Oak Hill locality of northern Crawford and southern Gasconade County, T. 40 N., R. 4 W., (4) the Elmont-Japan-Bourbon locality, T. 40 N., R. 3 W., in Crawford and Franklin Counties, and (5) the Dixon locality, Ts. 37 and 38 N., R. 11 W., Pulaski and Maries Counties.

The foregoing described areas are shown on the map accompanying this report. Careful prospecting within them should result in the discovery of additional clay.

FUTURE OF THE DISTRICT.

In 1929, the writer prepared a short paper describing the diaspore and flint fire clays. At the end of that paper, there was a brief statement under the same heading as above, which was as follows:

"The high alumina refractories industry is alive to the fact that the present rate of consumption of diaspore clay will exhaust, within a comparatively short time, the material occurring in the deposits found to date. Apparently the future of this industry lies in the discovery of new areas and in new deposits."

In the district under discussion, a thousand sink-hole type deposits have probably been found. One-half to possibly three-fourths are of commercial size, but of these, only slightly more than one-fourth contain diaspore. It appears that the largest number of deposits marked by some surface expression, which serve as a guide in prospecting,[64] have been found, although a few additional deposits have been recently discovered. For some time the writer has been impressed by the flat upland surfaces of the area, which are known to be underlain by the Pennsylvanian series. To date, only a few clay deposits have been discovered in these areas, the largest number of the deposits having been found around the "breaks" or margins. During the past year, however a deposit larger than the average has been found in what is locally called "prairie" country. The surface was devoid of any suggestion of a deposit, and its presence was indicated in turning up a boulder of very high-grade diaspore clay in plowing. Additional deposits may be expected in these areas. They will only be found by systematic drilling, based on facts observed in the course of field studies, or possibly by means of prospecting, not utilized at present. At any rate, until these upland areas are thoroughly prospected, and the clay resources definitely determined, the district cannot be said to have reached its maximum development."

It is interesting to examine the record of the rate of discovery since that time, and the following Table 22 presents the statistics insofar as they are available to the writer.

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[64]For a detailed discussion of prospecting and mining methods the reader is referred to C. R. Forbes, "Winning of Missouri Diaspore, Burley, and Flint Clay," Jour. Amer. Ceram. Soc., 11 (3), 204-14 (1928).

TABLE 22.

STATISTICS OF DISCOVERY OF CLAYS, SOUTHERN DISTRICT.

County	Flint fire clay pits discovered to 1928 (inc.)	Flint fire clay pits discovered since 1928	Diaspore pits discovered to 1928	Diaspore pits discovered since 1928	Flint pits drilled but not opened since 1928	Diaspore and burley pits drilled but not opened since 1928	Total
Crawford	6	17	8	4	1	1	21
Franklin	31	15	8	2	2	0	58
Gasconade	111	79	36	97	44	20	387
Maries	15	9	18	17	10	2	71
Osage	92	4	42	23	5	17	183
Phelps	9	8	5	8	0	0	30
Totals	264	116	117	151	62	40	750

The figures are illuminating. They show that the rate of discovery of flint fire clay during the period since 1928 was less than half of the rate prior to that time. The rate of discovery of diaspore clay, however, was somewhat greater, and the ratio of diaspore as compared with the total number of pits was likewise. They further show, however, that the rate of discovery of diaspore clay did not keep pace with the rate of production for equivalent periods. This is apparent from a study of the tables in this report, which present the available statistics covering the production and value of these clays.

It therefore becomes apparent that the supply of clays is either rapidly diminishing or the methods of prospecting are wholly inadequate to meet present needs and conditions. The writer is of the opinion that the answer lies in the latter.

In the last few years the use of power drills has resulted in the successful prospecting of areas, in which pits have been found previously, as well as areas in which there had been little or no production in the past. The results have been the discovery of a number of new deposits of which perhaps several are not included in the foregoing discovery table. The answer then lies in the continuation of such drilling. However, the writer is of the opinion that the day is rapidly coming when the problem will cease to be the routine drilling of this or that farm, but rather the systematic drilling of large areas, and drilling based upon and conducted in conjunction with geological investigations. The day of the casual discovery of clay deposits is at a close. The day approaches when the attack must be made in an entirely different manner. That front or that approach is through an intimate study of the geology of the district. A number of suggestions for geological prospecting have been presented. Many more will occur to the operators, and many guides will be developed and used.

It stands to reason that in an area of comparatively small sink-hole type deposits, varying in size, in depth, and in the tonnage of the contained clays, and in an area that has not been systematically prospected of studied in detail geologically, no estimate of the reserve tonnage can be made.

For the same reasons no accurate future of the district can be predicted. The writer believes, however, that continued advances in ceramic technology, and the application of geology to the problem will bring fruitful results. Certainly all of the deposits have not been found by any means. In many large areas with practically no surface expression of a deposit, there has been no systematic prospecting. Until such intelligent prospecting, adapted to and comparable to the scale of consumption, is employed, until all the areas on the accompanying maps have been fully explored, until that time, then certainly it cannot be said that the district has reached its maximum point of development.

It is hoped that the present report will therefore be of assistance in the development of the district in the future.

CHAPTER IV.

ORIGIN OF THE CLAYS.

A discussion of the origin of the clays might be considered at the outset of academic interest only. The question is often asked, what difference does it make as to how the clays occur or how they were formed? Consideration of the origin, the mode of occurrence, and the physical and chemical composition may, however reasonably lead to a better, in fact a more complete understanding of the clays. This knowledge in turn could well be directed toward intelligent prospecting, and eventually could result in the discovery of additional deposits.

The origin of the clays of this report is virtually a recital of the geologic history of east central Missouri. It is a summary that is far from complete, and the present effort should not be considered as the final one. It is offered solely in the hope that it will stimulate thought on this interesting subject. Throughout this report an attempt has been made to classify the clays geologically. If a more definite correlation or the recognition of certain zones can be established, or if new classifications of the sink-hole type deposits can be made geologically and their distribution made known, then added information is present for future prospecting. With the rapid development of the clays, and the heavy withdrawals upon reserve supplies, it becomes apparent that the problem of finding clay is rapidly becoming more acute, and its solution more directly related to geology than it was in the era when deposits were found chiefly through surface expressions.

The geological history of east central Missouri is a complex one. The basement rocks were formed from the cooling of molten material, either at, or with varying distances from the surface of the earth's crust. The granites, rhyolites, and related igneous rocks were formed during the long period of the earth's history, which is generally designated as the pre-Cambrian. In some localities these rocks may have been changed or altered by heat and pressure to metamorphic rocks. The basement rocks now lie some 1800 to 2000 feet below the surface in the east central Missouri district.

Upon the basement rocks there was deposited a section consisting chiefly of dolomite, limestone, magnesian limestones (many of which are clayey), sandstone, and shale. These constitute formations ranging in age from the Upper Cambrian to and including the Mississippian. The arrangement or sequence of these rocks, and their character have been previously described in the chapters devoted to the two districts of this report.

The history of these formations may be stated as a combination of deposition in the seas, which at various times covered the area, in their withdrawal, in periods of erosion or weathering of varying duration, of folding of the rocks into anticlines (upfolds) and synclines (downfolds), and of the development of faulting and particularly the development of the related system of joints, which have played an important part in the localization of the clay deposits of this area. These structural features seem to have been most commonly developed with a northwest-southeast alignment, along which recurrent movement appears to have taken place from the pre-Cambrian to near or following the close of the Mississippian period.

Near or shortly after the close of the Mississippian period or more probably in the early history of the Pennsylvanian period, the first definite evidence of cross folding with a northeast-southwest direction is manifested. The exact age of this folding cannot be specifically determined in east central Missouri, except that development had progressed prior to the deposition of the Graydon formation. In the Forest City basin area of northwestern Missouri and contiguous portions of Kansas, Nebraska, and Iowa, the geologic record is more complete and specific. There it appears that the last regional downwarping occurred in early Pennsylvanian time, and was the accompanying result of the uplift of granite into a mountainous mass, which now forms the west side of this basin. This mass is termed the Nemaha granite ridge. It is now covered by younger Pennsylvanian and Permian sediments, but its presence with an axis aligned in a northeast-southwest direction has been revealed in central Oklahoma, south central to northeastern Kansas, and into extreme eastern Nebraska, by deep wells drilled in the search for oil.

Accompanying the making of this mountain range were related parallel folds, some of which were of large magnitude.

Two well defined folds with this alignment have been discussed in this report. One, the Mexico fold, a prominent feature in the northern district, and the other the Kreugers Ford anticline in the southern district, but, as mentioned, the record following the deposition of the Mississippian formations and the development of the Nemaha granite ridge and related folds is not perfect in east central Missouri.

The newly formed Nemaha granite ridge, marked on the east by a steep, almost vertical face was subjected to rapid erosion. From it there was obtained a fairly coarse sand and "granite wash", which was spread over a wide area. Earth movements elsewhere were recorded, and great masses of residual material, which had accumulated in a long period of weathering, were being reworked and deposited in other areas, the Graydon formation of east central Missouri being an example.

It would appear, however, that between the deposition of the Mississippian limestones and the Graydon formation, which attests to the great period of rejuvenation in early Pennsylvanian time, that some of the earlier Cherokee sediments were deposited, but now remain as occasional remnants of small size, which in this report have been described as an unnamed pre-Graydon-Pennsylvanian formation. In some instances remnants of this unnamed formation are found occupying old chimney-like or sink-hole type structures in the old rocks. This implies that a cavernous condition had been and probably was being developed. These caverns were to assume later an important role in the development of the Cheltenham clays. The writer believes that these sediments may have contributed to the great blanket of residual material that was being formed in east central Missouri in the interval between the deposition of the Mississippian and the Graydon formations. In addition, it should be remembered that in this long period of erosion and weathering, the formations underlying the Pennsylvanian in this area were being intensely weathered, the final product being the removal of some 750 feet of pre-Pennsylvanian section, as shown by the available deep well records in the northern and southern district. These formations were now truncated, with the older ones being at the surface in the southern district and the younger ones being at the surface in the northern district. They contributed the great mass of chert and sandstone, which was reworked by streams and the advancing sea into what is now the Graydon formation. In addition to this clastic material produced, the very nature of these formations of dolomite, limestone, and magnesian limestone is such that the contained clay or silt would be set free and become a part of the residuum, also. And as such it would become a possible source of clay for the Cheltenham clay formation. In addition, there was being deposited to the south in the Ouachita geosyncline of Arkansas, a tremendous thickness of shale and sandstone, and some of the former may also have served as a source for the Cheltenham clay.

As mentioned, the great residual blanket or mantle was reworked into the Graydon formation with its coarse chert rubble and sandstone and into the overlying and seemingly closely related Cheltenham formation. The history of the latter as previous pages have indicated was not a simple one. The lower member of the Cheltenham was deposited in east central Missouri in shallow, quiet bodies of water over a wide area. The water was probably brackish for coal was also being formed, which indicates a warm, humid climate, sub-tropical at least, and one favorable for the development of the rank vegetation that was characteristic of this part of the Pennsylvanian period. Abundant rainfall, perhaps periodic in nature, is also suggested. These environmental conditions no doubt were instrumental in inaugurating the period of alteration which these clays have undergone, and in bringing about some of the changes in the residual clay material derived from the sources previously described.

Following the deposition of the lower member of the Cheltenham formation a long period of erosion appears to have taken place. It was accompanied or preceded by a period of gentle folding and by a rejuvenation of the underground drainage, with the attendant collapse of the caverns formed in and subsequent to this period of erosion. Into these caverns the clays slumped, or more correctly probably settled. The sink holes in the southern district were larger and deeper and formed more satisfactory "leaching pots" than the smaller and shallower sink holes of the northern district. The differences manifested by the geologic column underlying the two as well as the relative solubility of the component formations were factors. Following the settling mentioned, erosion continued until the lower Cheltenham was no longer the original continuous, blanket-like deposit, but was now a series of isolated remnants of varying size and shape over the entire area. Although definite evidence is not at hand, there is a suggestion that the northern district was elevated comparatively more than the southern district, and as a result of erosion, the isolated deposits of lower Cheltenham clay were reduced in thickness to a greater extent in the former. In any event it appears that a peneplain was developed and the surfaces of the clay remnants were involved. Harder[65] has shown that "perhaps the most striking characteristic of recent laterite deposits is their occurrence on flat or gently undulating surfaces which are without doubt remnants of former peneplains. Similarly, the most striking characteristic of older laterite and bauxite deposits is their relation to geologic unconformities, suggesting their formation during post erosion periods and probably on former peneplains or baseleveled surfaces."

The east central district appears to have been brought to the state of a peneplain at the end of lower Cheltenham time. The writer believes that the process of alteration then proceeded to the point that high alumina "caps" were formed in some instances, and some of these have been preserved. The hard-fine-grained, rock or flint-like high alumina clay, now identified (chapter VI) as boehmite was developed, as was some of the diaspore clay. The Kallmeyer pit, NW¼ sec. 35, T. 45 N., R. 6 W., the Klossner pit, sec. 15, T. 44 N., R. 5 W., and possibly the Aufderheide pit, NE¼ NE¼ sec. 36, T. 43 N., R. 6 W., all in Gasconade County, are believed to be examples. At one time the writer believed that the diaspore clay was formed at a comparatively late period in the geologic history of the

[65]Edwards, J. D., Frary, F. C., and Jeffriess, Zay, The aluminum industry, Vol. I, Chapter IV, Ores of Aluminum, by E. C. Harder, pp. 86-104, McGraw-Hill Book Company, 1930.

area, and the idea that some of it, at least, was formed much earlier was first suggested by Ben K. Miller.[66] With that idea the writer is in agreement. In this period of weathering and alteration of the clays, the environmental conditions enumerated were present. They were common to tropical and subtropical regions, and hence, favorable to a process known as laterization, a term that is sometimes loosely and vaguely applied, and with various interpretations. Under the lateritic conditions described bauxite appears to have formed in other areas and the term "bauxitization" or even "aluminization" might be applied also. Whatever the term, the process is one of leaching of a rock or clay, usually an hydrous aluminum silicate, under favorable geologic, topographic, and climatic conditions, with the resultant leaching of the soluble salts, calcium, magnesium, sodium, potassium, and finally silica, and the concentration of the more insoluble constituents of which alumina, titania, and iron are examples. Many published discussions are available for reference relative to the process of laterization, of the formation of bauxite, of the alteration of clays. Two of the most excellent summaries, both of which present an extended list of references have been prepared by Clarke[67] and Harder.[68]

The alteration of a clay can be brought about in nature by a number of media, or possibly by their combinations. The removal of silica, in a colloidal or possibly finely divided state, is accomplished through solutions of percolating surface water charged with carbonic acid, or alkaline carbonates. Acid-bearing waters are also effective. Of them, sulphuric, formed most commonly through the oxidation of pyrite, and nitric acid are most effective. Percolating water charged with organic acids, which originate from the decay of vegetable matter, are also effective and would probably be highly so under conditions simulating the tropical.

