Geology and Refractory Clay Deposits of the Haldeman and Wrigley Quadrangles, Kentucky

GEOLOGICAL SURVEY BULLETIN 1122-F

Prepared in cooperation with the Kentucky Geological Survey and the Kentucky Agricultural and Industrial Development Board

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By SAM H. PATTERSON *and* JOHN W. HOSTERMAN

With a section on COAL RESOURCES

By JOHN W. HUDDLE

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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GEOLOGY AND REFRACTORY CLAY DEPOSITS OF THE HALDEMAN AND WRIGLEY QUADRANGLES, KENTUCKY

By Sam H. Patterson and John W. Hosterman

ABSTRACT

The Haldeman and Wrigley 7½-minute quadrangles are near the western edge of the eastern Kentucky coal field and cover an area of approximately 117 square miles in parts of Carter, Rowan, Elliott, and Morgan Counties, Ky. The rocks exposed in the two quadrangles are of Early and Late Mississippian and Early and Middle Pennsylvanian age. The Mississippian rocks are composed of the thick Brodhead formation, which consists of siltstone and shale, and eleven thin marine limestone and shale formations, having an aggregate thickness of about 150 feet. The Lee and Breathitt formations, of Pennsylvanian age, consist of sandstone, siltstone, and shale; they also contain thin beds of coal and several beds of underclay, including the economically important Olive Hill clay bed of Crider, 1913. Pennsylvanian rocks include beds of both continental and marine origin. The eleven thin Mississippian formations and the uppermost part of the thick Brodhead formation are truncated by a prominent unconformity on which rocks of Pennsylvanian age rest. The rocks occupy a region of gentle dips between the Cincinnati arch and the Appalachian Mountains.

Refractory clay deposits are in the Olive Hill clay bed, which occurs in the lower part of the Lee formation. The Olive Hill clay bed is discontinuous and consists of a series of irregularly shaped lenses. The bed is approximately two-thirds semiflint clay and one-third flint clay, and it contains minor amounts of plastic clay. Some of the flint clay is nearly pure kaolinite, but the semiflint and plastic clay consists of mixtures of kaolinite, illite, and mixed-layer clay minerals. The structure of the kaolinite ranges from highly crystalline to very poorly crystalline "fireclay" type. The degree of crystallinity of the kaolinite and the hardness of the clay vary inversely with the amount of illite and mixed-layer clay minerals present. The nearly pure kaolinite is believed to have formed by the removal of alkalies and some silica from mixtures of kaolinite, illite, and mixed-layer clays by leaching in swamps to the deposition of the beds overlying the clay. The refractory properties of the clay vary directly with the purity of the kaolinite, and refractoriness decreases as the proportions of illite and mixed-layer clays increase. Certain nonclay minerals, chiefly siderite, pyrite, and iron oxide-bearing minerals, also act as fluxes, reducing the refractory properties of the clay. The entire resources of clay in the Olive Hill clay bed are

roughly and tentatively estimated to include 105,000,000 tons in the Haldeman quadrangle and 175,000,000 tons in the Wrigley quadrangle. Much of this clay is of poor quality and the amount that is better than the minimum requirements for use in refractories is probably about 30,000,000 tons. Only a fraction of this tonnage is suitable for superheat-duty products.

Limestone is the only nonmetallic mineral resource other than refractory clay that has been developed in the two quadrangles, but large amounts of shale suitable for use in making lightweight aggregate and structural clay products may also be present. Most of the limestone, which is quarried in both quadrangles, is used for road-metal, concrete aggregate, and agriculture stone, but some of the limestone is of the quality that would be suitable for other uses. Virtually all the Mississippian Beech Creek limestone of Malott, 1919 which is as much as 18 feet thick, consists of high-calcium limestone. Shale beds that appear most favorable for making lightweight aggregate are in the shale facies of the Lee formation of Pennsylvanian age. Shale that is probably suitable for structural clay products is present in the shale facies of the Lee formation and in the Muldraugh formation of Mississippian age.

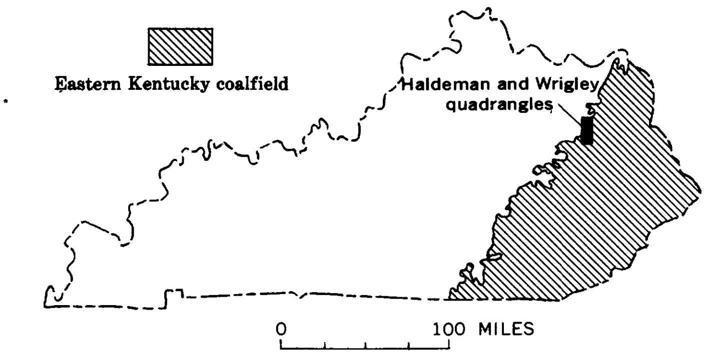
Several dry holes have been drilled in search for oil and gas within the area of the two quadrangles. Though no commercial production was ever attained, one well furnished a supply of gas for one farm home for several years.

At least five of the major producing coal beds of eastern Kentucky are present in the Haldeman and Wrigley quadrangles. However, none of these beds is more than 14 inches thick except at a very few localities. Virtually no minable reserves of coal under foreseeable economic conditions are present in the Haldeman and Wrigley quadrangles.

INTRODUCTION

LOCATION AND EXTENT OF THE AREA

The Haldeman and Wrigley quadrangles are located along the western edge of the eastern Kentucky coal field (fig. 1*A*) and occupy approximately 117 square miles in parts of Carter, Rowan, Elliott, and Morgan Counties. These two areas are the northeast and southeast 7½-minute quadrangles of the Morehead 15-minute quadrangle (fig. 1*B*). Haldeman, a small community in which firebrick was formerly made, is in the north-central part of the area, about 55 miles southwest of Ashland and about 80 miles east of Lexington by road. The village of Elliottville, the only other center of population in the Haldeman quadrangle, is located on the headwaters of Christy Creek, in the east-central part of the quadrangle. Wrigley is a small settlement in the valley of the North Fork of the Licking River in the southeastern corner of the Wrigley quadrangle. U.S. Highway 60 and the Chesapeake and Ohio Railroad, the main regional communication lines, extend across the northwestern part of the Haldeman quadrangle, and Kentucky Route 32 extends from east to west across the central part. Route 173 branches from Route 32, 1½ miles south of Elliottville. It extends southward to a point near the southeastern corner of the quadrangle and crosses the northeastern corner of the



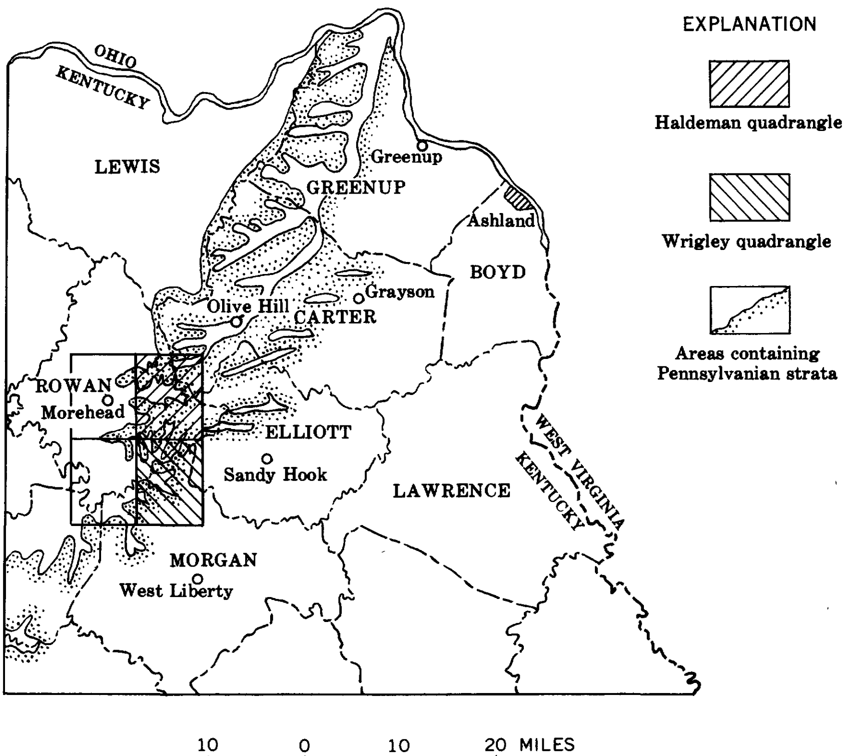


FIGURE 1.—*A*, location of the Haldeman and Wrigley quadrangles and the eastern Kentucky coal field; *B*, position of the Haldeman and Wrigley 7½-minute quadrangles within the Morehead 15-minute quadrangle and their relation to the western boundary of Pennsylvanian strata.

Wrigley quadrangle. Kentucky Route 7 passes through Wrigley and services the southeastern part of the area. A network of graveled roads, unimproved roads, and trails extends from the primary roads to most parts of the area. Twenty years ago a railroad used for logging extended along the North Fork of the Licking River. The bed of that railroad now forms the grade of a gravel road.

PREVIOUS INVESTIGATIONS

Refractory clay in Carter County, Ky., was briefly described by Phalen (1906, p. 411–412). A year later Greaves-Walker (1907, p. 461–472) discussed in more detail the clay deposits of the area covered by this report and elsewhere in northeastern Kentucky. Galpin (1912, p. 324–329) included several samples from the Olive Hill clay bed in his studies of flint clays from several districts, and this work represents the only previous attempt to study the petrography of the Olive Hill clay bed. The first detailed geological study of the clay deposits in this area consisted of a series of spot examinations by Crider (1913), whose report also contains the results of ceramic tests, chemical analyses, and an account of the development of the clay industry in northeastern Kentucky. Developments in knowledge and utilization of the Olive Hill clay bed during the decade following Crider's work are summarized briefly by Ries (1922, p. 154–205). A reconnaissance map of the Morehead quadrangle was made by Crabb (1930) to show the distribution of the clay deposits and the areal geology. Perry, Hudnall, Miller, and Lane (1930) attempted to show the distribution of clay deposits on a structural geology map of Carter County. A structure contour map of Morgan County, on which the Lee formation of Pennsylvanian age was shown as Pottsville conglomerates, was prepared by Robinson and Hudnall (1925). A similar map of Elliott County, on which the outcrop of Mississippian rocks was shown in a general way, was prepared by Robinson, Hudnall, and Richardson (1928).

The stratigraphy of Mississippian rocks in eastern Kentucky was investigated by Butts (1922). A more detailed study of rocks of Osage age (Brodhead and Muldraugh formations, pl. 1) was made by Stockdale (1939), and McFarland and Walker (1956) have recently correlated the rocks of Chester age [Paoli limestone to Pennington formation(?), pl. 1] with those in surrounding regions. No detailed investigations of Pennsylvanian stratigraphy have been made in the immediate vicinity of the Haldeman and Wrigley quadrangles, and the nomenclature herein employed was introduced into other parts of eastern Kentucky and adjoining parts of Virginia by Crandall (1880), Campbell (1893), and Morse (1931).

PRESENT INVESTIGATIONS

This report is part of an investigation of refractory clay deposits in eastern Kentucky by the U.S. Geological Survey. Laboratory investigations and report writing completed since January 1, 1958, was in cooperation with the Kentucky Geological Survey and the Kentucky Agricultural and Industrial Development Board. The geology of the Haldeman quadrangle (pl. 2) was mapped by the authors during the summer of 1955 and March 1956. They were assisted by Mr. Guillermo Armando Bustos during the summer of 1955. Most of the Wrigley quadrangle (pl. 3) was mapped by Hosterman assisted by Mr. Constante B. Belandres and Mr. Sylvio deQueiroz Mattoso during the summer of 1956. The authors completed the mapping of this quadrangle in April and November 1957. The assistants were participants in the Geological Survey's program under the auspices of the International Cooperation Administration. Mr. Bustos was from Mexico, Mr. Belandres from the Philippine Islands, and Mr. Mattoso from Brazil. Mrs. Hildreth Schultz assisted with the laboratory investigations from January to June 1958. Coal beds in the Wrigley quadrangle were investigated in April and May 1957 by Mr. John W. Huddle, who also wrote the section on coal. The refractory tests contained herein were made by members of the Department of Ceramic Research, College of Ceramics, Alfred University, Alfred, N.Y. Mr. Richard West and Mr. Leon B. Coffin conducted the tests under the supervision of Dean J. F. McMahon and Dr. W. G. Lawrence. Three samples of shale were tested for possible use as bloating material for lightweight aggregate at the U.S. Bureau of Mines, Electrotechnical Experiment Station, Norris, Tenn. This work was under the supervision of Mr. Howard P. Hamlin, Supervising Ceramic Engineer.

TOPOGRAPHY AND DRAINAGE

The Haldeman and Wrigley quadrangles lie along the west margin of the Cumberland Plateau, which is characterized by gently rolling upland surfaces incised by steep-walled valleys with narrow flood plains. The elevation ranges from less than 720 feet on the North Fork of the Licking River to somewhat more than 1,280 feet in the southwestern part of the Haldeman quadrangle. In most places local relief is less than 250 feet. A divide that separates the basins of large tributaries of the Ohio River extends across the northeast part of the Haldeman quadrangle. Streams northeast of the divide flow into Tygarts Creek and those to the southeast flow into the Little Sandy River. Drainage of the rest of the quadrangle is to the Licking River through its major tributaries: the North Fork and Triplett and Christy Creeks. The North Fork flows in a northwesterly direction across the southern and central parts of the Wrigley quadrangle. This stream and its major tributaries, Devils Fork and Minor, Craney, Yocum, and Stonecoal Creeks, drain all of the quadrangle except a few square miles in the southern part and about 200 acres in the northeast corner. The small area in the northeast corner lies in the watershed of the Little Sandy River and four small streams in the southern part of the quadrangle flow southward into the Licking River.

ACKNOWLEDGMENTS

Members of the Kentucky State Geological Survey assisted the investigations in several ways, but particularly valuable aid was given by Mr. Preston McGrain and Mr. Frank Walker, who visited the party in the field and assisted with correlation problems related to Mississippian stratigraphy. Mr. Fred Gesling, Consulting Engineer, Ashland, Ky., Mr. J. G. Henthorne of the General Refractories Co., Olive Hill, Ky., Mr. P. C. Mitchel and Mr. Freeman Russell of the Harbinson-Walker Co., Pittsburgh, Pa., and officials of the North American Refractories Co., Enterprise, Ky., and the Ironton Firebrick Co., Ironton, Ohio, gave permission to use a great deal of core drilling information which contributed materially to this study. Mr. Martin Bowen of the Lee Clay Products Co., Morehead, Ky., contributed information pertaining to clay deposits and records of holes drilled for oil and gas in the two quadrangles. The writers express for themselves and members of the party appreciation for many courtesies given by residents of the area.

STRATIGRAPHY

The formation mapped in the Haldeman and Wrigley quadrangles (pls. 2, 3) from oldest to youngest are as follows: Brodhead and Muldraugh formations of Early Mississippian age; undifferentiated formations of Late Mississippian age; Lee and Breathitt formations of Pennsylvanian age; and Recent alluvium. These formations and most of the units comprising the undifferentiated Upper Mississippian formations, are shown graphically in plates 4 and 5. The rocks are siltstones, shales, sandstones, limestones, unconsolidated silt and sand, and poorly sorted stream gravels. Except for outcrops of siltstone in the Brodhead formation and the cliff-forming sandstone unit of the Lee formation, exposures are small and widely scattered. Much of the area is blanketed by a thick mantle of soil and partly weathered bedrock and is heavily covered by brush and secondary growth of timber. Fortunately, the formations are nearly horizontal, and it is possible to make rather accurate inferences as to the location of stratigraphic contacts in the covered areas between scattered outcrops.

MISSISSIPPIAN SYSTEM

The Mississippian rocks that crop out in the Haldeman and Wrigley quadrangles comprise several units, which can be lumped together into Lower Mississippian formations of Osage age and Upper Mississippian formations of Meramec and Chester age. No rocks of Kinderhook age appear at the surface in these two quadrangles. Lower Mississippian rocks consist of two formations that are dominantly siltstone and shale; Upper Mississippian rocks consist of 10 thin formations that are dominantly limestone but also contain beds of shale, dolomitic limestone, and a few beds of calcareous sandstone.

LOWER MISSISSIPPIAN FORMATIONS

The rocks of Early Mississippian age that crop out in the Haldeman and Wrigley quadrangles consist of a complex group of beds that are difficult to divide into mappable units. These rocks have an aggregate thickness of about 280 feet, and they are characterized by numerous lateral and vertical gradations and much variation in thickness of units. Stockdale's (1939, p. 1–248) work is now generally regarded as authoritative, but his exceedingly detailed study has established several members and facies that are not practical mapping units. In the present study, the Lower Mississippian rocks have been divided into two formations, the Brodhead and Muldraugh. In the remainder of this section, considerable space has been devoted to clarifying the relation between Stockdale's units and those used in this report.

BRODHEAD FORMATION

The Brodhead formation was defined by Stockdale (1939, p. 135–136) as follows:

> The Brodhead formation is a generalized unit in Kentucky which lies between the New Providence formation beneath and the thin Floyds Knob formation above. It falls within the Burlington-Keokuk range of the general Mississippian column . . .
>
> As the writer regards only the lower part of the clastic section in Kentucky (lower half of Butts' "New Providence") as the "true" New Providence formation, the remainder of the column, up to the all-important Floyds Knob unit near the top is designated separately as the Brodhead unit . . .