Of the media above summarized, several were probably present in east central Missouri. Pyrite and marcasite were associated with the clay and coal of the lower Cheltenham, and upon oxidation formed an acid bearing water. Organic acids from the decay of the rank vegetation flourishing in the area

[66] Oral communication.
[67] Clarke, F. W., The data of geochemistry, U. S. Geol. Survey, Bull. 770, pp. 497-504, 1924.
[68] Harder Op. cit. pp. 86-104.

were present also. Alkaline carbonate bearing water may also have been present from the break down of the limestones of the Jefferson City and Cotter dolomite, the country rock of the sink-hole type deposits of the southern district, or the Burlington limestone, the country rock of the smaller, shallower sink-hole type deposits of the northern district. The question may be asked, how did these contribute, when in each instance these carbonate rocks are separated from the clay by a varying thickness of Graydon chert conglomerate and sandstone. The writer believes this was accomplished by periodic fluctuations of the ground water level. That is, the ground water level was in contact with these rocks, dissolved them, then rose until it was in contact with the clay, then was again lowered. The vertical movement would not have been great, and possibly represented a seasonal change. In the state last mentioned surface waters could then percolate through the clays and effect alteration also.

If the alteration of the lower Cheltenham took place in the general manner described, why wasn't diaspore formed in the northern district? As pointed out above, the sink-holes in that area are smaller, they are shallower, and the caverns into which they were dropped were limited to the Mississippian-Burlington formation. In the southern district the reverse was true. Here the sink-holes were larger, they were deeper, the bottoms were more open, and the caverns were not localized, but some of them were developed a considerable depth below the base of the clays and in a geologic section of apparently greater solubility. At this point it would be well to recall, however, that in a few isolated cases in the extreme southern and extreme eastern portion of the northern district, burley or diaspore clay or both have been found. Also, one can see from some of the higher and northernmost diaspore deposits of the southern district, the bold bluff line on the north bank of Missouri River, which is arbitrarily, if not exactly geographically, the boundary between the two districts. In the exceptions mentioned, the type of containing structure is that of the southern district. It is sandstone lined, deeper, has visibly undergone more subsidence, and has been a more favorable place for thorough leaching. On the other hand, if the higher alumina clays were ever present, for instance, at or in the vicinity of Mexico, Vandalia, Wellsville, and Fulton, they appear to have long since been eroded. The writer does not believe they were formed, however, due to the fact the small sink-like structures and the relation of the underlying small caverns were such, that thorough and prolonged leaching was not possible. It appears, however, as discussed in the section devoted to the Cheltenham clay of the northern district, that the leaching was of sufficient extent to develop, probably from plastic clays, types ranging from the semi-plastic, to the semi-flint and finally the flint fire clays.

From the foregoing it should not be concluded that only diaspore was formed in the southern district exclusively, or at this time alone. Certainly some of the associated flint clay was developed from the original clay, but alteration was not as complete. Also as will be pointed out, diaspore and burley clays were also formed at a later period in the geological history, when the clay of the lower, as well as probably the other members of the formation were again leached.

The close of lower Cheltenham time was marked by folding, evidently a slight rejuvenation of the northwest-southeast alignment, to which the masses or horses of chert conglomerate are parallel. This folding may have preceded the subsidence of the clay masses into the sink-like structures, in fact it may have been the movement that brought the subsidence about.

The middle Cheltenham clay was laid down upon the remnants of the lower member, or upon the Graydon formation where the latter was absent. The conditions of deposition appear to have been much the same with quiet, shallow water of probably a brackish nature. Rank vegetation again flourished, and coal was formed, again indicating that conditions approaching the tropical, at least, prevailed. Periodic and heavy rainfall can be safely assumed.

The middle member of the Cheltenham clay can be readily identified in the northern district, where it is a widespread uniform semi-plastic clay and its relations to the lower member definitely established (Pl. IX). In the southern district it cannot be identified as specifically, although it may well be represented by the thick sections of white, homogenous, fine-grained flint fire clay or possibly by thick sections of carbonaceous flint fire clay, which in some places also contains lenses and seams of coal. In either event, what is believed to be an angular unconformity has been noted in a few instances in both districts between them. This seems to be true between the flint clay mentioned and an underlying clay, such as the occurrences of boehmite and diaspore. The latter two possibly represent in part the altered surface of the lower Cheltenham.

Following the period of deposition, erosion again took place and the middle Cheltenham appears to have been reduced in thickness in some localities. There was also renewed subsidence or settling into the sink-like structures, but this is manifested in so far as the writer has been able to determine, only in the northern district, as the relations are too obscure in the larger sink-hole type deposits of the southern district. In addition, the process of leaching is believed to have continued with the alteration of the middle clay and additional alteration of the clay of the lower member also.

The upper member of the Cheltenham was laid down under conditions similar to the other members of the formation. The period of erosion was not as long, however, nor the leaching as thorough, for this clay is of inferior grade and different from the other two members in refractoriness. No specific information is available for the southern district for it has not been identified with certainty. As previously mentioned, however, it may be present in a few pits as a "soft" or "plastic" flint fire clay. During this period of erosion, the surface of the Cheltenham was bevelled, and as a net result, all of the members were at the surface in one locality or another, and in some, the entire formation had been reduced in thickness until only a small part of the lower member remained. Hence the period appears to have been one of erosion and one of removal, rather than subsidence and marked leaching.

Upon the bevelled and weathered surface of the Cheltenham clay, the Loutre formation was deposited. Conditions were not unlike those existing previously, for clay and coal were again laid down. In addition, fossiliferous limestone was also deposited and thus becomes the first occurrence on record of marine conditions in this portion of the Pennsylvanian section. There was also formed within, and particularly at the base of the Loutre, small to fairly large nodules of carbonate of iron, siderite, the presence of which suggests swamps into which iron bearing water was introduced. The breakdown of this siderite, as will be mentioned later, may have resulted in another medium that entered into the alteration of the clays. Erosion followed and over a large area in the northern district the Loutre was either completely removed, if it was ever deposited, or was reduced greatly in thickness. No information regarding the formation is available in the southern district, although remnants of the clays may be present in some of the deposits.

The Tebo formation had a similar history. Clay, coal, black slate, sandstone, and locally limestone concretions were formed. A fairly long period of erosion is indicated, which was sufficient to permit the removal of the formation over a wide area. Further subsidence of the clays into local sink-like structures also appears to have followed and continued leaching has been indicated (Pl. XII). The foregoing applies to the northern district, as the formation has not been specifically identified south of the river. It may well be represented, however, by some of the coal and clay described.

The Ardmore formation marks what appears to be the first widespread change in sedimentation in the lower Pennsylvanian, and by the contained fossiliferous limestones, the first widespread marine deposition. The Ardmore seas spread over the surface formed in the period of erosion following the deposition of the Tebo. The initial deposits consisted of green shale, usually bearing nodules of calcium phosphate at the base, and were laid down in contact with the various members of the Cheltenham and the Tebo formations. The upper part of the Ardmore consists of fossiliferous limestone that is widespread throughout east central, northern, northwestern, and western Missouri. The Ardmore, however, has not been identified to date in the southern district.

The overlying Bevier formation marked a return to the deposition of coal, a related gray underclay and a characteristic "roof" or black slate. A period of erosion followed and in the northern district it was of sufficient duration locally to result in the removal of this formation. The writer believes it was also of sufficient duration to have removed this formation, the Tebo, and the Loutre from the southern district, provided of course they were ever deposited.

The succeeding formation, described in this report as the Lagonda, was deposited in the northern district as shale and plastic clay. A similar plastic clay, of local occurrence, and possibly the equivalent, has been noted in southern Missouri. A long period of erosion followed the Lagonda and it was succeeded unconformably by the sediments of the Henrietta group, namely, the Fort Scott formation. This formation marked again the return to marine conditions as is evidenced by the contained fossiliferous limestone. In addition iron-carbonate, siderite, was again deposited, as were coal, shale, and sandstone. The Fort Scott formation overlapped the bevelled surface of the underlying formations from north to south and in the southern district rests upon the Cheltenham clays (Pl. V). In the central Kansas uplift, a regional feature having many geological features in common with the Ozark uplift, clay filled sink-holes, similar to those under discussion are also known to occur. The country rock is the Arbuckle dolomite, a broad stratigraphic unit, which in that area contains, in addition to other formations, representatives of the Jefferson City and Cotter formations. That these sinks have general features similar to those in the southern district and that similar processes were taking place over a wide area, is indicated by the following data supplied by Koester.[69]

"The sink holes and other erosional features on the uneven surface of the Arbuckle dolomite on the Central Kansas uplift are covered by beds of either Kansas City or Marmaton age. I know of no case in which definitely definable Cherokee beds go over the sink holes, although there may be such occurrences. I am speaking now of the nuclear part of the uplift, namely that portion lying chiefly in Ellis, Russell, Barton, Rush and adjacent counties. As to exactly which bed of the Marmaton covers these sinks, I cannot say, although there is some evidence to suggest that the equivalent of the Fort Scott limestones overlies some sinks."

In east central Missouri, there is no record of the long series of events that mark the geological history of the region after the deposition of the Fort Scott. Scattered deposits of upland gravel, usually considered to be of Tertiary age, are found in the southern district, and in the northern district the comparatively recent ice sheets of the Pleistocene epoch have left a widespread mantle of clay, gravel, and sand of varying thickness.

In this long interval, however, the final stages of the alteration of the clay are believed to have been completed. After the deposition of the Fort Scott, the deposits of the southern district

[69]Koester, Edward A., written communication, dated Dec. 19, 1942.

underwent marked subsidence, in fact, collapse. Where they had heretofore settled, they now "fell in", and in some instances assumed an expression that has caused the writer to apply to them the term "flap valve" structure; that is, one or more sides moved downward while at least one side was hinged. As a result of this collapse, the contained clays were badly fractured and jointed. In some of the larger and deeper deposits remnants of brecciated Fort Scott limestone are found, as well as oxidized iron ore, the character of which would suggest that siderite was the original mineral. With this collapse and the formation of the sink structures, which in effect were natural "leaching pots", percolating ground water began to move through the clay particularly the highly fractured areas. With the carbonic acid from the break down of the siderite, described as occurring in both the Loutre and Fort Scott formations, the alkaline carbonate solutions from the break down of the Fort Scott limestones and possibly the pre-Pennsylvanian country rock adjacent to the sinks consisting of limestone and dolomite together with acid bearing water from the observable oxidation of pyrite, and possibly with organic acids as well, every condition for leaching was present.

Many writers have discussed the effect on clays of leaching by solutions charged with carbonic acid. The writer has recently had a splendid opportunity to observe actually such an effect. In prospecting for bauxitic clay in southeastern Missouri, a shaft was sunk to a total depth of 25 feet on the Merle Dunn farm in the SW¼ NE¼ SE¼ sec. 21, T. 26 N., R. 10 E., Stoddard County, into the high silica clay of the Porters Creek formation of the Midway group of the Eocene series. The upper few feet of the clay showed some slight alteration by weathering, but the lower part was the typical gray conchoidal fracturing clay of this formation.

A fault plane was also uncovered in this shaft and adjacent to it, at one point, were two nodules of iron oxide measuring 2 by 2 by 1, and 1 by 1 by ½ feet. These nodules were obviously oxidized from siderite (iron-carbonate) nodules so characteristic of the Porters Creek clay in this locality. Adjacent to the nodules and the plane of the fault, was a local area of clay, obviously of different character from the Porters Creek clay into which it graded imperceptibly. There seems to be no question that the altered material was originally a part of the latter.

The following analyses indicate the change in chemical composition of the clays resulting from alteration by water containing carbonic acid from the breakdown of the iron-carbonate nodules.

Sample No.	*1*	2
Silica (SiO_2)	61.52%	35.72%
Alumina (Al_2O_3)	14.64	28.29
Ferric Oxide (Fe_2O_3)	3.93	8.05
Titania (TiO_2)	0.59	0.40
Lime (CaO)	0.83	5.81
Magnesia (MgO)	0.74	1.51
Moisture (H_2O,-110°C)	7.51	6.62
Ignition Loss (H_2O,+110°C)	6.28	9.98
Total	96.04	96.38

Of the above, Sample No. 1 was taken from the shaft on the Merle Dunn farm, SW¼ NE¼ SE¼ sec. 21, T. 26 N., R. 10 E., 2 miles west and one-half mile south of Bloomfield, Stoddard County. The shaft was sunk in May, 1942 to a total depth of 25 feet. The sample represents the unweathered Porters Creek clay from bottom of the shaft and away from plane of fault previously described.

Sample No. 2, was taken from the same shaft, but from the area of altered clay lying between limonite (altered iron carbonate) nodules, and on the downthrown side of the fault described. The clay is white, although iron-stained along fractured surfaces. It grades into gray colored typical Porters Creek clay, a short distance away. The high iron and lime content of the altered sample was probably imparted by the solutions, which derived these constituents from the original nodules.

This example serves to illustrate that the oxidization of iron carbonate may have been equally effective in east central Missouri. It also calls to mind the previously described occurrences of unaltered siderite associated with diaspore clay. Such occurrences also suggest a source for the iron of the iron band diaspore. In some pits containing iron band diaspore, it is obvious that some of the original flint or burley clay has a fracture that is roughly rectangular or on the other hand concentric. This has been determined by breaking down large pieces of clay. A similar structural arrangement may also be observed in the associated iron band diaspore clay in the same pit. Obviously iron-carbonate has been deposited in such fractures of the clay, either after it was altered to diaspore, or more likely, before it was fully altered. In the latter case, oxidization of the iron carbonate would assist in completing the alteration process, and in addition, would leave bands or iron oxide in the clay. The Langenberg pit, NE¼ sec. 28, T. 44 N., R. 7 W., Osage County, is an excellent one now available for observation.

In other cases the iron carbonate was not deposited, and the iron bearing solutions moved through the fractured clay and through the bottom of the sink. Deposition could reasonably result as above described, however, where the bottom of the sink was closed up and the circulation of water was stopped. Such cessations could be brought about through choking up mechanically by clayey sediments, or by chemical precipitates of soluble salts, or by changes in the ground water level.

Evidence that a second period of leaching took place and one not related to that affecting the peneplained surface of the lower Cheltenham clay, may be seen in the irregular occurrence of diaspore clay, as veins, as lenses, as masses, grading into flint and burley clays in the area of a deposit containing the most broken or fractured clay. In fact at first glance, it would appear that diaspore clay is limited in occurrence to that portion of a deposit. Burley clay occurs similarly and sometimes has a high alkali content, in some cases in the basal portion of the deposit. As a result of this fracturing and faulting, as a result of at least two major periods of "aluminization", the deposits often show a jumbled nature that is not only difficult to observe and describe, but more to the point, expensive to mine.

The leached out, or more soluble salts were carried in some instances through the bottom of the sink into the caverns in the dolomite below. Some of these caverns were of great size and in them some of the soluble salts were redeposited. In the opinion of the writer the occurrence of iron-ore in a district just south of the southern district in structurally similar, sandstone lined sink-hole type deposits, is a manifestation of the lower part of a sink-hole type structure of which the clay bearing portion is the upper part. The contained iron is simply that iron carried through or out of the clay deposit and reprecipitated in the lower part of the same structure. In addition peculiar manifestations of silicon dioxide in the iron ore deposits might well represent the colloidal or finely divided silica leached from the clays.

A late chapter in the history of these clays was the development, by later Tertiary time, of a peneplain, the conspicuous remnants of which are now reflected by the even-topped sky line of the Ozark region. This peneplain cuts across the clay pits of the southern district, and also, some of those in the extreme southern part of the northern district, but in that district proper, it transects the limestones of the Fort Scott, Ardmore, and associated formations. Consequently, the main body of the Cheltenham clay is not affected.

The formation of this peneplain was followed by uplift of the Ozark region, by rejuvenation of the streams and their downward cutting. As a result the present topography was formed. The last stage before recent times in the history of the district was the invasion of the ice in Pleistocence time, an event previously mentioned and one indicated by the debris, which forms a material part of the overburden over the Cheltenham clays in the main producing portion of the northern district.

Chapter V

PHYSICAL CHARACTERISTICS OF MISSOURI REFRACTORY CLAYS

As McQueen has mentioned previously, the refractory clays of central Missouri are the basis for an extremely large industry in the State. The refractory industry is not only large, but is well organized and has put in effect such developments that it has rapidly become the leading refractory field in the United States, both as regards high grade raw material and outstanding products.

This report is the first attempt to give an analysis of the various characteristic clays of the entire central district. The test data were collected on samples whose origins and detailed geologic position have already been described by McQueen in previous chapters. Table 23 gives a summary of the locations of the twenty clays investigated, and hereafter they will be designated by the appropriate number. The samples as recived were dried at 212° F. for several days, and then run through a jaw crusher and rolls until all the material passed a 40 mesh sieve. Samples were quartered out for (a) chemical analysis, (b) sieve analysis, and (c) fusion temperature determination (pyrometric cone equivalent). The remaining clay after being thoroughly mixed was processed into sample bars 1 by 1 by 2 inches and into others 1 by 1 by 6 inches. To do this the clay was mixed with water to a soft mud consistency and formed in brass molds. Shrinkage marks were placed on the large size bars, while the small bars were individually weighed for the water of plasticity determination. All bars were air dried for at least 72 hours and then placed in a dryer kept at 110° C. for at least 24 hours more. After the bars were removed from the dryer and cooled, the large ones were measured for dry length, which was calculated to percent dry shrinkage as follows:

$$\text{Percent dry shrinkage} = \frac{\text{plastic length—dry length}}{\text{dry length}} \times 100$$

Upon cooling, the small dry bars were weighed to the nearest tenth of a gram and then saturated with kerosene. This was done by placing the bars in a dessicator, covering with kerosene, and evacuating the air space above the liquid until bubbles of air no longer escaped from the clay bars. The bars were weighed individually suspended in kerosene and also weighed after the excess liquid was removed from the surface with a damp cloth. From these data the dry volume was calculated as follows:

$$\text{Dry volume} = \frac{\text{saturated weight—suspended weight}}{\text{specific gravity of kerosene}}$$

Ten bars of each clay measuring 1 by 1 by 6 inches were measured for dry strength according to the standard formula for square test specimens as follows:

$$\text{Dry strength as modulus of rupture} = \frac{3 \times \text{load} \times \text{span}}{2 \times \text{breadth} \times \text{depth}^2}$$

A more complete discussion of the raw and fired properties tests is given by Davis[1] in a recent publication.

The data as determined for each typical clay are given in table 24. In analyzing any data taken on the dry properties of clays, it must be remembered that the technique of the operator controls and influences the numerical results to a very marked degree. Therefore, the analyses will be treated in a very broad way which can become more specific only upon the prosecution of a very extensive program of testing.

In all subsequent discussion, the clays are divided into similar groups and any remarks made about an individual clay can be applied to the whole group. The clays, thus, were divided into these four groups:

A. High alumina clays (clays No. 1 to 7)
B. Semi-flint clays (clays No. 8 to 12)
C. Semi-plastic and plastic clays (clays No. 13 to 17)
D. Flint clays (clays No. 18 to 20)

Discussion of Raw Properties of the Clays

When considering the raw properties of the high alumina clays of Missouri, such as the diaspores and burleys, one finds that such properties can be estimated on the basis of the alumina content as given in the chemical analysis. For instance,

[1]Davis, W. E., Herold, P. G., and McManamy, L., Further investigations of southeastern Missouri clays: Missouri Geol. Survey and Water Resources, 61st Bien. Rept., app. I, pp. 7-13, 1941.

pure diaspore has a chemical analysis of 85 percent Al_2O_3 plus 15 percent ignition loss. Thus, a diaspore clay containing 72 percent Al_2O_3 would be composed of approximately 73 percent pure diaspore. The remaining material is composed of an indefinite amount of cliachite ($Al_2O_3 \cdot nH_2O$) and leucoxene,[2] which are always present in diaspore clays as well as a small amount of accessory minerals. These minerals are discussed in Chapter VI.

An examination of table 24 shows that on an average the group of true flint clays have the lowest water of plasticity, followed in order by the high alumina clay group, the semi-flint clay group, and finally the semi-plastic and plastic clay group. This is what is expected when we remember that true flint clay is a very hard rock-like material, which does not develop much plasticity even upon extensive weathering. On the other hand, diaspore contains leucoxene, which is a fine grained colloidal material weakly plastic. The dry strengths of the clay groups do not follow in exactly the same order as the water of plasticity classification as would be expected. The dry strength of the high alumina clays is just about one quarter that of the flint clays. However, the other groups follow in the same order as was indicated by the water of plasticity data. It is also observed that in the high alumina clays, the greater the alumina content, the lower is the dry strength and water of plasticity. This illustrates the well known fact that pure diaspore is relatively non-plastic and only becomes plastic when impurities are present, which means a lowering of the alumina content of the mixture.

The semi-flint clay group (lower Cheltenham) is characterized by a medium dry strength and water of plasticity, which indicates that these clays do have some plasticity. Upon fine grinding and weathering these clays should, and do, develop plasticity so that they can be used in hand molding refractory shapes. There is nothing in the physical test data to indicate why there should be such a wide difference between the various semi-flint clays. For instance, the dry strength of clays No. 9, 10, 11, and 12 are low, while clay No. 8 (see table 24) is high. An examination of the chemical analyses of these clays (see

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[2]Mineral composition and origin of Missouri flint and diaspore clays. Victor T. Allen, Missouri Geol. Survey and Water Resources, 58th Bien. Rept., app. IV, pp. 11-12, 1935.

table 25) indicates the answer to this question. The alkali content of clay No. 8 is 2.25 percent while the other clays in the group are lower than 2.0 percent. It is generally true that similar clays will have high plasticity, as indicated by dry strength and water of plasticity, when the alkali content is high and vice versa with low alkali content. In these cases, the alkalies are present as adsorbed salts on the clay colloidal particles, which the laws of colloidal chemistry indicate reduce the charge on the surface of the particle causing coagulation. Clays in the coagulated or flocculated condition are characterized by high plasticity. In the case of the semi-flint clays there are not enough colloidal particles present to cause extreme plasticity.

The semi-plastic and plastic clays (middle and upper Cheltenham) comprise a group having the highest dry strength and water of plasticity. The two semi-plastic clays being lower in dry strength and water of plasticity than the plastic clays, give us a measure of the colloidal particle content. It will be noticed that clay No. 15, called "foundry clay", is very plastic as indicated by the dry strength. Again the alkali contents within the group are directly related to the degree of plasticity.

The last group of clays, Missouri flints, show low dry strength and low water of plasticity. These data support the generally recognized character of true flint clays.

Explanation of the Chemical Analyses of the Clays

The chemical analyses are given in table 25 and cover the analyses of the usual oxides in addition to sulphur and phosphorus pentoxide. The complete chemical analysis is a very important tool used for determining the type of clay, the type and amount of impurities present, and also gives an indication of the melting point. Of course, such deductions are based on past experience, or calculations changing the oxide analysis into amounts of minerals, which are known to be present.

When considering high alumina clays, the alumina content of the clay gives a very good indication of the degree of purity. In fact, the various grades of diaspore clay are designated according to alumina content as determined by chemical analysis. Several authorities have set up a series of standards, but the two most used by those mining and using the clays was described by McQueen on page 188 and Forbes[3] as follows:

Diaspore	85% alumina plus 15% ignition loss
Diaspore clay	68% alumina or more
Burley clay	56% to 68% alumina
Burley-flint clay	45% to 55% alumina
Flint clays	45% alumina and less

As the diaspore clay deposits become more depleted, this grading will gradually be lowered so that the prevalent idea of diaspore in the future may be the same as the present designation of burley clay.

An examination of the first seven chemical analyses in table 25 shows that all the clays can be considered to be diaspore clay except numbers 4 and 7. These two would be considered as very good burley clays, and number 4 is so near the border that it may be also considered as a diaspore clay. In high alumina clays such as these, the silica content is present tied up as an indefinite aluminum silicate, which has been tentatively termed leucoxene (see chapter VI). The only impurity, other than silica which is high in amount, is titania and this is usually considered to be a refractory material, which ordinarily is assumed to combine with the iron oxide present in the clay. The mineral formed is an iron titanate which has a high melting point. The chemical analysis of a high alumina clay, however, does not tell the whole story about the clay. This is very well illustrated by clay No. 6, which looks like a flint clay, has the analysis of a diaspore clay, and actually is a boehmite clay (see expanation in chapter VI).

The group of clays designated as semi-flint clays (Nos. 8 to 12) are characterized by a slight excess of free silica, but which are otherwise very pure clays. The fluxing oxides, which are lime, magnesia, soda, potash, and iron oxide, do not average more than 3.5 percent. The group of semi-plastic and plastic clays contain a little more free silica than the previous group, and are still quite pure as they contain fluxing oxides to the extent of not more than 3.25 percent on an average, if the foundry clay is disregarded. The last three clays designated as flint clays are the most refractory clays of the group, outside of the high alumina clays, as they contain a slight excess of alumina over that required to combine with the silica to make kaolinite. This indicates that these clays are either associated

[3]Forbes, C. R., Grading and sampling Missouri burley and diaspore clay: Jour. Amer. Ceramic Soc., vol. 14, pp. 382-388, 1931.

with diaspore clays, or are partially weathered toward high alumina clays. The fluxing materials present are not over 3 percent.

Discussion of Sieve Analyses of the Clays

The grain size of the individual clays were determined by washing 200 grams of the dry clay through sieves with water. After the wash water coming through the sieves was clear, the seive and contents were heated for 24 hours at 212° F. and the contents weighed to the nearest tenth of a gram. The sieves used were the U. S. Bureau of Standard series, having an opening size as follows:

Sieve	*Size of opening in inches*
50 Mesh	.0117
70 mesh	.0083
100 mesh	.0059
140 mesh	.0041
200 mesh	.0029
270 mesh	.0021
325 mesh	.0017

Table 26 shows that most of the clays tested are rather hard since they do not break down into much material through 325 mesh. The hardest clays seem to be the two semi-flint clays, Nos. 11 and 12, and the two flint clays Nos. 18 and 19.

Analysis of the Fired Properties of the Clays
Description of Tests

The usual firing behavior procedure was used in firing the clays as recommended by the American Ceramic Society.[4] In this procedure, the temperature of the kiln was raised at the rate of 45° C. per hour until cone 02 was reached and then 20° C. per hour until cone 14. Two small bars of each clay were removed from the kiln at cones 2, 4, 6, 8, 10, 12, and 14 and placed in sand until they reached room temperature. The dry weight of each bar was then recorded. Each bar was subsequently boiled in water for two hours after which the saturated weight and suspended weight was recorded.

From these data volume firing shrinkage was calculated as follows:

$$\text{Percent volume shrinkage} = \frac{\text{dry volume—fired volume}}{\text{dry volume}} \times 100$$

[4]Report of the Committee on Standards. Jour. Amer. Ceram. Soc., vol. 11, pp. 442-534, 1928.

Apparent porosity, absorption, and apparent specific gravity were also calculated:

$$\text{Percent apparent porosity} = \frac{\text{saturated fired weight—fired weight}}{\text{fired volume}} \times 100$$

$$\text{Percent absorption} = \frac{\text{saturated fired weight—fired weight}}{\text{fired weight}} \times 100$$

$$\text{Apparent specific gravity} = \frac{\text{fired weight}}{\text{fired vol—(saturated fired wt.—fired wt.)}}$$

The hardness of the clays after being fired to the above mentioned cones were determined according to Mohs' scale of hardness. This arbitrary scale is based on the increasing hardness of natural minerals according to:

Mohs' Scale of Hardness

Hardness	*Mineral*
1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Orthoclase
7	Quartz
8	Topaz
9	Corundum
10	Diamond