Stockdale's detailed description divided the rocks of the formation into 6 facies and 14 members. Within the limits of the Haldeman and Wrigley quadrangles, he recognized only one facies of the Brodhead formation, the Morehead facies, but divided the formation into four members, three of which were assigned names.

1. The lower unit, the Christy Creek siltstone member, is made up of massive greenish-gray, gray, and drab siltstone 130 feet thick. This unit forms prominent bluffs and steep rock slopes in the lower walls of the stream valleys in the western and northern parts of the Haldeman quadrangle and the western part of the Wrigley quadrangle.

2. The second unit consists of an unnamed group of bedded siltstones and silty shales, which grade southwestward into massive siltstones of the Frenchburg siltstone member. In most outcrops, the second unit is between 125 and 175 feet thick. The lithologic characteristics of the unnamed siltstones and of the overlying Haldeman siltstone member are similar.

3. Fresh outcrops of the Haldeman member, the third unit, are somewhat massive, but weathered outcrops reveal bedded siltstone with softer shaly partings. The Haldeman member contains many small, irregular lenses of silty, very fossiliferous limestone. In some of the lenses, the fossils are filled with pink and brown calcite; in others, most of the calcite has been dissolved, leaving the fossil molds in the siltstone. The common fossils are horn corals, bryozoans, brachiopods, and crinoid stems. This member is 70 feet thick in the type section at Haldeman, Ky., given by Stockdale (1939, p. 185), but it is much thinner in other nearby sections.

4. The upper unit, called the Perry Branch member, is chiefly a greenish-gray to bluish-gray, somewhat argillaceous, siltstone in uneven beds. This unit is between 25 and 40 feet thick. In a few places, the upper 2 feet are slightly calcareous siltstone that weathers yellowish brown. In the southwestern part of Rowan County, the entire unit grades from a siltstone to a soft olive-gray shale.

The Brodhead formation subdivisions of Stockdale outlined above are characterized by indistinct boundaries and similar topographic expressions. These subdivisions are recognizable only in scattered outcrops and the formation is mapped as a single stratigraphic unit (pls. 2, 3). The formation is composed of greenish-gray, very resistant siltstone and fine-grained sandstone which is irregularly interbedded with thin green shale that weathers greenish brown. Some zones in the siltstone contain crinoid and brachiopod molds, numerous curly worm marks, and *Taonurus*, a type of fossil marking that is thought to represent wallows of marine worms or the impression of marine plants swayed by currents. Much of the siltstone has no planes of weakness along the bedding and will break with equal ease in all directions; for this reason the rock is called "freestone" locally.

Well-rounded quartz grains make up 80 to 90 percent of the sandy and silty beds. The less than 2-micron fraction of one sample of siltstone was essentially of the same composition as the sample of a shale bed examined. Both samples contained the clay minerals illite, kaolinite, and chlorite in roughly 5:4:1 ratio. The shale sample also contained an appreciable amount of fine-grained quartz, and reflections corresponding to traces of feldspar were present in the X-ray diagram of the fine fraction from the siltstone.

The Brodhead and the underlying New Providence shale are rather difficult to distinguish because in most places the contact between them is poorly exposed and the two units are lithologically similar. The New Providence shale was not recognized within the limits of the Haldeman and Wrigley quadrangles. However, the thickness of the Brodhead exposed in the valley of Triplett Creek in the northwestern part of the Haldeman quadrangle is nearly as great as the 256 feet Stockdale (1939, p. 178) gives as the thickness of the entire formation in a nearby section, and the top of the New Providence shale is probably only a few feet below the surface of the alluvium along Triplett Creek (pl. 2). Elsewhere in the Haldeman and Wrigley quadrangles the thickness of the exposed Brodhead formation is less than 256 feet, and the New Providence lies well below the surface.

Thin beds of variable lithologic character that overlie the Brodhead formation (see section below) are identified as the Floyds Knob formation by Stockdale (1939, pp. 191–200), who regarded it as an important stratigraphic marker and based much of his regional correlation on it. Stockdale's Floyds Knob formation is included in the Brodhead formation in this report. It includes a buff-weathering calcareous siltstone bed and a thin stratum of greenish-black silt. In some places only the silt is present, and in other places all of the Floyds Knob, as well as some of the underlying siltstone beds of the Brodhead, are cut out by the unconformity between the Mississippian and Pennsylvanian systems. In the Haldeman quadrangle, the Floyds Knob is only 1 to 2 feet thick, much too thin to be mapped as a separate formation; therefore, it is mapped as the uppermost part of the Brodhead formation (pl. 2). In the Wrigley quadrangle the Muldraugh formation above the Brodhead formation is also very thin and could not be mapped as a separate unit. On the geologic map of this quadrangle (pl. 3) the positions of both the Floyds Knob and the Muldraugh formations are marked approximately by the contact between the Brodhead formation and the rocks mapped as Upper Mississippian formations undifferentiated.

The following sections of the Brodhead and Muldraugh formations were recorded by Stockdale (1939, p. 180 and 184).

"*ROWAN COUNTY, Kentucky. Section No. 66, at steep valley bluff and hill-slope above, north side of Christy Creek Valley, immediately north of State Highway No. 32; just east of Deep Fork Branch, 3¾ miles east of Morehead.*[1]

	Feet
Brodhead formation (Morehead facies):	
Covered.	
Siltstone and shaly siltstone, undifferentiated	130
Siltstone, somewhat clayey, soft and nonresistant; in abrupt contact with the massive rock beneath	10
Christy Creek member:	
Siltstone, very massive where fresh; gray, greenish gray, drab; yellow to brown where weathered; profuse worm marks; few *Taonurus*, rare fossils; weathers by spalling parallel to exposed surface	130

Altitude at top of Christy Creek member, approximately 935 feet."

"*ROWAN COUNTY, Kentucky. Section No. 67, in the vicinity of Haldeman 7½ miles northeast of Morehead. A composite section compiled from exposures along secondary road leading up steep hill to Carter County line along road cuts at Haldeman, and along railroad cuts immediately west of Haldeman.*

	Feet	Inches
Pottsville:		
Shale and sandstone, to top of hill along road leading to Carter County line; covered in part.		
Covered for the most part; shale and clay	65	
Unconformity.		
Muldraugh formation (Olive Hill facies):		
Clay, ocherous; residuum from leached limestone	3	
Rothwell shale member:		
Siltstone, laminated, and silty to clayey shale, green gray, with intercalated calcareous slabs; with profuse fossils in patches and lenses	12	6
Shale, clayey, olive to maroon; mostly covered	5	6
Silt, brown, streaked with bright greenish black, especially at base; residuum from leached limestone	1	6
Shale, very clayey, olive green to purple maroon	6	6
Floyds Knob formation:		
Silt, and ocherous clay; with greenish-black glauconitic[2] streaks, especially at top and bottom; residuum from leached calcareous layer	1	
Brodhead formation (Morehead facies):		
Perry Branch siltstone member:		
Siltstone, soft, roughly laminated in places, green gray; leached to yellow brown in places; with *Taonurus*, profuse bryozoans in patches; also brachiopods, crinoids, and few corals	6	6
Siltstone, in fairly even beds, and silty shale; green gray to drab; upper part laminated and ripple-marked; with *Taonurus*, few crinoids	20	

[1] Section located one-quarter mile west of Haldeman quadrangle.

[2] Samples of greenish material from both the Brodhead and Muldraugh formations examined by X-ray methods during the current investigation contained abundant illite but no glauconite. The mineral here referred to as glauconite is probably illite.

	Feet	Inches
Brodhead formation (Morehead facies)—Continued		
Haldeman siltstone member:		
Siltstone, in irregular beds of varying hardness, greenish gray to drab; shaly where weathered; lower part characterized by profuse fossils as molds, particularly bryozoans, crinoids, and horn corals; *Taonurus* abundant; less massive than rock beneath	20	
Siltstone, uneven, somewhat massive; partly shaly where weathered, partly well laminated; greenish gray to drab where fresh; characterized by enclosed calcareous patches and lenses carrying abundant fossils revealed as molds upon leaching; many fossils well calcified	50	
Covered; not measured.		
Siltstone, in layers separated by silty shale; not measured.		
Christy Creek siltstone member:		
Siltstone, massive, forming prominent cliffs or steep hillslopes; not measured.		

Altitude at top of Brodhead formation, approximately 1,025 feet."

MULDRAUGH FORMATION

The name Muldraugh formation was introduced by Stockdale (1939, p. 217–221) for a variable rock unit between the Floyds Knob formation (included in the Brodhead formation in this report) and the carbonate beds of Late Mississippian age. The lithologic character of the formation in Kentucky is so varied that Stockdale divided it into five facies and six members. Virtually all the rocks of the Muldraugh in the area covered by this investigation appear to fall within the unit he designated as the Olive Hill facies, Rothwell shale member, and, therefore, none of his subdivisions of the formation are used in this report. The Muldraugh formation is mapped with slight exaggeration of its outcrop width as a separate formation in the Haldeman quadrangle (pl. 2), where it is a rather persistent rock unit and in most outcrops is more than 10 feet thick. In the Wrigley quadrangle (pl. 3) it is mapped as part of the Brodhead formation, because it is less than 5 feet thick and completely covered in most places. Inasmuch as the line representing the contact between the Brodhead and the overlying undifferentiated Upper Mississippian formations covers a vertical interval of more than 5 feet on steep slopes, this line approximately represents the outcrop of both the Muldraugh and the thin Floyds Knob formation of Stockdale below it.

The Muldraugh rests conformably on the Brodhead formation and consists of red and green marine shales containing scattered lenses and thin beds of green siltstone. The siltstone beds contain *Taonurus*, fragments of crinoid stems, and a few large poorly preserved brachiopods, which indicate that the deposits are of marine origin. The shale from the Muldraugh formation consists chiefly of illite and mixed-layer clay with minor amounts of kaolinite (table 7). The only non-clay mineral present in sufficient amounts to cause X-ray reflections was a small amount of fine-grained quartz. The red and green shales are very similar in mineral composition, and the color variations are probably due to differences of hydration and oxidation of iron oxides. The iron oxide content of the green shale was determined chemically to be about 5 percent. By comparing a red shale sample with this green shale sample on the X-ray emission spectrometer, it was found that the red shale contained approximately 8 percent Fe_2O_3.

The Muldraugh ranges in thickness from 0 to about 30 feet. Minor variations in thickness may have resulted from differential compaction of the relatively incompetent shales and variations in the rate of accumulation of the sediments. Prominent variations in thickness, however, result from removal of all or part of the formation during the erosion intervals that occurred between the deposition of the uppermost Mississippian and lowermost Pennsylvanian sediments, and between deposition of the shale and sandstone facies of the Lee formation. These periods of erosion may also be responsible for the absence of some of the uppermost beds of the Brodhead as well as all of the undifferentiated upper Mississippian formations in large areas on the west side of the lower part of Wagner Fork and in Stonecoal valley in the Haldeman quadrangle (pl. 2), and in most of the areas in which the Lee formation is shown in contact with the Brodhead formation in the valleys of Craney, Slabcamp, and Minor Creeks in the Wrigley quadrangle (pl. 3).

UPPER MISSISSIPPIAN FORMATIONS

Rocks of late Mississippian age consist of 10 thin formations, which are variable in thickness and areal distribution, and all 10 formations have been lumped together as a single unit on the geologic maps (pls. 2 and 3). The irregular distribution of these formations is due chiefly to their truncation by a large pre-Pennsylvanian unconformity and smaller intra-Mississippian unconformities, and perhaps to a lesser extent to irregularities in deposition. The three lower formations, the Warsaw(?) and the St. Louis and Ste. Genevieve limestones, are of Meramec age according to the classification by Weller and others (1948, p. 163). The Paoli, Beaver Bend, Reelsville, Beech Creek, Haney, Glen Dean, and Pennington(?) formations are equivalent to rocks which MacFarlan and Walker (1956) regarded as Chester in age. The Beech Creek and Haney formations are equivalent in part, at least, to the Golconda formation. The total maximum thicknesses of these 10 formations is about 150 feet, but these rocks are everywhere much thinner. All of them have been truncated by the large pre-Pennsylvanian unconformity, some of them by intra-Mississippian unconformities, and some vary in thickness because of irregularities of deposition. No more than 8 of the 10 formations are present at any one locality in the Haldeman and Wrigley quadrangles, and the maximum thickness of Upper Mississippian beds is only about 80 feet. Furthermore, only 2 to 4 of the formations are present at most places and the total thickness of Upper Mississippian rocks is less than 30 feet. Though these 10 formations are distinguishable in the field, they are too thin, discontinuous, and poorly exposed to be shown as separate units on the geologic maps, therefore, they have been lumped together into the unit referred to (pls. 2 and 3) as "Upper Mississippian formations undifferentiated."

The correlations of the seven formations of Chester age by McFarlan and Walker (1956) are part of a regional study, during which they were able to trace beds from western Kentucky to Indiana, and to eastern Kentucky. The framework for their correlations in eastern Kentucky lies chiefly in the distinctive fauna of the Glen Dean limestone, a shale parting below the Glen Dean, and the massive, light-gray, crinoidal to oolitic characteristics of the Reelsville limestone of Malott (1919), which are persistent throughout most of the region. Correlations of other formations of Chester age are based chiefly on stratigraphic position, lithologic characteristics, types of fossil preservation, local unconformities, and certain sedimentary structures such as mud flows and limestone breccias.

Erosion represented by the pre-Pennsylvanian unconformity removed all of the Upper Mississippian rocks at several localities, and intra-Mississippian erosion appears to be the chief cause for the local absence of some of the limestone formations. No Upper Mississippian rocks are present at several places in the northwest, southwest, and south-central parts of the Haldeman quadrangle (pl. 2) and along Minor Creek and some of its tributaries in the Wrigley quadrangle (pl. 3). A long period of pre-Reelsville erosion during Late Mississippian time appears to be responsible for the absence of the Ste. Genevieve limestone and the two formations that overlie it in the Wrigley quadrangle and all but the east-central and northeastern parts of the Haldeman quadrangle. Other minor Upper Mississippian unconformities are indicated by limestone breccia zones, small submarine mud flows, and undulating contacts between formations, which can be seen in the upper part of the St. Louis formation at the limestone quarry along the North Fork of the Licking River, in the quarries on the north side of Christy Creek valley, and in outcrops at several localities.

WARSAW(?) FORMATION

The lowermost formation of Late Mississippian age is a unit that consists of calcic dolomite, thin beds and lenses of green shale, and clastic quartz, and is tentatively correlated with the Warsaw limestone of southern and central Kentucky. The unit has been included in the overlying St. Louis formation in the vicinity of the Haldeman and Wrigley quadrangles by McFarlan and Walker (1956, pl. 2), but it is lithologically distinct from that formation and is herein considered as a separate stratigraphic unit. The Warsaw(?) is chiefly a calcic dolomite that contains some clastic quartz and little or no chert; the St. Louis, on the other hand, is limestone and contains abundant chert nodules and concretions. Butts (1922, p. 91) describes the Warsaw as extending throughout central Kentucky and southward into Tennessee. In eastern Kentucky he recognized it as far north as a locality 8 miles east of Berea, about 60 miles southwest of the area mapped. The tentative correlation of the lowermost unit in the area mapped with the Warsaw is based largely on its stratigraphic position below the St. Louis, its content of detrital quartz, and the presence of thin beds and lenses of green shale, which are characteristic of beds in the Warsaw limestone described by Butts.

The Warsaw(?) formation is the most widespread in the Haldeman and Wrigley quadrangles of all the undifferentiated Upper Mississippian formations. It is normally overlain by the St. Louis limestone, and it is present nearly everywhere the Upper Mississippian rocks crop out. The Warsaw(?) is the only Upper Mississippian formation present at several localities in the western and southern parts of the Haldeman and the northern part of the Wrigley quadrangles. The maximum observed thickness of the formation was 10 feet, in outcrops along Christy Creek about a quarter of a mile west of Elliottville, Haldeman quadrangle. Its thickness in most outcrops in the Haldeman quadrangle is 3 to 6 feet, and it is slightly thinner throughout most of the Wrigley quadrangle. The contact between the Warsaw(?) and St. Louis formations is a rather gently rolling surface at most places, including exposures in the floor of the quarry along the North Fork of the Licking River (fig. 2) and the two formations appear to be conformable. In exposures below the WPA quarry in Craney Creek valley and a few other places, the upper surface of the Warsaw(?) is sharply irregular, suggesting a local unconformity.

The Warsaw(?) formation is chiefly a soft, very finely crystalline calcic dolomite that contains scattered fragments of marine fossils, some quartz sand and silt, and thin lenses of green shale. White calcite and dolomite veins and small partially or completely filled vugs are common throughout the formation. The fresh rock is bluish gray,

FIGURE 2.—Limestone quarry operated by the Kentucky Road Oiling Co. along the North Fork of the Licking River 0.9 mile downstream from Leisure, Wrigley quadrangle.

but at the surface it weathers rapidly to yellowish brown, and where thoroughly weathered it forms a zone of silty yellow ocherous clay. The dolomite, even the unweathered part, is so soft that it is easily carved with a knife; nevertheless it is sufficiently resistant to remain in many places where all the Mississippian limestones above it have been eroded away. The resistance is probably due to low solubility of the dolomite, aided by the presence of clastic quartz and clay materials which resist chemical attack. Apparently the formation possessed some of these resistant properties prior to the time of the erosion represented by the pre-Pennsylvanian unconformity, inasmuch as the basal Pennsylvanian sediments rest on the thin formation of the Warsaw(?) in many places.