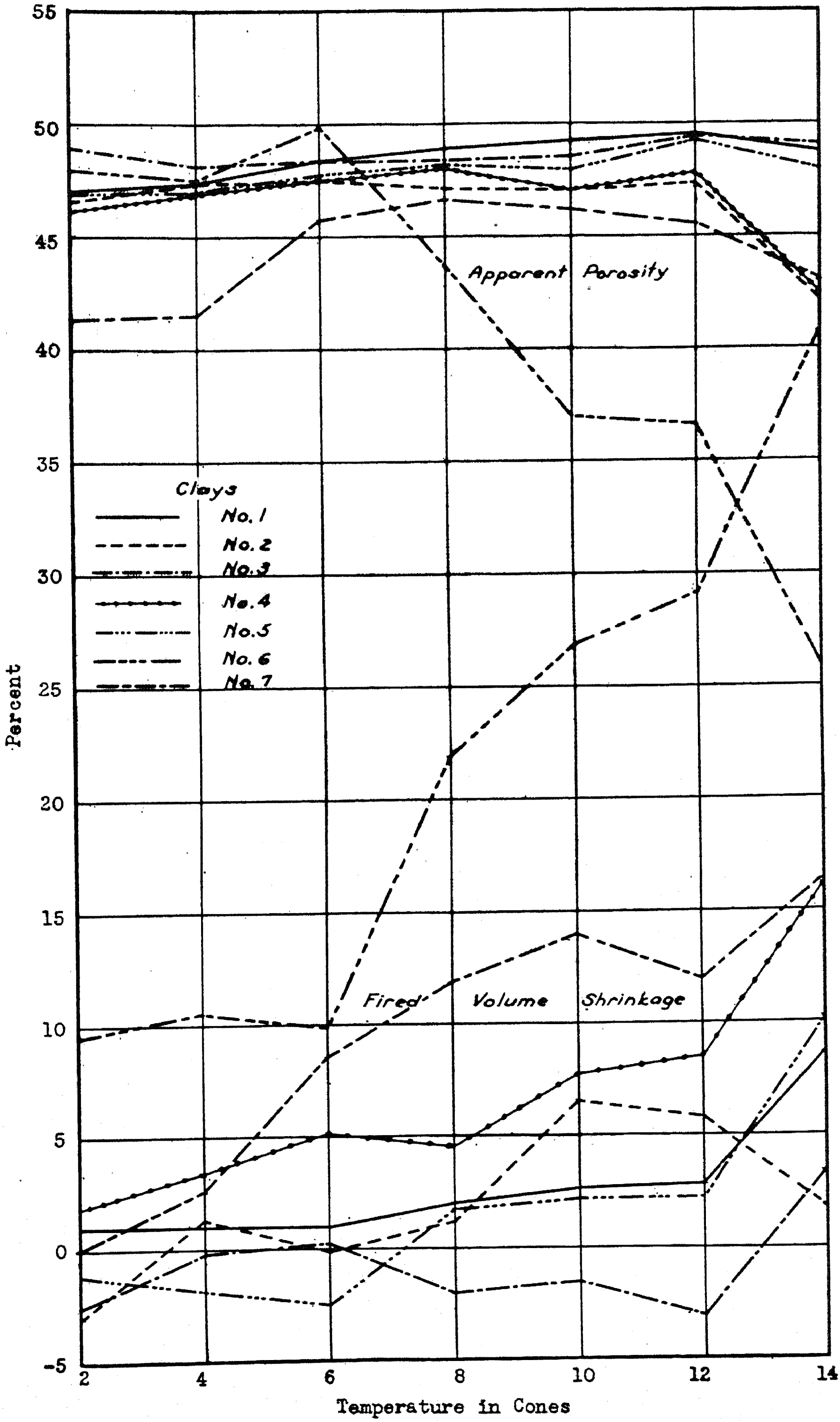
The fired clays were compared to this scale by scratching them with each mineral until one mineral was found which would just slightly scratch the clay. Thus, the hardness of the clay is given by a number which represents the hardness of the appropriate natural mineral.

The color of the fired bars was estimated by visual observation and is based entirely on the judgment of the observer and a very inadequate nomenclature. However, color is not the most important property of refractory products or the clays from which they are manufactured. Color can give an indication of the amount and type of impurities present in the clay.

The softening point (pyrometric cone equivalent) of each clay was determined according to standard practice as established by the American Society for Testing Materials.[5]

Before making any of the test cones for the softening point test, the clay was ground finer than 60 mesh (0.0098 inches)

[5] A.S.T.M. designation C24-42, A.S.T.M. Standards 1942, Part II, pp. 247-249.



Firing behavior of high alumina clays.

and fired to 1000° C. to remove any organic materials and some of the shrinkage. In this way the test cones more nearly compare in size to the standard cones during the heating required in the test.

The fired strength determined as modulus of rupture was determined on bars 1 by 1 by 6 inches, which had been fired to cone 14. The calculations were made using the same formula as given previously for dry strength determination.

The fired shrinkage was determined on the fired bars before being broken on the modulus of rupture machine and calculated as follows:

$$\text{Percent fired shrinkage} = \frac{\text{dry length—fired length}}{\text{dry length}} \times 100$$

Analysis of Fired Properties

An examination of figure 3 shows the change in apparent porosity and fired volume shrinkage of the high alumina clays. The same properties for the other clays are given in figures 4, 5, and 6. Since in most cases these two properties plus absorption and apparent specific gravity are all interrelated, the apparent porosity will be the only one discussed in detail. Percent apparent porosity is the percentage of open pores based on the total volume of the fired clay sample.

It will be noticed in Fig. 3 that all of the high alumina clays except No. 6 have about the same percentage of open pores, and that they stay open even to as high a temperature as cone 14. In comparsion with all the other clays they have about twice as much volume of open pores and therefore can be considered as very open burning clays. The burley clay (No. 7) has a little less volume of open pores, but follows the higher alumina clays nearly throughout its temperature changes. The clay No. 6, which has been identified as a boehmite clay (see chapter VI), departs very radically from the other high alumina clays. Thus, the open pores of clay No. 6 rapidly close above cone 6. The clew to the difference in behavior between diaspore and boehmite was given by Huttig,[6] who stated that upon dehydration diaspore changes into corundum while boeh-

[6]Huttig, G. E., and Kostelitz, O., Beitrage zur Kenntnis der Oxydhydrate: XX Das System Aluminumoxyd—Wasser. Z. anorg. allgem. Chem. *187*, p. 1-15.

mite changes into gamma-alumina. This statement cannot be strictly applied to diaspore clay, since the writer[7] has found that a small amount of gamma-alumina does form when diaspore clay is heated at low temperatures.

This small amount of gamma-alumina changes to corundum before 950° C. and all the corundum present is in the form of porous grains occupying a large space. The gamma-alumina of boehmite does not start to change appreciably to corundum until a temperature of 1200° C. is reached, when the corundum being formed coalesces into small rather non-porous grains. Although boehmite has an excessive shrinkage as compared to diaspore clays, it should not have the troublesome shrinkage upon reheat, which is encountered with diaspore clays.

Table 27 gives the hardness of the high alumina clays in terms of Mohs' scale of hardness. These clays are usually rather soft at high temperatures as compared to other fire clays, unless there are excessive amounts of such fluxes, as alkalies and alkaline earths. The flux bonds the grains of alumina at high temperatures to produce a very hard refractory. Again clay No. 6 (boehmite clay) stands out as evidenced by the greatest hardness. This is due to the greater consolidation of the alumina brought about by the excessive shrinkage. In the case of the other clays in the high alumina group, the hardness of the fired clay is in inverse ratio to the purity as evidenced by the alumina content given by the chemical analysis (table 25).

Usually the fired color can be used as a measure of the iron content of the clay, or at least, to the relative ratio of the iron oxide to the alkaline earth (calcium oxide plus magnesia) content. In the case of the high alumina clays, however, the colors are so nearly the same, as are the impurity contents, that no conclusions can be reached.

The high alumina group of clays have a rather high strength when fired to cone 14. The fired strength is directly related to firing shrinkage, so that clay No. 1 has a low shrinkage and strength while clay No. 4 has a high shrinkage and strength. These two properties should be related to the amount of the usual fluxes, especially the alkalies. In general, strength does depend on the flux content in the high alumina clays when the

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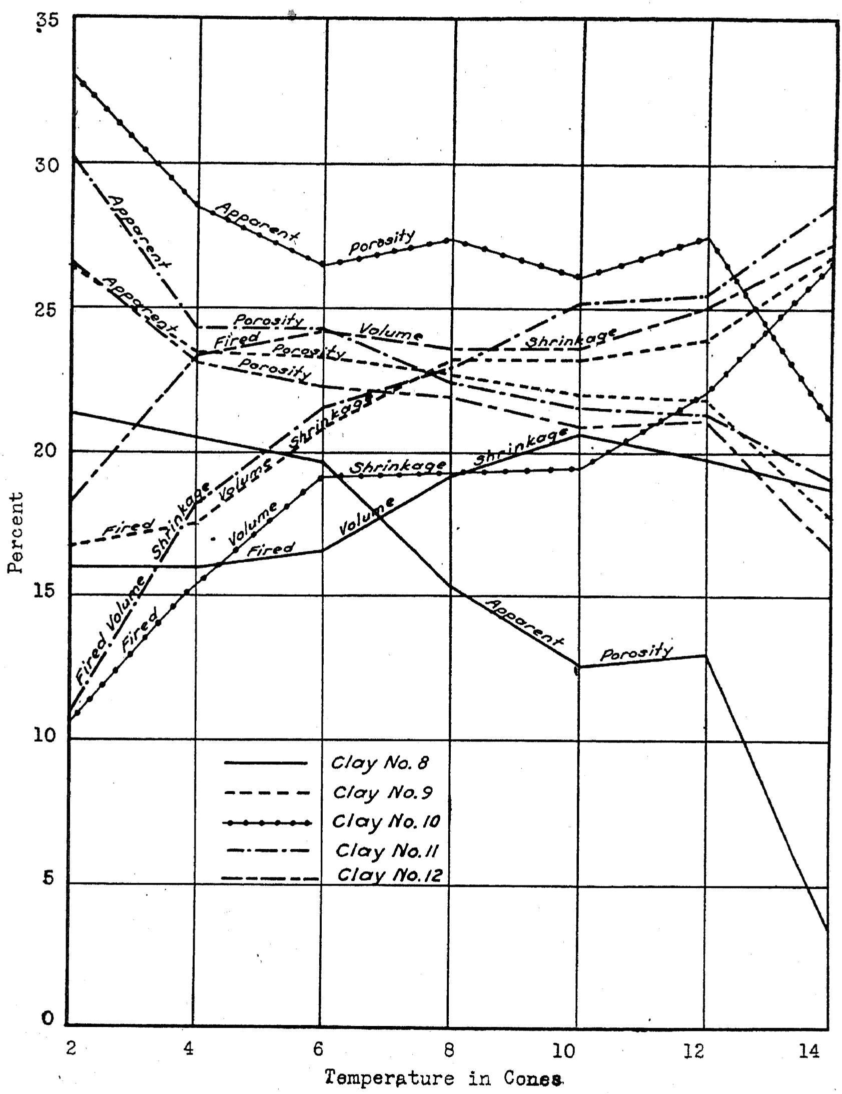
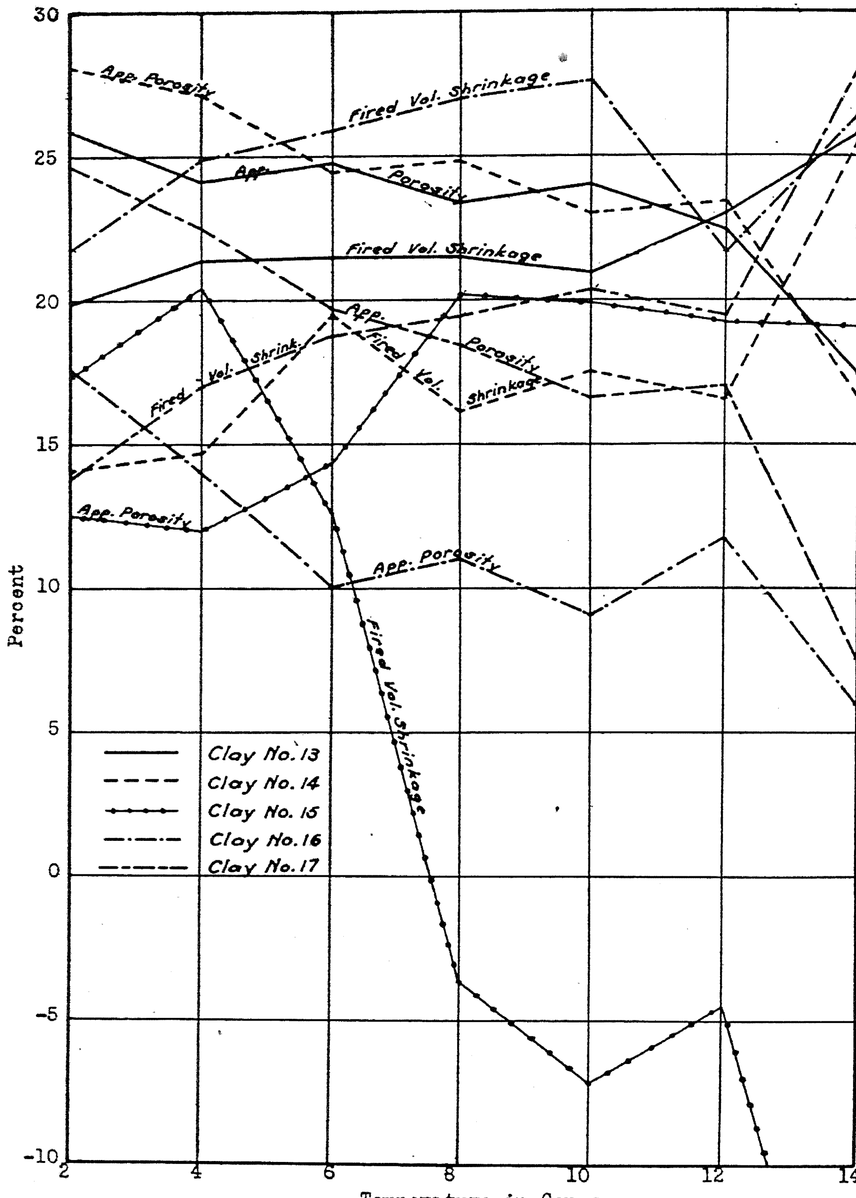
[7]Herold, P. G., and Dodd, C. M., Thermal dissociation of diaspore clay: Jour. Amer. Ceramic Soc. vol. 22, pp. 388-391, 1939.



Firing behavior of lower Cheltenham semi-flint clays.



Firing behavior of middle and upper Cheltenham semi-plastic and plastic clays.

phosphorus oxide content is low. The presence of phosphorus oxide produces a glass, which is usually regarded as rather weak and brittle.

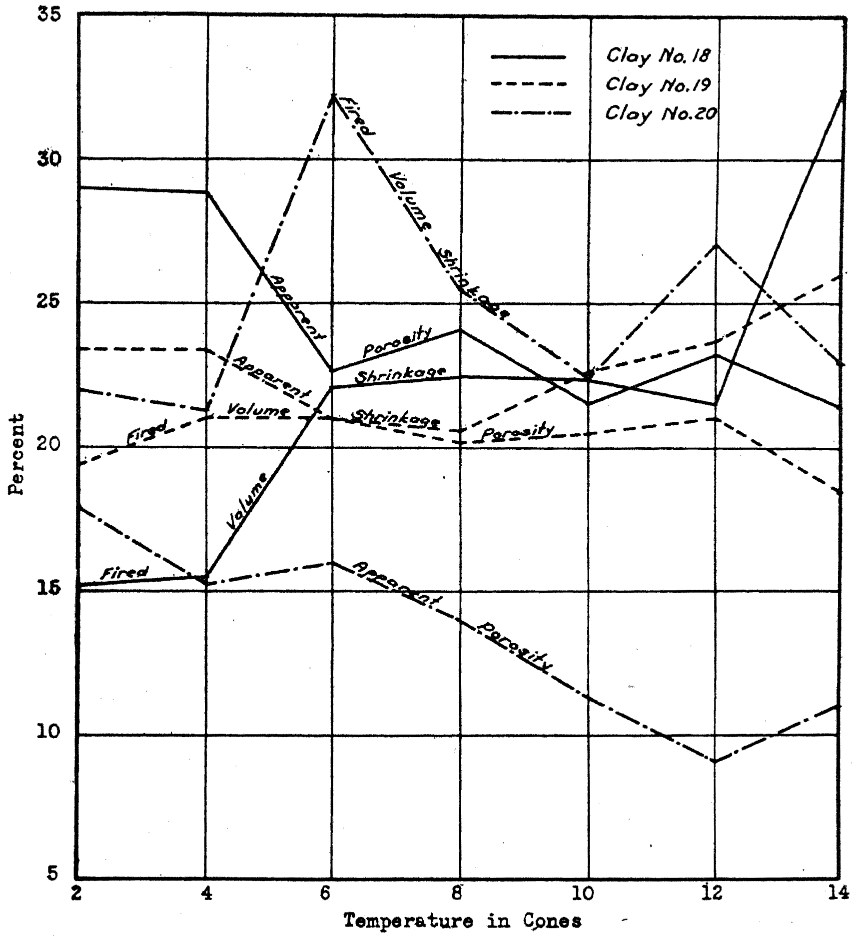
The fusion temperature of the high alumina clays as given by the P. C. E. figures of table 24 were determined by the American Refractories Institute Fellowship, Mellon Institute of Industrial Research, since the equipment at the Missouri School of Mines could not be used for determining fusion temperatures higher than cone 35. As may be noted the fusion temperature is related to the amount of alumina and fluxes present in the clay.

Clays No. 8 to 12 all come from the lower Cheltenham and are designated as semi-flint clays. The great bulk of refractories are manufactured in the central Missouri district from these clays. An examination of figure 4 shows some of the characteristics of semi-flint clays. As this type of clay is raised in temperature to a maturing point of cone 14, the closed pore space gradually contracts until an average of about 15 percent remains. The porosity of the five clays in this group decreases as the flux content increases as shown by the chemical analyses. It is interesting to note in this connection how nearly parallel are the apparent porosity curves for clays No. 11 and 12, both of which come from the same pit. However, clay No. 12, which is the dark colored pocket material occurring in clay No. 11, does differ in some of its other properties.

In general the hardness of the semi-flint clays (table 28) correlates very well with the chemical analyses as do the fired strength and firing shrinkage. For instance, clays No. 8 and 9 are very hard at cone 14, have a moderately high shrinkage and a very high strength. The fired color is directly related to the amount of iron present in the chemical analysis. The fusion temperatures of the semi-flint clays are in the range expected of such clays, and again, are influenced by the relative amounts of refractory alumina and fluxing materials present.

The middle and upper Cheltenham clays are designated as semi-plastic and plastic clays respectively, of which two in each group were tested. In this group is also placed the "foundry clay", which can hardly be classed as a refractory clay although it has been used locally in some types of mortars for foundry work. As would be expected, the apparent porosity of the semi-plastic clays is higher than that of the plastic clays. The apparent porosity of the "foundry clay" increases considerably above cone 4, since bloating takes place. The plastic clays contract to such an extent, that at cone 14 the pores present are only about 7 percent of the mass. The plastic clays are not as refractory as the semi-plastic clays and do not have as high a fired strength (table 24). Table 29 indicates quite a good hardness for these clays which can be related to the alumina and fluxing content of the individual clays. As a rule the fired color of the clays is much darker than any of the other clays due to the iron contents.

The flint clays (figure 6) vary quite a bit among themselves, although, they have the characteristic of not changing appreciably in apparent porosity at high temperatures. They are refractory clays since an inspection of the fusion temperatures (table 24) shows a high P. C. E. Likewise the chemical analyses show these three clays to be rather pure, containing about the correct ratio of silica and alumina so that there apparently is no free silica or sand present. Table 30 gives a high hardness for the clays and a very light color at high temperatures.



Firing behavior of flint clays.

TABLE 23.

LOCALITIES FROM WHICH CLAY SAMPLES WERE OBTAINED.

Clay No.	Location.	County.	Name of pit.	Owner.	Description.
1	NW¼ sec. 17, T.44N., R.5W......	Gasconade....	Linneman.........	A. P. Green Fire Brick Co.........	Diaspore clay, soft, fine-grained, "mealy" variety.
2	NE¼ NE¼ sec. 36, T.43N., R.6W.	Gasconade....	Aufderheide.......	Harbison-Walker Refractories Co...	Diaspore clay, hard, very fine-grained, rock-like variety.
3	NW¼ sec. 35, T.45N., R.6W......	Gasconade....	Kallmeyer........	General Refractories Co..........	Diaspore clay, fairly hard, fine-grained.
4	NW¼ sec. 21, T.44N., R.5W......	Gasconade....	Krull No. 2.......	....	Burley clay, very oolitic.
5	SE¼ sec. 22, T.44N., R.5W.......	Gasconade....	Albert Kahle......	A. P. Green Fire Brick Co........	Diaspore clay, very porous, open textured, "sponge" variety.
6	Sec. 15, T.44N., R.5W., Swiss.....	Gasconade....	Klossner..........	A. P. Green Fire Brick Co.........	High alumina clay, hard, fine-grained, flint-like.
7	NW¼ sec. 3, T.41N., R.7W.......	Osage........	Jett.............	General Refractories Co..........	Burley clay, high grade.
8	Sec. 36, T.51N., R.9W., Mexico...	Audrain......	Plant pit No. 4....	A. P. Green Fire Brick Co.........	Semi-flint clay, lower Cheltenham, adjacent to "rock roll", hard, black, "slaty."
9	Sec. 36, T.51N., R.9W., Mexico...	Audrain......	Plant pit No. 4....	A. P. Green Fire Brick Co.........	Semi-flint clay, lower Cheltenham, light colored or gray "Empire clay No. 110," just below base of middle Cheltenham.
10	Sec. 7, T.52N., R.5W., Vandalia...	Audrain......	Plant mine (Renner tract)..........	Harbison-Walker Refractories Co...	Semi-flint clay, lower Cheltenham, brown.
11	NW¼ sec. 34, T.48N., R.9W......	Callaway.....	Stoltz............	Mexico Refractories Co...........	Semi-flint clay, lower Cheltenham, light colored.
12	NW¼ sec. 34, T.48N., R.9W......	Callaway.....	Stoltz............	Mexico Refractories Co...........	Semi-flint clay, lower Cheltenham, dark colored, occurs in pockets in lighter colored clay No. 11.
13	Sec. 36, T.51N., R.9W., Mexico...	Audrain......	Plant pit No. 4....	A. P. Green Fire Brick Co.........	Semi-plastic clay, middle Cheltenham, "Empire clay No. 111," above dark sandy clay.
14	Sec. 7, T.52N., R.5W., Vandalia...	Audrain......	Plant mine (Renner tract)..........	Harbison-Walker Refractories Co...	Semi-plastic clay, middle Cheltenham, overlies greenish gray pyritic clay.
15	Sec. 36, T.51N., R.9W., Mexico...	Audrain......	Plant pit No. 4....	A. P. Green Fire Brick Co.........	Plastic clay, upper Cheltenham, known as "foundry clay."
16	NW¼ SE¼ sec. 29, T.48N., R.9W.	Callaway.....	Weatherall........	Mexico Refractories Co...........	Plastic clay, upper Cheltenham, dark gray.
17	S½ NW¼ sec. 28, T.55N., R.9W...	Monroe.......	Coy Rives........	General Refractories Co..........	Plastic clay, upper Cheltenham, dark gray.
18	SW¼ sec. 11, T.42N., R.5W.......	Gasconade....	Pieuch No. 2......	General Refractories Co..........	Flint clay, typical white hard, "pop corn flint clay."
19	NW¼ sec. 2, T.46N., R.8W.......	Callaway.....	Arthur Nichols....	Mexico Refractories Co...........	Flint clay, Callaway County pit type.
20	Sec. 24, T.42N., R.5W...........	Gasconade....	Henneke..........	General Refractories Co..........	Flint clay, dark gray, hard.

TABLE 24.

GREEN AND FIRED PROPERTIES OF CLAYS.

Clay No.	Water of plasticity, per cent.	Linear drying shrinkage, per cent.	Dry modulus of rupture, lbs. per sq. in.	Linear firing shrinkage at cone 14, per cent.	Fired modulus of rupture at cone 14, lbs. per sq. in.	Softening point.	
						P. C. E.	°F.
1	26.1	4.9	45	3.5	1045	35–36**	3270
2	26.8	4.0	40	7.1	2285	36–37**	3300
3	21.7	1.4	10	3.2	1215	36–37**	3300
4	31.0	6.6	50	7.4	2530	35–36**	3270
5	23.3	3.2	40	4.6	1105	36–37**	3300
6	29.9	5.8	55	13.3	2080	35–36**	3270
7	25.7	8.0	65	3.6	1015	33–34	3190
8	33.5	9.5	215	4.2	1890	30–31	3030
9	25.8	6.8	75	9.3	2170	32½	3130
10	27.2	6.7	85	9.7	2595	32½	3130
11	25.4	6.5	85	9.7	2185	34	3200
12	29.9	8.7	135	10.1	3415	32½	3130
13	32.0	9.4	125	10.0	3085	32½	3130
14	25.6	7.2	125	8.7	4205	30	3000
15	38.8	14.1	435	*	*	18–19	2740
16	35.8	10.9	215	6.1	3060	31	3055
17	32.2	11.1	170	6.3	2290	30–31	3030
18	21.1	4.4	195	10.9	620	34–35	3225
19	23.8	6.5	200	10.0	1240	34	3200
20	28.8	8.0	80	10.6	2875	32½–33	3150

*Clay No. 15 is known as a "foundry clay" and is not used as a refractory. Therefore, some of the fired properties were not determined.

**These P. C. E. values determined by American Refractories Institute Fellowship, Mellon Institute of Industrial Research, University of Pittsburgh.

TABLE 25.

CHEMICAL ANALYSES OF CLAYS.

R. T. ROLUFS, analyst.

PERCENT.

Clay No.	Silica (SiO_2)	Alumina (Al_2O_3)	Ferric oxide (Fe_2O_3)	Titania (TiO_2)	Lime (CaO)	Magnesia (MgO)	Soda (Na_2O)	Potash (K_2O)	Sulphur (S)	Phosphorus pentoxide (P_2O_3)	Moisture (H_2O)	Ignition loss.	Total.
1	6.18	72.54	1.56	3.16	.22	.11	.25	1.09	.10	.316	.14	14.08	99.746
2	6.00	72.67	1.91	3.16	.14	.14	.23	.80	.02	.085	.20	14.18	99.535
3	2.84	77.00	1.65	3.16	.12	.09	.05	.57	.02	.066	.03	14.55	100.146
4	11.20	67.87	1.73	3.06	.22	.09	.45	1.68	.09	.339	.12	13.61	100.459
5	4.06	75.32	1.91	3.06	.17	.08	.27	.97	.03	.126	.04	14.26	100.296
6	7.64	72.12	1.65	3.06	.22	.09	.13	.97	.02	.032	.14	14.33	100.402
7	10.80	67.09	1.73	3.16	.32	.17	.89	1.13	.055	.62	.00	13.57	99.535
8	54.46	28.43	2.08	1.38	.46	.42	.22	2.00	.04	.034	.40	9.63	99.554
9	52.02	32.70	.81	1.80	.27	.38	.25	.73	.040	.01	.50	10.94	100.550
10	44.62	34.49	1.82	3.26	.44	.43	.28	.97	.061	.07	.75	11.88	99.071
11	45.20	35.98	1.73	1.68	.46	.23	.21	1.33	.000	.09	.69	11.84	99.440
12	47.60	32.79	2.42	1.68	.54	.41	.23	1.75	.003	.05	.90	10.98	99.353
13	48.90	33.20	1.47	1.58	.56	.34	.10	1.53	.006	.05	.81	10.74	99.286
14	53.64	29.20	2.25	1.58	.49	.46	.10	1.22	.114	.03	.39	10.07	99.544
15	56.10	24.47	3.64	1.58	.61	1.11	.17	2.89	.164	.15	.88	7.51	99.274
16	50.96	29.91	2.69	1.68	.49	.38	.15	2.50	.058	.16	.65	9.56	99.188
17	57.20	26.90	2.25	1.58	.63	.30	.15	1.22	.004	.07	.35	9.29	99.944
18	43.32	38.18	1.56	1.58	.39	.11	.08	.49	.02	.098	.43	13.19	99.548
19	43.46	38.08	1.73	1.38	.46	.16	.32	.86	.02	.508	.47	13.05	100.498
20	43.40	37.21	1.65	1.68	.46	.36	.56	1.94	.012	.14	.71	11.38	99.502

TABLE 26.

HYDRAULIC SIEVE ANALYSES OF CLAYS.

PERCENT.

MESHES PER INCH.

Clay No.	+ 50	− 50 + 70	− 70 + 100	− 100 + 140	− 140 + 200	− 200 + 270	− 270 + 325	− 325
1	8.5	10.4	10.5	8.2	10.8	7.9	7.0	36.7
2	13.0	13.1	16.5	6.7	7.2	4.0	2.9	36.6
3	9.7	11.7	8.5	6.1	6.5	5.0	5.9	46.6
4	9.6	11.1	9.5	7.4	8.2	6.4	7.0	40.8
5	9.8	11.4	8.4	5.9	7.9	6.3	11.1	39.2
6	9.7	17.7	15.2	11.4	11.7	6.4	4.3	33.6
7	25.0	7.6	9.1	4.5	6.3	3.6	2.6	41.3
8	7.6	11.6	10.3	6.7	7.5	4.1	5.3	46.9
9	8.7	15.3	10.1	7.5	6.5	3.7	2.0	46.2
10	10.8	14.4	12.7	9.3	10.7	5.7	6.4	30.0
11	12.2	17.2	13.4	9.7	10.1	5.7	5.7	26.0
12	10.6	17.6	15.9	9.4	10.5	5.7	5.6	24.7
13	9.6	15.5	13.2	8.8	9.8	5.1	5.9	32.1
14	10.7	14.1	11.1	7.2	7.1	4.6	3.5	41.7
15	7.4	14.6	12.2	8.5	8.2	4.3	4.8	40.0
16	4.3	14.9	9.8	8.4	7.7	4.6	5.0	45.3
17	2.1	13.5	11.1	7.9	8.7	5.0	4.8	46.9
18	16.3	16.5	13.4	8.8	8.9	5.0	3.9	27.2
19	13.3	13.4	13.8	13.5	9.5	5.7	4.7	26.1
20	10.2	10.3	14.0	6.6	7.7	4.3	2.2	44.7

TABLE 27.

FIRING BEHAVIOR OF HIGH ALUMINA CLAYS.