The high dolomite [$CaMg(CO_3)_2$] and low calcite ($CaCO_3$) contents of the Warsaw(?) formation are shown in the chemical analysis (No. 1, table 1) of a sample from the Kentucky Road Oiling Co. quarry, Wrigley quadrangle. The dominance of dolomite over calcite was also recognized in optical and X-ray examinations of samples from three widely spaced localities in the Haldeman quadrangle. Examinations of insoluble residues of these samples indicate that illite, rounded quartz sand grains, and silt are locally present in considerably higher proportions than indicated by the small amount of Al_2O_3 and SiO_2 in the chemical analysis (No. 1, table 1). The amounts of clay and silt in the formation probably vary considerably from place to place. Illite and very finely divided quartz were the only minerals recognized by X-ray methods in a sample from a green shale bed. This shale bed ranged from 5 to 12 inches in thickness and occurred near the middle of the formation in an outcrop along Christy Creek, a quarter of a mile west of Elliottville, Haldeman quadrangle.

TABLE 1.—*Chemical analyses of limestones from the Haldeman and Wrigley quadrangles*

[Weight percent. Summations rounded to nearest whole number. Analyzed by Paul L. D. Elmore, Samuel D. Botts, Marvin D. Mack, and Julius H. Goode under the supervision of W. W. Brannock, employing methods similar to those of Shapiro and Brannock (1956)]

	Warsaw (?) formation	St. Louis limestone					Beech Creek limestone of Malott, 1919					Haney limestone of McFarlan and Walker, 1955		Glen Dean limestone
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	3.5	1.7	1.1	9.8	6.4	11.7	0.94	1.6	0.75	1.1	1.1	9.0	12.8	3.5
Al^2O_3	.66	.37	.42	.62	.67	.28	.32	.50	.22	.34	.32	1.7	1.8	.60
Fe^2O_3	1.3	.10	.01	.07	.12	.05	.19	.20	.11	.12	.12	.41	.42	.24
FeO	.31	.05	.13	.10	.10	.06	.04	.04	.10	.13	.10	.34	.27	.16
MgO	17.2	.32	.33	.27	.34	.32	.22	.36	.24	.31	.15	.62	.54	.61
CaO	32.4	54.4	55.0	50.0	51.8	49.2	55.1	54.5	54.9	55.0	55.0	48.4	46.4	52.6
Na_2O	.11	.11	.06	.07	.14	.08	.09	.06	.05	.07	.06	.11	.09	.10
K_2O	.20	.06	.11	.16	.16	.06	.04	.08	.04	.06	.05	.47	.46	.11
TiO_2	.06	.01	.02	.03	.03	.02	.02	.01	.02	.03	.06	.10	.09	.04
P_2O_5	.11	.01	.01	.01	.05	.02	.00	.01	.00	.00	.00	.04	.06	.05
MnO	.23	.02	.03	.04	.02	.01	.04	.04	.04	.03	.02	.02	.02	.03
H_2O	.39	.23	.33	.32	.21	.31	.13	.22	.13	.12	.08	.60	.74	.22
CO_2	43.9	42.7	42.8	37.6	40.8	38.4	43.0	42.5	43.2	43.2	43.4	38.5	36.7	41.9
Sum	100	100	100	99	101	101	100	100	100	101	100	100	100	100

NOTE.—Materials for analyses were composites of chips taken from quarry faces at 6 to 12 inch intervals. The samples are from the following limestone formations:

1. Warsaw (?), 3 feet thick, Kentucky Road Oiling Co. quarry, 1.8 miles downstream from Leisure, Wrigley quadrangle. (lab. No. 150133.)
2. St. Louis (lower gray ledge), 12 feet thick, Kentucky Road Oiling Co. quarry, Haldeman quadrangle (fig. 3, section 6). (lab. No. 148105.)
3. St. Louis (lower gray ledge), 10 feet thick, abandoned quarry near Christian Cemetery, Haldeman quadrangle (fig. 3, section 7). (lab. No. 148107.)
4. St. Louis (lower gray ledge), 13 feet thick, abandoned WPA quarry on tributary to Craney Creek, Haldeman quadrangle (fig. 3, section 14). (lab. No. 148109.)
5. St. Louis, 10 feet thick, Kentucky Road Oiling Co. quarry, 0.9 mile downstream from Leisure, Wrigley quadrangle. (lab. No. 150126.)
6. St. Louis, 10 feet thick, Kentucky Road Oiling Co. quarry, 1.8 miles downstream from Leisure, Wrigley quadrangle. (lab. No. 150132.)
7. Beech Creek of Malott, 1919 (upper white ledge), 18 feet thick, Kentucky Road Oiling Co. quarry, Haldeman quadrangle (fig. 3, section 6). (lab. No. 148104.)
8. Beech Creek of Malott, 1919 (upper white ledge), 10 feet thick, abandoned quarry near Christian Cemetery, Haldeman quadrangle (fig. 3, section 7). (lab. No. 148106.)
9. Beech Creek, of Malott, 1919, 5 feet thick, abandoned WPA quarry on tributary to Craney Creek Haldeman quadrangle (fig. 3, section 14). (lab. No. 148108.)
10. Beech Creek of Malott, 1919, 8 feet thick, Kentucky Road Oiling Co. quarry, 0.9 mile downstream from Leisure, Wrigley quadrangle. (lab. No. 150127.)
11. Beech Creek of Malott, 1919, 10 feet thick, Kentucky Road Oiling Co. quarry, 1.8 miles downstream from Leisure, Wrigley quadrangle. (lab. No. 150131.)
12. Haney of McFarlan and Walker, 1955, 10 feet thick, Kentucky Road Oiling Co. quarry, 0.9 mile downstream from Leisure, Wrigley quadrangle. (lab. No. 150128.)
13. Haney of McFarlan and Walker, 1955, 10 feet thick, Kentucky Road Oiling Co. quarry, 1.8 miles downstream from Leisure, Wrigley quadrangle. (lab. No. 150130.)
14. Glen Dean, 8 feet thick (top not exposed), Kentucky Road Oiling Co. quarry, 1.8 miles downstream from Leisure, Wrigley quadrangle. (lab. No. 150129.)

ST. LOUIS LIMESTONE

The St. Louis limestone is the second most widespread limestone formation. It crops out at scattered localities in the Haldeman quadrangle and can be recognized in the Wrigley quadrangle (pl. 3) at most places where Upper Mississippian formations are present. The color of the St. Louis ranges from light to dark gray, but it is chiefly a medium gray, massive, very finely crystalline to dense limestone that contains a lot of chert and a few marine fossils. The chert occurs as spherical concretions 1 to 3 inches in diameter and irregular nodules up to a foot or more in longest dimension. Some of the chert is pink, but most of it is gray. Small calcite crystals and veins are quite common throughout the formation. At a few places 1 to 3 thin beds of green shale crop out in the lower half of the formation. In some outcrops the limestone is extremely brecciated and locally the bedding is complexly involute and contorted and appears to have been disturbed by submarine flowage prior to consolidation of the rock.

The St. Louis ranges in thickness from 3 to 12 feet in most outcrops in the Haldeman quadrangle, but it is 17 feet thick at the abandoned WPA quarry on a tributary to Craney Creek northwest of Poplar Grove school. It is about 10 feet thick throughout the extensive workings in the quarry along the North Fork of the Licking River, Wrigley quadrangle, and this thickness is roughly representative of the formation throughout the entire quadrangle.

The St. Louis limestone is overlain by the Ste. Genevieve limestone, but inasmuch as the Ste. Genevieve is missing in all but a few places in the Haldeman quadrangle, the upper contact of the St. Louis marks a stratigraphic break throughout most of the area. In the quarry along the North Fork in the Wrigley quadrangle (fig. 2), the St. Louis is overlain by a bed of soft green fissile shale 3 feet thick. Three formations are missing between the St. Louis and the Reelsville limestone of Malott that overlies the thin shale bed, and therefore the formation to which it should be assigned has not been established. It may be part of the St. Louis, any of the three missing limestones, or the Reelsville limestone.

A fossil coral from a chert nodule in the St. Louis was collected from an outcrop in Hans branch of Yocum Creek (USGS loc. 16320–PC) and was identified by Miss Helen Duncan as *Dorlodotia* sp., a form that would have been referred to *proliferum* Hall in earlier reports. In a written communication (October 9, 1956) she states,

> *Lithostrotion proliferum* of authors is ordinarily regarded as a guide fossil for the St. Louis limestone, but it has been reported in the lower Ste. Genevieve.

STE. GENEVIEVE LIMESTONE

The Ste. Genevieve limestone, as well as the overlying Beaver Bend limestone of Malott (1919) and the Paoli limestone of Elrod (1899), is restricted to the east-central and northeastern parts of the Haldeman quadrangle. Apparently these formations either were never deposited or were removed by erosion prior to accumulation of younger Mississippian formations throughout the remainder of the area mapped. The aggregate thickness of these three formations is about 30 feet in the Proctor Branch and Greenbriar Branch valleys, and they pinch out within 2 to 3 miles in all directions except to the east. The hypothesis that three limestone formations with the varied lithologic composition of the Ste. Genevieve, Paoli, and Beaver Bend were restricted to such a small area is untenable; therefore, erosion prior to deposition of younger Mississippian sediments seems to be the explanation for their absence over much of the area.

In the few outcrops where the Ste. Genevieve limestone is present it consists of light gray, very sandy, nonfossiliferous limestone. The sand consists of well-rounded frosted quartz and occurs in crossbedded laminae in the limestone. The formation ranges from 4 to 8 feet in thickness; however, it thickens sharply to the east, and it is more than 30 feet thick in Proctor Branch valley, approximately half a mile beyond the east boundary of the Haldeman quadrangle. At this locality the formation contains sandy brecciated limestone with abundant rounded pebbles of chert and quartz.

PAOLI LIMESTONE OF ELROD (1899) AND BEAVER BEND LIMESTONE OF MALOTT (1919)

The Paoli and Beaver Bend limestones were recognized in eastern Kentucky by McFarlan and Walker (1956, p. 9), but because of their similar lithologic composition they were not distinguishable in the vicinity of the Haldeman and Wrigley quadrangles. These two formations occur only in the valleys of Proctor and Greenbriar Branches, in the Haldeman quadrangle, where they rest on the Ste. Genevieve limestone and are overlain by the Reelsville or the Beech Creek limestones of Malott (1919). Both the Paoli and Beaver Bend limestones consist chiefly of very fine grained light-gray limestone, most of which is in beds 2 to 8 inches thick. Small crystals and specks of calcite and fossil fragments are scattered throughout the two formations. Along Proctor Branch approximately 22 feet of beds make up the Paoli and Beaver Bend. From the base upward they are: (1) about 2 feet of green, platy, argillaceous, siltstone, probably a lens, resting on a covered zone; (2) 5 feet of light-gray fine-grained limestone; (3) 4 feet of soft red and green shale; (4) 4 feet of interlayered red and green shale and limestone in beds 4 to 8 inches thick; (5) 8 feet of light-gray fine-grained limestone. Presumably the red and green shale bed corresponds to the Mooretown sandstone horizon which, according to McFarlan and Walker (1956, p. 8), forms a break between the Paoli and Beaver Bend. If this correlation is correct, the upper limestone, including the interbedded limestone and shale zone, is Beaver Bend; the lower limestone and siltstone are Paoli.

REELSVILLE LIMESTONE OF MALOTT (1919)

Thin beds between the Beaver Bend and Beech Creek limestones were correlated by McFarlan and Walker (1956, p. 8) with the Reelsville limestone of southern Indiana and northwestern Kentucky. In the Haldeman quadrangle, the Reelsville limestone crops out in the Proctor Branch valley and in the vicinity of the WPA quarry in the Craney Creek valley, where it is no more than 2 feet in thickness. Elsewhere in the quadrangle, it is either missing or indistinguishable from the Beech Creek limestone. McFarlan and Walker consider the two formations an inseparable unit over much of eastern Kentucky. In the Wrigley quadrangle, the Reelsville beds are present between the St. Louis and the Beech Creek limestones in the valleys of Yocum Creek and the North Fork of the Licking River (pl. 2). Thicknesses are approximately the same as in the Haldeman quadrangle.

The Reelsville consists of very finely crystalline calcic dolomite and dolomitic limestone that contains a great deal of shale and silt. The fresh rock is olive gray, but weathered surfaces are light yellowish brown and are very similar to weathered beds of the Warsaw(?) formation. Two samples of Reelsville beds from the North Fork quarry examined by insoluble-residue and X-ray techniques were mixtures of quartzose calcic dolomite containing subordinate amounts of clay. One sample was approximately 35 percent quartz, 25 percent calcite, 30 percent dolomite, and 10 percent illite. The second sample consisted of 30 percent quartz, 60 percent dolomite, and 10 percent calcite and clay minerals. The quartz in both samples was all of silt size or finer and consisted of both rounded and euhedral clear grains. The calcite and dolomite were very fine grained and intimately intermixed.

Mr. Ellis L. Yochelson identified the fossils collected from the Reelsville at the WPA quarry locality (USGS loc. 16660–PC). The fauna included numerous specimens of *Straparollus* (*Euomophalus*) sp., a few bellerophontid gastropods, and one brachiopod, *Composita* sp. According to Mr. Yochelson (written communication, 1957) this type of fossil assemblage is not limited to the Chester or even the Mississippian rocks and is therefore of little value for regional correlation.

BEECH CREEK LIMESTONE OF MALOTT (1919)

The Beech Creek limestone is a distinctive formation which occurs in both the Haldeman and the Wrigley quadrangles and has been recognized from the Ohio River to the Kentucky-Tennessee boundary. It is approximately the same unit as the Gasper oolite described by Butts (1922, p. 157–164). Scattered outcrops indicate that the Beech Creek once formed a rather uniform layer over all of the Haldeman and Wrigley quadrangles; however, most of it was removed by pre-Pennsylvanian erosion, and its distribution is now irregular. In the Haldeman quadrangle the thickness of the formation ranges from 0 to 18 feet. The formation is thickest where the overlying Haney limestone of McFarlan and Walker (1956) has protected it from pre-Pennsylvanian erosion. The thickness, where it was similarly protected in the Wrigley quadrangle, ranges from 6 to 10 feet. The formation is fairly consistent in thickness and distribution in the Christy Creek, Mocabee Creek, and Proctor Branch valleys in the Haldeman quadrangle, and along the North Fork of the Licking River and in the valleys of Yocum Creek and its tributaries in the Wrigley quadrangle.

The Beech Creek limestone consists of nearly pure limestone of uniform chemical and lithologic composition. In most outcrops the lower part of the formation is coarse bedded and the upper part is massive. The limestone is nearly white to light yellowish gray, medium to coarsely crystalline, and oolitic, and locally it contains abundant crinoid stems and plates. Both coarse calcite crystals and some oval-shaped sections of oolites are present in a thin section of the limestone (fig. 3, *A*) cut from a sample taken from the upper massive part of the formation at the Kentucky Road Oiling Company quarry on the north side of the Christy Creek valley, Haldeman quadrangle (pl. 4, section 6). McFarlan and Walker (1956, p. 8) found foraminifera very numerous in some parts of the formation, and they regard a large crinoid stem ½ to ¾ inch in diameter as the distinctive fossil. The limestone is of the high-calcium type, and it is nearly uniform in composition throughout much of the formation. The Beech Creek has been an important source of the limestone quarried in both the Haldeman and Wrigley quadrangles. Additional information on the quality of this limestone is given on pages F87 to F89 and chemical analyses of samples from the formation at five localities are given in table 1. More chemical data on the limestones can be found in the Kentucky Industrial limestone reports 2 and 3 by Stokley and McFarlan (1952) and Stokley and Walker (1953).

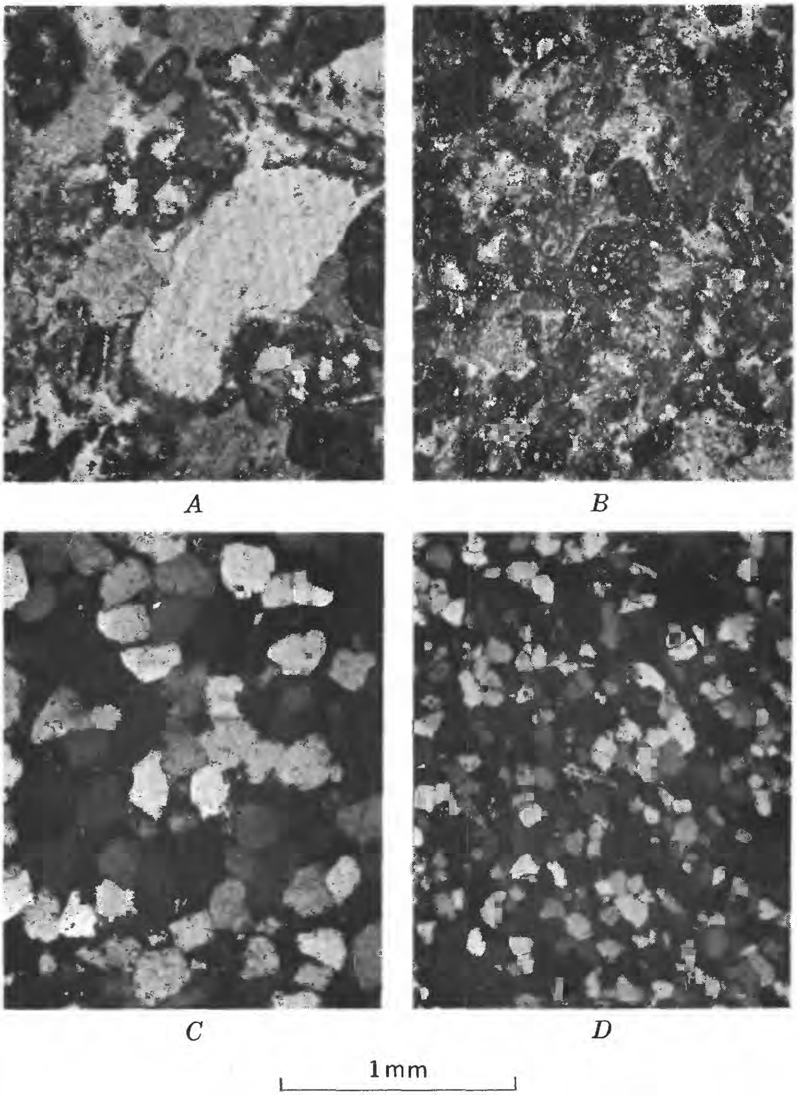


FIGURE 3.—Photomicrographs of limestone and sandstone. (*A*), Beech Creek limestone of Malott, 1919; (*B*), Glen Dean limestone; (*C*), sandstone from Lee formation; (*D*), sandstone from Breathitt formation.