Cone.	Absorption, per cent. Clay number.							Apparent specific gravity. Clay number.							Hardness. Clay number.							Fired color. Clay number.						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
2..........	27.9	27.5	29.9	27.7	28.0	27.2	25.4	3.18	3.18	3.17	3.10	3.15	3.35	2.77	3	3	3	4	3	4	3	Light cream.	White	Light cream.	Light cream.	Light cream.	White	Light cream
4..........	28.0	27.7	29.3	28.2	28.0	27.0	25.4	3.20	3.25	3.20	3.21	3.15	3.36	2.80	3	3	3	5	3	5	4	Light cream.	White	Light cream.	Light cream.	Light cream.	White	Light cream
6..........	28.8	27.3	28.7	28.2	28.2	27.0	25.4	3.25	3.31	3.24	3.27	3.20	3.61	3.36	3	3	3	5	3	5	4	Light cream.	White	Light cream.	Light cream.	Light cream.	White	Light cream
8..........	28 8	27.0	28.7	28.1	28.2	21.4	25.4	3.32	3.35	3.25	3.30	3.28	3.62	3.44	3	4	3	5	3	5	4	Light cream.	White	Light cream.	Light cream.	Light cream.	White	Light cream
10..........	28.8	26.1	28.7	26.6	28.2	17.0	24.7	3.38	3.41	3.30	3.34	3.35	3.62	3.44	3	4	3	5	3	5	4	Light cream.	White	Light cream.	Light cream.	Light cream.	White	Light cream
12..........	28.7	26.4	29.5	26.5	28.7	15.8	24.1	3.39	3.42	3.32	3.38	3.38	3.62	3.45	3	4	3	5	3	6	5	Light cream.	White	Light cream.	Light gray..	Light cream.	White	Light cream
14..........	26.8	20.4	27.5	21.6	25.8	9.9	23.3	3.55	3.59	3.47	3.41	3.57	3.62	3.51	3	4	4	5	3	6	5	Light cream.	White	Light cream.	Very lt. pink.	Light cream.	White	Light cream

TABLE 28.

FIRING BEHAVIOR OF LOWER CHELTENHAM SEMI-FLINT CLAYS.

Cone.	Absorption, per cent. Clay number.					Apparent specific gravity. Clay number.					Hardness. Clay number.					Fired color. Clay number.				
	8	9	10	11	12	8	9	10	11	12	8	9	10	11	12	8	9	10	11	12
2.......	10.8	14.3	17.4	15.5	13.1	2.50	2.53	2.86	2.77	2.76	5	5	4	4	5	Light buff......	White..........	White..........	White..........	White
4.......	10.3	12.4	14.2	11.5	10.9	2.50	2.55	2.86	2.79	2.78	5	6	5	5	5	Buff............	White..........	White..........	White..........	White
6.......	9.9	11.9	12.6	11.3	10.3	2.48	2.61	2.86	2.83	2.80	6	6	5	5	5	Buff............	White..........	White..........	White..........	Light cream
8.......	7.4	11.7	12.5	10.2	10.3	2.41	2.61	2.86	2.83	2.80	7	7	5	5	5	Light gray......	White..........	Light cream.....	White..........	Light gray
10.......	6.0	10.6	12.2	10.2	9.7	2.40	2.63	2.86	2.83	2.82	7	7	6	5	6	Light gray......	Light gray......	Light cream.....	Light gray......	Light gray
12.......	5.6	9.7	12.2	9.7	9.7	2.38	2.62	2.90	2.83	2.82	8	7	6	5	6	Light gray......	Light gray......	Light cream.....	Light gray......	Light gray
14.......	1.5	7.7	9.4	8.4	7.4	2.18	2.63	2.90	2.83	2.83	8	8	6	5	6	Gray...........	Light gray......	Buff............	Light cream.....	Buff

TABLE 29.

FIRING BEHAVIOR OF MIDDLE AND UPPER CHELTENHAM SEMI-PLASTIC AND PLASTIC CLAYS.

Cone.	Absorption, per cent. Clay number.					Apparent specific gravity. Clay number.					Hardness. Clay number.					Fired color. Clay number.				
	13	14	15	16	17	13	14	15	16	17	13	14	15	16	17	13	14	15	16	17
2	12.5	14.1	5.7	8.4	12.4	2.79	2.80	2.4	2.70	2.67	5	5	5	6	5	Light cream	White	Buff	Cream	White
4	12.0	13.4	6.6	6.2	10.9	2.85	2.78	2.6	2.63	2.65	5	6	6	6	5	Light cream	White	Dark gray	Dark cream	White
6	11.7	12.0	7.1	3.5	9.4	2.85	2.72	2.3	2.52	2.59	6	6	6	6	6	Light cream	White	Dark gray with slight bloating	Dark gray	White
8	10.9	12.0	9.8	4.8	8.7	2.80	2.71	2.2	2.52	2.58	7	6	7	7	7	Light cream	Light gray	Dark gray, bloating	Dark gray	White
10	10.9	10.5	12.0	3.8	7.8	2.80	2.71	2.1	2.57	2.56	7	6	7	7	7	Light gray	Light gray	Dark gray, bloating	Dark gray	White
12	10.2	10.5	12.0	5.2	8.1	2.79	2.71	2.1	2.55	2.56	8	7	7	7	7	Light gray	Light gray	Dark gray, bloating	Dark gray	Lightgray
14	7.8	7.0	13.1	2.6	3.1	2.69	2.67	1.8	2.45	2.52	8	8	7	7	8	Light buff	Buff	Brownish red, extreme bloating	Buff	Buff

TABLE 30.

FIRING BEHAVIOR OF FLINT CLAYS.

Cone.	Absorption, per cent. Clay number.			Apparent specific gravity. Clay number.			Hardness. Clay number.			Fired color. Clay number.		
	18	19	20	18	19	20	18	19	20	18	19	20
2	14.9	11.5	8.2	2.72	2.66	2.64	6	7	7	White	White	White
4	14.9	11.2	7.2	2.71	2.69	2.53	7	7	8	White	White	White
6	11.5	9.9	6.7	2.68	2.69	2.83	7	7	8	White	White	Yellowish gray
8	11.5	9.4	6.1	2.70	2.69	2.69	8	8	8	White	White	Yellowish gray
10	10.1	9.6	5.2	2.69	2.70	2.47	8	8	8	White	White	Yellowish gray
12	10.2	9.8	5.0	2.69	2.70	2.42	8	8	8	White	White	Yellowish gray
14	7.8	8.4	5.0	2.69	2.69	2.42	8	8	8	Grayish white	White	Light gray

Chapter VI

MINERALOGICAL CHARACTERISTICS OF CENTRAL MISSOURI CLAYS

by PAUL G. HEROLD

In previous reports Allen[1] has given an excellent description of the crystalline materials occurring in the diaspore and flint clays of Missouri. The present work will review Allen's results briefly, and will also extend his work by discussing the semi-flint, semi-plastic, and plastic clays of the central Missouri district. The high alumina clay, boehmite, the identification of which has been made in connection with this investigation, will be discussed also.

When clays are being examined for mineral content, the standard instrument has been the petrographic microscope. However, most clays are so very fine grained as to be indistinguishable even under the highest powered microscope. In later years the use of the X-ray as a diffraction instrument has been available for use on fine grained clays. Another instrument for studying clays, the electron microscope, has just recently appeared. This instrument gives good resolution at 25,000 diameters magnification as compared to 8000 diameters for the usual optical microscope. In the present work, the X-ray and petrographic microscope were used.

The clays examined in this investigation were collected from localities given in the following table.

Analysis of High Alumina Clays

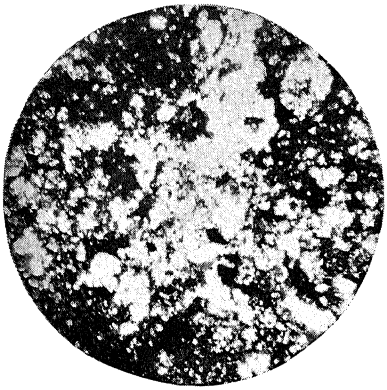
Based on chemical composition all the clays from number 1 to 7 inclusive are classed as diaspore and burley clays. As has already been pointed out in chapter V, the firing behaviors and general physical properties are essentially similar except in the case of clay number 6.

In both the Klossner (Sec. 15, T. 44 N., R. 5 W.) and the Kallmeyer (NW¼ sec. 35, T. 45 N., R. 6 W.) pits a clay was observed which has all the appearances of flint clay but contains

[1]Mineral Composition and Origin of Missouri Flint and Diaspore Clays. Victor T. Allen. Biennial Report of the State Geologist, Missouri Geological Survey, Appendix IV, 24p (1935).

LOCALITIES FROM WHICH CLAY SAMPLES WERE COLLECTED.

Clay No.	Type of clay.	Name of pit.	Location.
1	"Mealy" soft diaspore	Linneman	NW ¼ sec. 17, T.44N., R.5W., Gasconade Co.
2	Hard diaspore	Aufderheide	NE ¼ sec. 36, T.43N., R.6W., Gasconade Co.
3	Fairly hard diaspore	Kallmeyer	NW ¼ sec. 35, T.45N., R.6W., Gasconace Co.
4	Oolitic burley clay	Krull No. 2	NW ¼ sec. 21, T.44N., R.5W., Gasconade Co.
5	"Spongy" diaspore	Albert Kahle	SE ¼ sec. 22, T.44N., R.5W., Gasconade Co.
6	Flint-like boehmite	Klossner	Sec. 15, T.44N., R.5W., Swiss, Gasconade Co.
7	Burley clay	Jett	NW ¼ sec. 3, T.41N., R.7W., Osage Co.
8	Hard, black, semi-flint clay	A. P. Green plant pit No. 4	Sec. 36, T.51N., R.9W., Mexico, Audrain Co.
9	Gray semi-flint clay	A. P. Green plant pit No. 4	Sec. 26, T.51N., R.9W., Mexico, Audrain Co.
10	Brown semi-flint clay	Harbison-Walker plant mine	Sec. 7, T.52N., R.5W., Vandalia, Audrain Co.
11	Light colored semi-flint clay	Stoltz	NW ¼ sec. 34, T.48N., R.9W., Callaway Co.
12	Dark colored semi-flint clay	Stoltz	NW ¼ sec. 34, T.48N., R.9W., Callaway Co.
13	Semi-plastic clay	A. P. Green plant pit No. 4	Sec. 36, T.51N., R.9W., Mexico, Audrain Co.
14	Semi-plastic clay	Harbison-Walker plant mine	Sec. 12, T.52N., R.6W., Vandalia, Audrain Co.
15	Plastic clay "foundry clay"	A. P. Green plant pit No. 4	Sec. 36, T.51N., R.9W., Mexico, Audrain Co.
16	Dark gray plastic clay	Weatherall	SE ¼ sec. 29, T.48N., R.9W., Callaway Co.
17	Dark gray plastic clay	Coy Rives	NW ¼ sec. 28, T.55N., R.9W., Monroe Co.
18	White, hard, flint clay	Pleuch No. 2	SW ¼ sec. 11, T.42N., R.5W., Gasconade Co.
19	Flint clay	Arthur Nichols	NW ¼ sec. 2, T.46N., R.8W., Callaway Co.
20	Dark gray flint clay	Henneke	Sec. 24, T.42N., R.5W., Gasconade Co.



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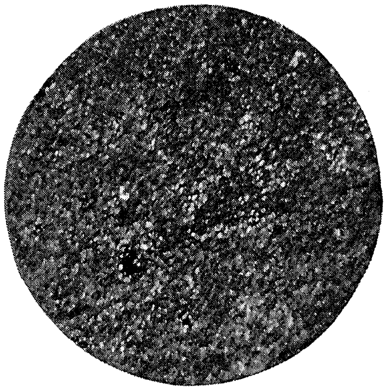

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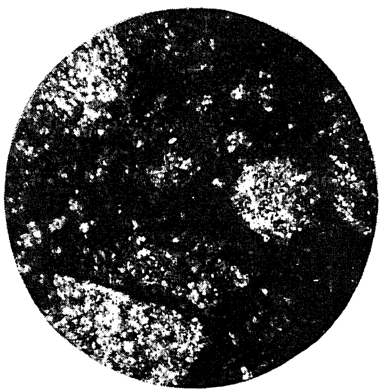


D

A. Clay number 1. Soft, fine-grained, "mealy" variety of diaspore clay from Linneman pit, NW¼ sec. 17, T. 44 N., R. 5 W., Gasconade County. Viewed through crossed nicols. x65.

B. Clay number 2. Hard, very fine-grained, rock-like variety of diaspore clay from Auferheide pit, NE¼ NE¼ sec. 36, T. 43 N., R. 6 W., Gasconade County. x65.

C. Clay number 3. Fairly hard, fine-grained diaspore clay from Kallmeyer pit, NW¼ sec. 35, T. 45 N., R. 6 W., Gasconade County. x65.

D. Clay number 4. Very oolitic burley clay from Krull pit No. 2, NW¼ sec. 21, T. 44 N., R. 5 W., Gasconade County. x65.

72.3 and 77.77 percent alumina respectively by chemical analysis. In this section (Plate XXXV, B) the Klossner clay has the appearance of an isotropic material whose mean index of refraction is 1.645. The birefringence is very low as compared to diaspore whose mean index is 1.72, which indicated at once that the material is not diaspore although the chemical analysis indicates that it must be an hydrous oxide of alumina. The only aluminum hydroxide which would fit the petrographic and X-ray data is the mineral boehmite, also known as α $Al_2O_3 \cdot H_2O$. This latter designation is described by Edwards and Tosterud[2] who also designate diaspore as β $Al_2O_3 \cdot H_2O$. In order to further identify the clays from the Klossner and Kallmeyer pits, an artificial boehmite was examined with the X-ray. The X-ray photographs, when compared, clearly show that the Klossner and Kallmeyer clays are composed mainly of boehmite, since all the lines correspond to those of artificial boehmite (see Plate XXXVI). It is also reported that French bauxite contains the mineral boehmite and such is the case as shown by the X-ray photograph (Plate XXXVI, A). This sample of French bauxite was obtained from the Geology Museum of the Missouri School of Mines and Metallurgy and is representative of the high iron type of material. A chemical analysis is as follows:

Chemical Analysis of French Bauxite
R. T. Rolufs, analyst

Constituent	*Percent*
Silica (SiO_2)	1.38
Alumina (Al_2O_3)	58.82
Ferric oxide (Fe_2O_3)	23.83
Titania (TiO_2)	1.98
Lime (CaO)	.20
Magnesia (MgO)	.20
Soda (Na_2O)	.11
Potash (K_2O)	.36
Moisture (H_2O)	.12
Ignition loss	12.13
Total	99.13

The thin section of French bauxite (Plate XXXV, D) shows a very oolitic structure containing much fine grained reddish material which is probably limonite. The white areas are a mixture of diaspore, boehmite and cliachite, all of which are extremely fine grained.

[2]Edwards, J. D. and Tosterud, M. The oxides and hydrates of aluminum. J. Phys. Chem. v. 37, p. 485 (1933).