HANEY LIMESTONE OF McFARLAN AND WALKER (1956)

The Haney limestone is the name McFarlan and Walker (1956, p. 7, and 8) apply to beds that are in part equivalent to strata referred to by earlier authors as the Golconda formation (Butts, 1922, p. 169–171). In much of eastern Kentucky the Haney is a medium-crystalline limestone that occurs in beds 6 inches to 2 feet thick. It overlies the Beech Creek limestone and is separated from the Glen Dean limestone above by a thin but persistent shale unit a few feet thick. This shale unit has been referred to by McFarlan and Walker (1956, p. 7) as the "Pencil Cave," a term used by drillers. In the area of this report the Haney is represented by a facies containing a great deal of shale. Inasmuch as the formation is dominantly shale in its upper part, there is no lithologic basis for distinguishing it from the so-called "Pencil Cave" shale. As used herein the name Haney applies to all beds between the Beech Creek and Glen Dean limestones and may include thin strata that correspond to the "Pencil Cave."

In the Haldeman quadrangle the Haney limestone of McFarlan and Walker is represented only by calcareous shale containing a few thin nodular limestone beds. The formation was either never deposited or removed from more than three-fourths of the quadrangle area during the pre-Pennsylvanian erosional interval. Where it is present it is as much as 20 feet thick. In exposures in the high wall of limestone quarries along the north side of Christy Creek the formation consists of gray marine shale that weathers purple and reddish gray and contains several zones of limestone nodules 1 to 4 inches thick. Both the nodules and the shale contain a very prolific bryozoan fauna. Similar beds crop out in natural exposures along the north side of Proctor Branch near the east edge of the quadrangle. At this locality the upper few feet of the formation consist of noncalcareous green shale that may represent thoroughly weathered material of the type that occurs in the Christy Creek vicinity. About 5 feet of the lower part of the Haney is exposed at the abandoned WPA quarry in the Craney Creek valley in the southern part of the Haldeman quadrangle. The rocks consist of thin-bedded very fossiliferous olive-gray limestone interbedded with green shale. A collection of fossils from this locality (USGS 16671–PC), which were examined by Mr. J. Thomas Dutro, Jr., and Miss Helen Duncan, consisted of brachiopods, echinoderms, bryozoans, and a coral. This collection included:

Amplexizaphrentis spinulosus (Milne-Edwards and Haime)
Platycrinus? sp.
echinoderm debris, indet.
bryozoan fragments, indet.
Diaphragmus cf. *D. cestriensis* (Worthen)
Spirifer cf. *S. leidyi* (Norwood and Pratten)
Composita cf. *C. subquadrata* (Hall)

In the Wrigley quadrangle the Haney limestone of McFarlan and Walker crops out along the North Fork of the Licking River and in the valleys of Yocum Creek and its tributaries. It is cut out by the pre-Pennsylvanian unconformity in most of the northern third of the quadrangle. In exposures in the North Fork quarry (fig. 2) the formation is 10 feet thick and is about 60 percent limestone and 40 percent shale. At this locality the formation consists from the base upward of (1) 8 inches of dusky yellowish green shale which overlies the Beech Creek limestone, (2) 8 feet of limestone and shale, in which the lower two-thirds is thin-bedded light-olive-gray shale interbedded with a few thin shale strata, and the upper third is interbedded limestone and shale in approximately equal proportions, (3) 16 inches of grayish green shale containing a few thin nodular limestone beds. The Haney of this neighborhood is apparently an intermediate stage in the gradation between the shale facies in the Haldeman quadrangle and the thin-bedded limestone characteristic of the formation farther to the southwest.

GLEN DEAN LIMESTONE

The Glen Dean limestone, like the Pennington(?) formation above it, has been removed in all but a few places by erosion prior to the deposition of lowermost Pennsylvanian beds. In the Haldeman quadrangle the formation was recognized only on the north side of the Proctor Branch valley, where it consisted of bluish gray, crystalline oolitic limestone about 5 feet thick. In the Wrigley quadrangle the Glen Dean limestone crops out in the valleys of the North Fork of the Licking River and Yocum Creek. It ranges in thickness from 10 to 16 feet in the extensive limestone quarry operated by Kentucky Road Oiling Co. along the North Fork of the Licking River. In this quarry, it is made up chiefly of bluish-gray, finely crystalline, massive oolitic limestone and is overlain by a zone of very calcareous quartzose sandstone that contains brown limonite spots and small greenish-gray clay chips. Most of the formation contains abundant remains of invertebrate animals, and several dozen genera and species of macrofossils have been identified (Butts, 1922, p. 174–178). A thin section (fig. 3,*B*) of a sample of the Glen Dean, which was collected from the limestone quarry about 1 mile downstream from Leisure, Wrigley quadrangle, contained abundant oolites, most of which have formed around microfossils. The most common fossil present in this slide has been identified as *Endothyra discoidea* Girty, 1915, by Mr. L. G. Henbest.

PENNINGTON(?) FORMATION

Regional correlations of a thin sequence of variable beds above the Glen Dean limestone and below the Lee formation are uncertain, and these beds are somewhat arbitrarily referred to as the Pennington(?) formation. The beds consist chiefly of green and purple shale, but they also contain strata of dark-gray shale, calcareous sandstone, dark-gray limestone, and blue and green dolomite. Similar strata near Berea, Kentucky, some 60 miles southwest of the area described in this report, have been called Pennington by Butts (1922 p. 179). McFarlan and Walker (1956, p. 12) have questionably assigned the name Pennington to a thin shale formation in essentially the same stratigraphic position at several localities near the Haldeman and Wrigley quadrangles.

Apparently the Pennington(?) formation was removed from most parts of the Haldeman and Wrigley quadrangles during the pre-Pennsylvanian erosional interval, and only remnants of its variable beds are present at scattered localities. The only place where the formation was recognized in the Haldeman quadrangle is in the north side of the Proctor Branch valley near the east boundary of the quadrangle. At this locality, the formation consists of green shale approximately 6 feet thick, cropping out above the Glen Dean limestone. The Pennington(?) formation is present in several outcrops in the southern half of the Wrigley quadrangle, along Laurel Branch, Yocum Creek, and North and Devils Forks of the Licking River. The lithologic composition of the rocks and the thicknesses of the unit vary considerably in these outcrops, but the thickest sequence of beds and presumably the most typical composition are present in outcrops along the North Fork near Leisure. At this locality, the formation is dominantly green shale that contains several thin dolomite beds and concretions in the upper part, and a bed of standstone cemented by calcite in the lower part.