No diaspore has actually been manufactured artificially, however, boehmite can be manufactured as described by Edwards and Tosterud.[3] This is readily and quickly done by heating the trihydrate as a powdered material in contact with a weak solution of sodium hydroxide at 170° C.

It is well known that diaspore is rather insoluble in acids but boehmite is very soluble. In order to test the Kallmeyer clay further, leaching tests were run. The procedure worked out by Gandrud and De Vaney[4] for determining solubilities of bauxite samples was used directly. In this test, "a one gram sample was treated with 20 cc. of 1:1 sulfuric acid (H_2SO_4) and 50 cc. of triacid mixture. The triacid mixture consists of water and acids in the following proportions: Water, 1,800cc.; hydrochloric acid (HC1) 1,200 cc.; sulfuric acid (H_2SO_4), 600 cc.; and nitric acid (HNO_3), 400 cc. The sample was heated and evaporated on a hot plate until the SO_3 fumes were evolved. Then 200 cc. of water were added, and after the sample had been digested on a hot plate for two hours it was filtered. The residue after being washed on the filter paper was ignited and weighed and reported as insoluble." All of the high alumina clays previously described, the French bauxite and a typical example of Arkansas bauxite were subjected to the solubility test.

TABLE 31

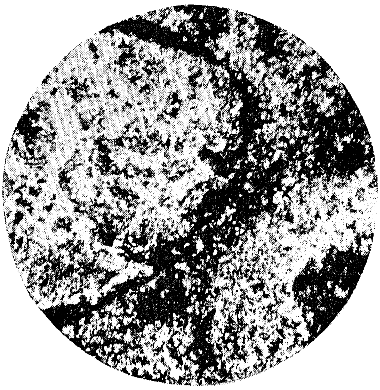
Results of Solubility Tests
R. T. Rolufs, analyst

Material	*Insoluble*	*Chemical Analysis*	
		SiO_2	Al_2O_3
Clay No. 1 (Diaspore)	56.19	6.18	72.54
Clay No. 2 (Diaspore)	54.78	6.00	72.67
Clay No. 3 (Diaspore)	60.17	2.84	77.00
Clay No. 4 (Diaspore)	54.89	11.20	67.87
Clay No. 5 (Diaspore)	59.71	4.32	75.32
Clay No. 6 (Boehmite)	9.80	7.64	72.12
Clay No. 7 (Burley)	42.52	10.80	67.09
French bauxite	1.12	1.38	58.82
Arkansas bauxite	5.39	5.44	55.05
Artificial boehmite	.08		

Table 31 shows that the Klossner clay (No. 6) is not entirely soluble as is artificial boehmite, but does show a markedly increased solubility over that of the known diaspores.

[3]Ibid p. 485.

[4]Gandrud, B. W., and De Vaney, F. D. Bauxite: Float and Sink Fractionations and Flotation Experiments. U. S. Bur. Mines Bull. No. 312, p. 56 (1929).



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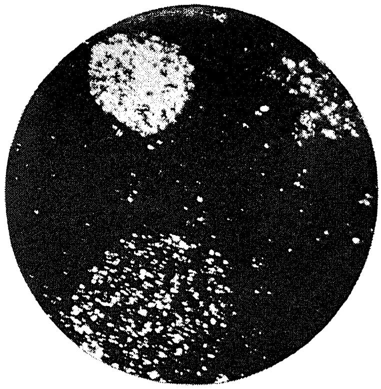

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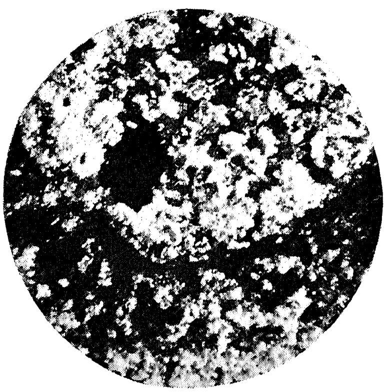

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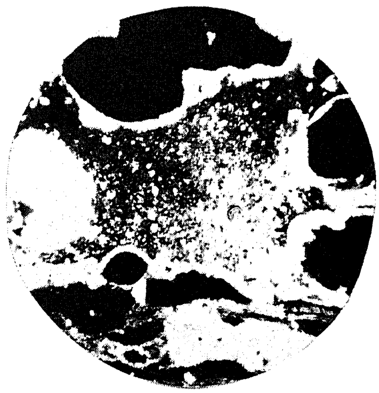

D

A. Clay number 5. Very porous, open textured, "sponge" variety of diaspore clay from Albert Kahle pit, SE ¼ sec. 22, T. 44 N., R. 5 W., Gasconade County. x65.

B. Clay number 6. Boehmite clay, hard, fine-grained, and flint-like from Klossner pit, sec. 15, T. 44 N., R. 5 W., Swis, Gasconade County. x65.

C. Clay number 7. High grade burley clay from Jett pit, NW ¼ sec. 3, T. 41 N., R. 7 W., Osage County. x65.

D. French bauxite. x65.

Both French bauxite and Arkansas bauxite are also quite soluble. French bauxite contains boehmite as the soluble constituent while the Arkansas bauxite is composed essentially of gibbsite as the soluble alumina hydrate.

The reason for the difference in solubility, index of refraction, and other physical properties between boehmite and diaspore can be explained on the basis of atomic arrangement. Both materials crystallize in the orthorhombic system and the atomic arrangement for diaspore has been worked out in detail by Deflandre.[5] The atomic structure for boehmite has not been completed but by comparison with the similar iron mineral, lepidocrocite, it is possible that the formula is AlO (OH). Thus the three ions Al, O, and OH have their centers in a plane which is repeated in a direction perpendicular to the cleavage planes. Diaspore is much more complex in arrangement having a tetrahedral building block of hydrogen and oxygen atoms to form ions.

A detailed examination of the thin section of the Klossner high alumina clay (Plate XXXV, B) shows that most of the material is a light tan color, having a much lower index of refraction than diaspore and also having a very low birefringence. Occasionally scattered through the mass are indications of oolites of perfectly clear boehmite containing many small crystals of diaspore. The light colored portions in the photograph of the thin section are patches of diaspore imbedded in the clear boehmite. Occasional small crystals of diaspore also occur scattered through the tan colored boehmite. The total amount of diaspore contained in the Klossner clay is not very great, which is the reason why no traces of the diaspore pattern appear superimposed on the X-ray pattern of the boehmite.

Summing up the evidence, there seems to be no doubt that the white flint like clay occuring in the Klossner and Kallmeyer pits is a boehmite clay. This is indicated by optical examination and X-ray diffraction patterns which check with those published in the literature. The solubilities also indicate that the clay is not diaspore but boehmite.

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[5]M. Deflandre. Crystal Structure of Diaspore. Bull. soc. franc. mineral., v. 55, p. 140-65 (1932).

In 1927 De Lapparent[6] first identified the new mineral $Al_2O_3 \cdot H_2O$ which occurred in certain European bauxites. He gave the new mineral the name boehmite in honor of the great authority on bauxites, Bohm. A few years later Hocart and De Lapparent[7] did some detailed X-ray work on the bauxites which had been investigated by Bohm[8] and found that they were composed largely of the new mineral, boehmite. In this same work De Lapparent points out that boehmite and diaspore are the homologs of lepidocrocite and goethite, respectively. Thus with the hydrated iron compounds lepidocrocite would have the chemical formula $\alpha Fe_2O_3 \cdot H_2O$ similar to boehmite ($\alpha Al_2O_3 \cdot H_2O$) while goethite has the formula $\beta Fe_2O_3 \cdot H_2O$ similar to diaspore ($\beta Al_2O_3 \cdot H_2O$).

Several years later some samples of bauxite from Ayrshire, Scotland were examined by De Lapparent[9] and were found to contain the mineral boehmite. In this work he gives a detailed geological description of the bauxite deposits as well as a mineralogical identification of boehmite. He also ventures an opinion on the origin of the diaspore, boehmite, and kaolin, which were associated in the bauxite. He states:[10]

"We may suppose, therefore, the weathering under the influence of a somewhat tropical climate of an area of basaltic rocks poured out soon after the beginning of Millstone Grit times (upper Jurassic), and that the original minerals were in this manner hydrolyzed. As the basalt breaks up into fragments it forms impure alumino-siliceous gels which retain to some degree the primary structure of the basalt. These fragments are collected in basins which are flooded by humic waters, and under these conditions the mixed alumino-siliceous gels are formed in which boehmite and kaolinite come to be developed. The waters which drain into these sinking basins carry other materials than basalt, such as superficial clays of which the original presence is betrayed by the rutile which occurs in the pisolitic crusts. As subsidence goes on and the gel becomes

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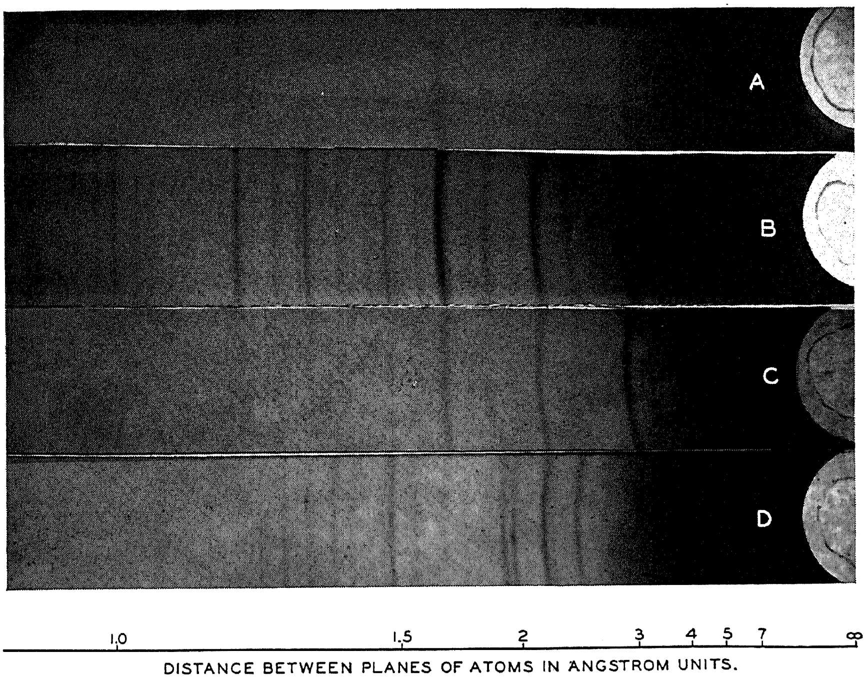
[6]De Lapparent, J. L. alumine hydratee des bauxites. Compt. rend., v. 184, p. 1661 (1927).

[7]Hocart, H. and De Lapparent, J. Sur la boehmite des bauxites. Compt. rend. v. 189, p. 995 (1929).

[8]Bohm, Von J. Uber Aluminum-und Eisenhydroxide. I. Z. anorg. allgem. Chem. v. 149, p. 203-16 (1925).

[9]De Lapparent, J. Boehmite and diaspore in the bauxitic clays of Ayrshire. Progress Reports Geol. Survey Gt. Brit. Part II, p. 1 to 7 (1936).

[10]Ibid p. 4.



A. X-ray diffraction pattern of French bauxite.

B. X-ray diffraction pattern of artificial boehmite ($\alpha Al_2O_3 \cdot H_2O$).

C. X-ray diffraction pattern of clay from Klossner pit (sec. 15, T. 44 N., R. 5 W.).

D. X-ray diffraction pattern of diaspore clay (β $Al_2O_3 \cdot H_2O$) from Linneman pit (NW¼ sec. 17, T. 44 N., R. 5 W.).

older those parts which have not been saturated with humic solutions are not completely transformed and are in turn affected by the rise of the isogeotherms. In those parts of the gel that are not completely transformed the germs of diaspore will form, and these will go on developing even at the expense of the minute crystals of boehmite in a manner similar to the development of crystals in general from the micellae of a colloidal mass. The colloidal condition in turn will disappear when the kaolinite crystallizes and the development of diaspore will stop.

The occurrence of diaspore and boehmite is comparable to the 'index minerals' which have been described by English petrographers (Barrow and Tilley) in their studies of metamorphism. In accordance with this hypothesis we understand why the diaspore crystals are always found among the submicroscopic crystals of boehmite. In such situations the colloidal gel has not been able to promote the development of boehmite since it was protected from humic solutions."

The writer would like to point out that humic solutions are considered to be necessary by De Lapparent for the formation of boehmite while such solutions must be absent when diaspore is being formed. This has not been reproduced in the laboratory but is an observation when only considering the formation of bauxite deposits. At present the knowledge of the occurrence of boehmite is very meager so that we do not know even remotely the mechanism whereby boehmite and diaspore are formed in the southern district other than that leaching does take place.

Plates XXXIV and XXXV show characteristic areas of the clays when a thin section of the clay is viewed with the petrographic microscope. These views were photographed through crossed nicols in order to give a better idea of the grain size of the diaspore particles.

Clay No. 1 has been described by McQueen as a soft, fine-grained "mealy" variety of diaspore clay. However, the individual diaspore grains as indicated by the white areas (Plate XXXIV, A) indicate a maximum size of one-tenth of a millimeter. These grains were the largest ones observed in any of the diaspore clays tested. The hard, very fine grained rock like diaspore clay No. 2 is indeed very fine grained (Plate XXXIV, B) and shows a maximum grain size of around .02 millimeters. Most of the diaspore clay in this sample, however, is much smaller in diameter. The essential grain size of the diaspore mineral is very small in the other high alumina clays (Plate XXXIV, C and D and Plate XXXV, A and C). McQueen has described clay No. 4 as a very oolitic variety which is indicated by the picture of the thin section (Plate XXXIV, D). The size of the individual oolite near the bottom of the section is slightly less than one half millimeter and is only of average size. Clay No. 5, (Plate XXXV, A) which is a spongy type of diaspore clay, contains many smaller oolites and some small holes throughout the mass. A portion of two of the oolites is pictured as well as holes indicated by the very black portion.

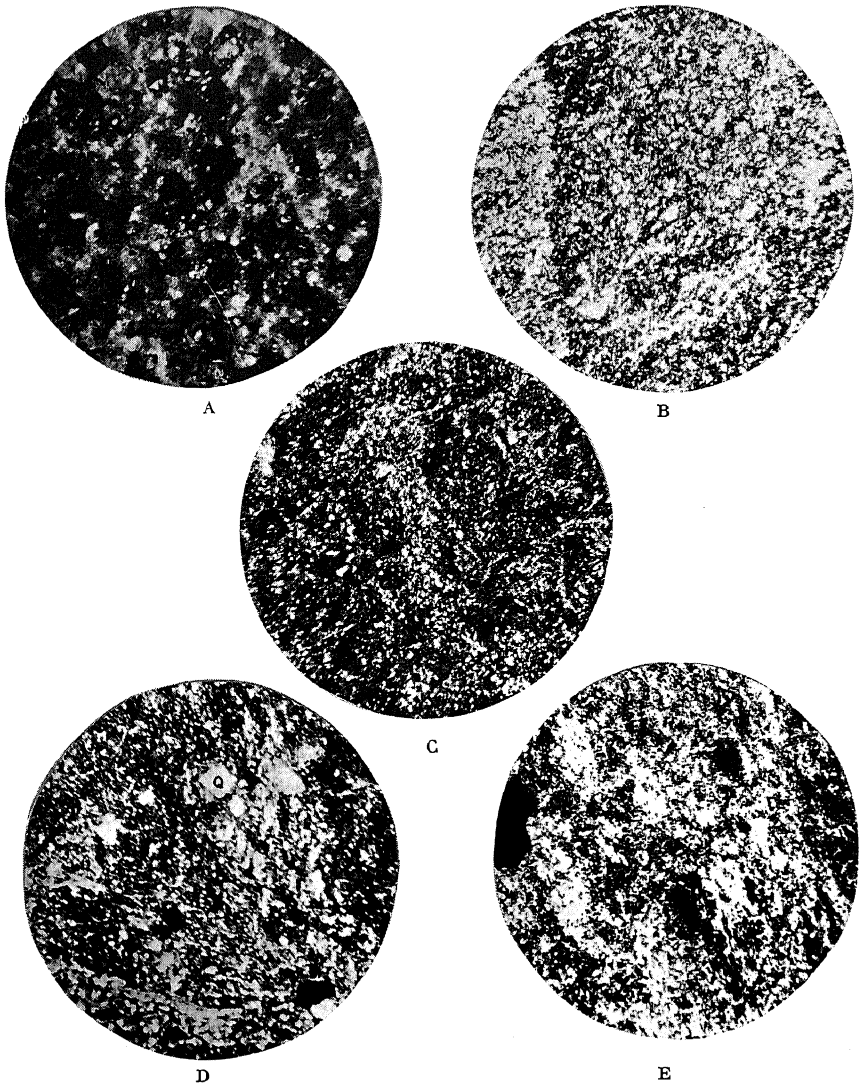
The essential material which is present in all the high alumina clays except No. 6 is the mineral diaspore. This has been verified both with the microscope and with the X-ray diffraction apparatus. The fine grained mass of material surrounding the diaspore grains is so poorly crystallized that no decision could be reached as to its composition. Allen[11] has described this fine material as being a mixture of cliachite and leucoxene, the latter accounting for the presence of titanium dioxide.

Analysis of Lower Cheltenham Semi-Flint Clays

Clays number 8, 9, 10, 11, and 12 were examined with both the x-ray and the microsope and revealed the presence of three minerals in major proportions. These are halloysite, kaolinite, and quartz. There were occasional crystals of other minerals present which will not be described since they are usually not important to the ceramic worker.

Both clays 8 and 9 are from the same pit of the A. P. Green Fire Brick Company and presented fairly identical appearances under the microscope. The dark areas Plate XXXVII, A and B indicate very fine grained halloysite which acts as a matrix for the light colored small elongated worm forms of kaolinite. There are occasional crystals of quartz present which appear as very white more circular spots. The photographs of the thin sections indicate a very pronounced bedding

[11]Allen, V. T. Mineral Composition and Origin of Missouri Flint and Diaspore Clays.



A. Clay number 8. Hard, black, "slaty," semi-flint clay from A. P. Green Fire Brick Co. plant pit No. 4, Mexico, Audrain County. x65.

B. Clay number 9. Gray semi-flint clay from A. P. Green Fire Brick Co. plant pit No. 4, Mexico, Audrain County. x65.

C. Clay number 10. Brown semi-flint clay from Harbison-Walker plant mine (Renner tract), Vandalia, Audrain County. x65.

D. Clay number 11. Light colored semi-flint clay from Stoltz pit, NW¼ sec. 34. T. 48 N., R. 9 W., Callaway County. x65.

E. Clay number 12. Dark colored semi-flint clay from Stoltz pit, NW¼ sec. 34, T. 48 N., R. 9 W., Callaway County. x65.

of the kaolinite flakes. Clay 8 contains much carbonaceous material which is indicated as very small black specks in the thin section. The semi-flint clay from the Renner tract of the Harbison-Walker Refractories Company, No. 10, is very nearly the same as the preceding two clays judging by x-ray and optical methods except that fewer quartz crystals are present. This is substantiated by the chemical analysis which shows a lower silica content for clay No. 10 than for either No. 8 or No. 9.

As has been previously pointed out (chap. V) the two semi-flint clays (Nos. 11 and 12) from the Stoltz pit, NW¼ sec. 34, T. 48 N., R. 9 W., Callaway County are nearly identical as far as their physical properties are concerned. An examination of the mineral content, however, shows a slight difference in the amounts to the mineral constituents present in each clay. The light colored clay, which is representative of the major portion of the deposit, contains a large proportion of halloysite, a smaller quantity of kaolinite, a few large crystals of quartz, and a few crystals of weathered mica high in iron. Reference to Plate XXXVII, D shows a large quartz grain (Q) and a grain of weathered irony mica (M). The clay, which occurs as funnel like masses in the above clay designated as number 12, is made of the same minerals but in different proportions. The halloysite is less in quantity; there is kaolinite present; and there are more grains of quartz present, which are less than half the size of those found in clay number 11. Also there are many fine grains of the partially altered high iron mica.

Middle Cheltenham Semi-Plastic Clays

Two semi-plastic clays were collected, one from pit No. 4 of the A. P. Green Fire Brick Company and the other from the Renner tract of the Harbison-Walker Refractories Company at Vandalia. These clays were examined both by x-ray diffraction methods and with the petrographic microscope. Thin sections were photographed and appear pictured in Plate XXXVIII as A and B (clays 13 and 14 respectively). Both the thin sections show large areas of very fine grained kaolinite, which are white surrounded by dark areas of halloysite. In clay 13 there is an occasional large crystal of quartz present in the mass. Also there are many particles of lignitic material scattered throughout the clay and occasional masses of iron stained kaolinite. Clay number 14 is very similar to number

13 except that it contains a large number of small quartz grains, which when compared to the former clay having large grains of quartz, does not mean very much increase in total silica content of the sample. The clay from the Renner tract contains a large amount of finely disseminated organic material and more limonite stained clay patches.

Upper Cheltenham Plastic Clays

The plastic clays are all very difficult to identify as regards their mineral contents since there are so many minor minerals present. The x-ray diffraction equipment cannot be used except to identify small amounts of material except in the case of well crystallized materials such as quartz. Therefore the three plastic clays were investigated largely by using the petrographic microscope.

The three plastic clays collected were: (a) clay No. 15 known as a foundry clay coming from the upper Cheltenham portion of the pit number 4 of the A. P. Green Fire Brick Company. This clay is considered to be an inferior type of clay and is not used in the manufacture of fire brick, however, it has been used in mudding up the backing structures of cupolas in foundrys from which it derives the name, (b) clay No. 16 from the Weatherall pit of the Mexico Refractories Company, and (c) clay No. 17 from the Rives deposit (S½ NW¼ sec. 28, T. 55 N., R. 9 W., Monroe County).

Clay number 15, known as the foundry clay, has been shown (chap. V) to be a clay which apparently contains many impurities. An examination with the microscope of the thin section (Plate XXXVIII, C) shows that the dominant mineral present is kaolinite surrounding smaller areas of halloysite. There are occasional star shaped crystals of iron pyrite present and some very finely divided carbonaceous material disseminated throughout the mass. There are quantities of very fine grained topaz, tourmaline, rutile, and various types of mica present mixed thoroughly through the clay. All these account for the reduction in fusion temperature as indicated by the P. C. E. discussed in chapter V.

Clay number 16 (Plate XXXVIII, D) contains more kaolinite than the previous plastic clay and also much iron stained opaque areas of clay. The crystals of pyrite are very few in

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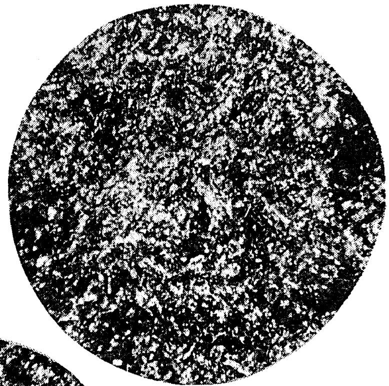

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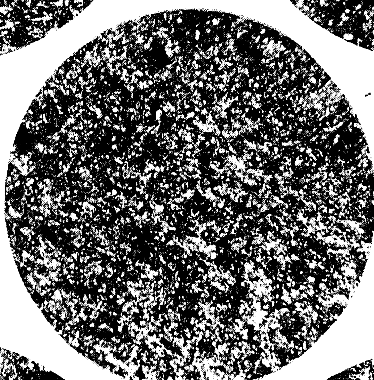

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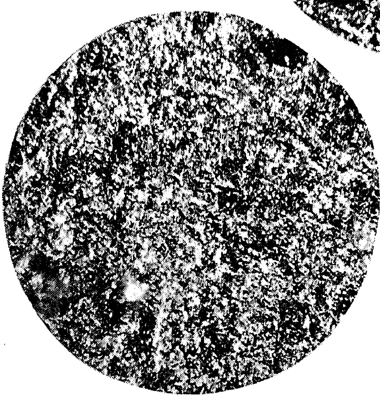

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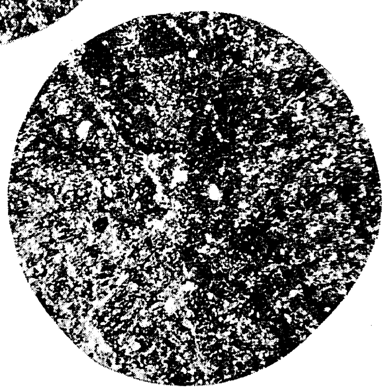

E

A. Clay number 13. Semi-plastic clay from A. P. Green Fire Brick Co. plant pit No. 4, Mexico, Audrain County. x65.

B. Clay number 14. Semi-plastic clay from Harbison-Walker plant mine (Renner tract), Vandalia, Audrain County. x65.

C. Clay number 15. Plastic clay known as 'foundry clay' from A. P. Green Fire Brick Co. plant pit No. 4, Mexico, Audrain County. x65.

D. Clay number 16. Dark gray plastic clay from Weatherall pit, NW¼ SE¼ sec. 29, T. 48 N., R. 9 W., Callaway County. x65.

E. Clay number 17. Dark gray plastic clay from Coy Rives pit, S½ NW¼ sec. 28, T. 55 N., R. 9 W., Monroe County. x65.

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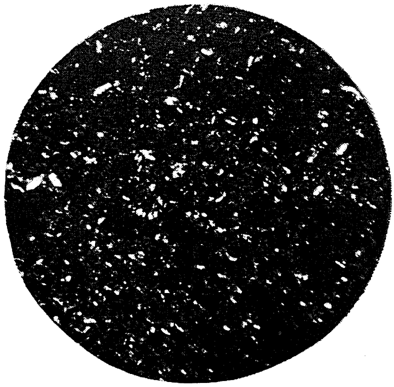

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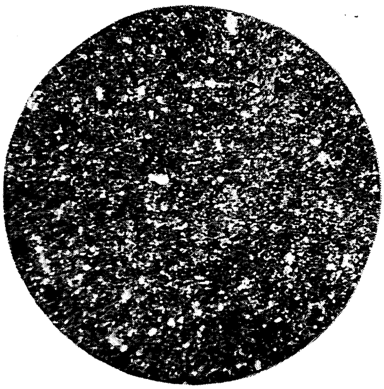

C

A. Clay number 18. White, hard, "popcorn" flint clay from Pieuch pit No. 2, SW¼ sec. 11, T. 42 N., R. 5W., Gasconade County. x65.

B. Clay number 19. Flint clay from Arthur Nichols pit, NW¼ sec. 2, T. 46 N., R. 8 W., Callaway County. x65.

C. Clay number 20. Hard, dark gray, flint clay from Henneke pit, sec. 24, T. 42 N., R. 5 W., Gasconade County. x65.

this sample as is indicated, too, by the low sulphur content in the chemical analysis. There are many fine grains of quartz scattered through the clay as well as carbon and a very few minor minerals. Clay 17 is very similar in mineral constitution and distribution, the only major difference being a larger amount of quartz is present and the individual grains are larger in size.

Flint Clays

Three flint clays were examined for mineral constitution. They were (clay number 18) one from the Pieuch pit number 2 of General Refractories Company (SW¼ sec. 11, T. 42 N., R. 5 W.) another from the Nichols pit of the Mexico Refractories Company known as clay number 19, (NW¼ sec. 2, T. 46 N., R. 8 W.) and another from the Henneke pit at Owensville designated as clay number 20 (Sec. 24, T. 42 N., R. 5 W.). These three clays were examined in a similar way to the previous ones and the thin section photographs are shown in Plate XXXIX, A, B, and C.

All three of the flint clays are very pure and contain very little in the way of accessory minerals. The large quantity of mineral present in all three clays is halloysite and some limonite stained clay. There is a small amount of kaolinite present as indicated by the white patches on the photographs and an occasional crystal of quartz. Clays 19 and 20 show small oolites of kaolinite and iron stained clay. In general, however, these clays stand out from the others because of their lack of contaminating accessory minerals.

SUMMARY

When considering high alumina clays found in the southern district, there are three types of diaspore containing clays and a previously undetermined mineral type of clay. The diaspore clays may be separated by the grain size of the diaspore. Thus there is a class of diaspore which is composed of large individual grains of diaspore, which are very well crystallized and tend to produce a "mealy" variety of diaspore clay. Second, there is the class of diaspore clay which covers most of the types and is composed of various sizes of oolites. The diaspore is concentrated in the oolites and is present as very individual fine grain crystals. Third, there is the porous type of diaspore clay which contains oolites of fine grained diaspore interspersed with small holes or pores.

The unusual type of high alumina clay occurring in the district is one containing boehmite in large quantities with small crystals of diaspore apparently crystallizing from the mass and concentrating into oolites.

The flint clays seem to be characterized by the presence of kaolinite and halloysite with very little quartz, the halloysite being present in larger amounts. The semi-flint clays of the northern district contain roughly equal amounts of kaolinite and halloysite with larger amounts of quartz in evidence. The semi-plastic clays contain large amounts of kaolinite with smaller amounts of halloysite, some impurities and quartz. The plastic clays are made up mostly of kaolinite with very little halloysite, impurities, and variable quantities of quartz.

The number of flint to plastic samples of clay examined were too few in number to make a generalization. However, it seems that just as the plastic clay may grade into semi-plastic to semi-flint to flint clay in a pit, so the clays will grade from low halloysite-kaolinite ratio in plastic clay to a high halloysite-kaolinite ratio in flint clay.

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