Two surface samples of sandstone and one drill-core sample of shale from the Pennington(?) formation were investigated in the laboratory. A sandstone sample from bed 12 of the preceding section consisted of about 94.3 percent quartz, 5 percent feldspar, 0.5 percent calcite, and 0.1 percent heavy minerals. Seventy percent of the quartz and feldspar was in fine sand-, 17 percent in very fine sand-, and the remaining material in silt- and clay-sized particles. Most of the quartz grains are well rounded, but some are euhedral and have been secondarily enlarged. Most of the feldspar grains are partially altered to clay minerals. A second sandstone sample from the lower part of the formation exposed in the bed of Laurel Branch near the southwestern corner of the Wrigley quadrangle contained 40 percent calcite, essentially no feldspar, and only trace amounts of heavy minerals. Fifty-one percent of the quartz in this sample was in fine and 26 percent in medium grain sizes. The clay mineral content of both sandstone samples was only about 4 percent. About two-thirds of the clays were kaolinite and one-third a mixture of illite and mixed-layer clays. The sample of green shale was from the upper part of

Section of the Pennington(?) formation and enclosing rocks in a road cut one-fourth mile south of Leisure, Wrigley quadrangle

	Inches	Feet
Lee formation:		
1. Sandstone, brown, quartzose, medium-grained, contains scattered quartz pebbles and small conglomerate lenses.		
2. Shale, very dark-gray, soft, at base a zone of iron-stained siderite concretions	1	6
Pennington(?) formation:		
3. Limestone, medium to dark-gray, dense, nonbedded	1	2
4. Shale, very dark greenish-gray, chunky	3	0
5. Limestone, medium-gray, dolomitic iron stained	0	6
6. Shale, dark-greenish gray and dark-gray, chunky	2	6
7. Dolomite, greenish-gray, weathers yellowish-brown, contains widely spaced medium-gray colored concretions of dolomite	0	6
8. Shale, purple with some green, chunky	0	8
9. Dolomite, greenish-gray, weathers yellowish brown, dense	0	7
10. Shale, purple and maroon with some green, hard, chunky	0	8
11. Shale, dark greenish-gray, chunky	4	6
12. Sandstone, light-gray, quartzose, fine-grained, weakly cemented with calcium carbonate, crossbedded, contains elongate green-shale pebbles up to 1 inch in diameter in upper part	5	0
13. Shale, dark-greenish gray, very silty in upper part	4	0
14. Covered	5	6
Total thickness of Pennington(?) formation	28	7
Glen Dean limestone.		

the formation penetrated by a drill hole located on the ridge south of Elm Log Branch, near the western boundary of the quadrangle. This shale consisted chiefly of illite and kaolinite in about 3-to-1 proportions, and it contained virtually no quartz.

PENNSYLVANIAN SYSTEM

The Pennsylvanian rocks in the Haldeman and Wrigley quadrangles are dominantly sandstones, siltstones, and shales, but they also contain thin coal beds, the economically important Olive Hill clay bed of Crider (1913) (see discussion p. F48 to F76), and a thin unit of shaly limestone. A few of the rocks are in massive and persistent beds, but most of them are discontinuous and grade laterally from one rock type to another. They contain a few stratigraphic marker zones, but owing to the large amount of cover and weathered outcrops such zones are difficult to trace. Most of the beds are continental-type deposits, as indicated by numerous layers of coal and abundant fragments of plant fossils including root fossils in underclays; however, several zones contain fossils that are indicative of deposition in marine or brackish water.

Pennsylvanian rocks are divided into two rather comprehensive formations: the Lee below and the Breathitt above, and they include the uppermost bedrock strata in the area mapped (pls. 2 and 3). The Lee formation and that part of the Breathitt formation present in the area herein described are correlated with rocks of Pottsville age in parts of Pennsylvania and West Virginia (Moore and others, 1944, chart 6). The Lee formation rests on the rolling pre-Pennsylvanian erosional surface, which has a maximum local relief of about 75 feet based on surface elevations in the Haldeman and Wrigley quadrangles, but according to McFarlan (1950, p. 96) the pre-Pennsylvanian erosional surface involves several hundred feet of relief elsewhere in Kentucky. The pre-Pennsylvanian erosional surface truncates ten thin Upper Mississippian formations, and in places, it truncates the thin Muldraugh formation and the uppermost part of the Brodhead formation, both of Early Mississippian age. Accordingly, the Mississippian formations that underlie the Lee formation range from the Brodhead to the Pennington(?) in age.

LEE FORMATION

In the northern half of the Haldeman quadrangle the Lee formation is chiefly composed of dark-gray shale containing some beds and lenses of sandstone, siltstone, underclay, and coal; however, in the southern half of the Haldeman and the Wrigley quadrangles it consists of a thick massive sandstone unit overlying thinner beds of shale. All but the lower part of the shale is in facies relation with the massive sandstone, inasmuch as the shale grades into and intertongues with the sandstone in a southerly direction. Where dominantly shale, the formation crops out in broad belts on hillsides and ridges; where dominantly sandstone, outcrops are restricted to cliffs and step valley walls. The formation thickens in a southerly direction. The shale facies ranges in thickness from 140 to about 165 feet, and the sandstone facies and underlying shale combined, from 165 to 200 feet. The shale unit below the sandstone ranges in thickness from 0 to 80 feet, though in most places it is less than 30 feet. In general, the thickness of the shale below the sandstone varies inversely with the sandstone; however, the greatest thickness of shale is where the pre-Pennsylvanian erosional surface cuts deepest into Mississippian strata.

The name Lee was introduced by Campbell (1893, p. 28, 36), who applied it to a thick sequence of sandstones, conglomerates, shales, and coals in southwestern Virginia. It has since been used throughout eastern Kentucky as the name for a Lower Pennsylvanian formation that is mostly massive sandstone. The lower part of the shale facies, including beds below the cliff-forming sandstone, may be correlated with rocks referred to by Miller (1919, p. 10, 147) as the Beattyville shale. That name is not used in this report because it appears to be applicable only to beds below cliff-forming sandstones of the Lee, and there is no basis for distinguishing such beds from higher shales that are clearly in facies relation with the sandstone.

In much of the area, the cliff-forming sandstone rests unconformably on the lower shale beds. In several places, as along Craney Creek, where the sandstone is in contact with the Brodhead formation (pl. 3), erosion preceding accumulation of the sandstone removed all of the Pennsylvanian shale beds and possibly part of the Upper Mississippian rocks. At other places the sandstone fills channellike depressions in the upper surface of the shale. In many places, however, the shale grades upward into the sandstone and no indication of an unconformity between the two units exists. Intertonguing and lateral gradation of the two facies in the northern part of the Haldeman quadrangle (pl. 4) indicate simultaneous deposition of the two units and rule out the possibility that the conformity at the base of the sandstone, though large at some localities, is responsible for the lateral change from sandstone to shale.

The contact between Pennsylvanian and Mississippian strata is largely covered and can be recognized only at scattered outcrops and in drill cores. Where the Pennsylvanian beds are sandstone or ocherous kaolinitic shale and where the dark-gray shale rests unconformably on limestone, there is little difficulty in recognizing the contact. Exposures are particularly poor where the beds both above and below the contact are shale, but in drill core of such strata the contact is marked in most places by a contrast in color and fossil content. Most of Mississippian shale in contact with Pennsylvanian beds is green and contains a varied marine fauna, whereas basal Pennsylvanian shale is dark gray and contains plant remains. In a few places, where the Pennington(?) formation is present, the contact between Mississippian and Pennsylvanian rocks is particularly difficult to recognize, because some of the sandstone and shale beds both above and below the contact are very similar. At such localities, marine and nonmarine fossils furnish the best evidence for distinguishing, respectively, Mississippian from Pennsylvanian beds. Supporting evidence may lie in the general tendency for Pennsylvanian sandstones to be noncalcareous, whereas those in the Pennington(?) formation are cemented with calcite.

Where the cliff-forming sandstone facies is present, the contact between the Lee and the overlying Breathitt formation is at the top of the sandstone. In the northern part of the Haldeman quadrangle (pl. 2), where the Lee is represented by the variable dark-gray shale facies, its gross lithologic character is similar to that of the Breathitt; therefore, it is difficult to distinguish the two formations in the poor exposures. For this reason, the contact between the two formations in the northern half of the Haldeman quadrangle is somewhat arbitrarily placed at the base of a thin discontinuous coal zone located at the approximate stratigraphic position of the top of the cliff-forming facies. The coal zone ranges from 165 to 140 feet above the base of Crider's Olive Hill clay. Although the coal crops out in only a few road cuts, its elevation has been rather accurately determined from information in several hundred drill logs in the records of clay companies. This zone, the Lee-Breathitt contact in the northern part of the Haldeman quadrangle (pl. 2), is shown on the map as inferred because outcrops are so sparse.

SHALE FACIES

The shale facies of the Lee formation is varied; it has a bulk composition roughly estimated as 70 percent shale (some of which is sandy), 20 percent sandstone, 5 percent siltstone, 5 percent underclay (including the Olive Hill clay bed), and very small amounts of coal. Most of the shale is nearly black where observed in fresh drill cuttings and strip-mine faces, but in natural exposures and road cuts it weathers to a characteristic iron-stained yellowish brown. The colors of the other rocks cover a broad range, but most of them are drab shades of gray and brown. The shale facies is divisible, for purpose of discussion, into five vaguely bounded lithologic subunits, which consist from the base upward of: (1) a varied group of shales and sandstones below the Olive Hill clay bed, ranging from 1 to about 20 feet thick; (2) the Olive Hill clay bed and the thin coal that overlies it (p. F50 and F94); (3) an extremely variable zone of shale, sandstone, siltstone, underclay, and coal ranging from 10 to 30 feet in thickness; (4) a dark-gray shale subunit 40 to 60 feet in thickness; and (5) an upper subunit of shale, sandy shale, and discontinuous massive cross-bedded sandstone beds, ranging from 60 to nearly 100 feet in thickness. The lower three subunits extend with varied continuity throughout the area of Haldeman and Wrigley quadrangles, but the upper two subunits are gradational into the sandstone facies and are restricted to the northern half of the Haldeman quadrangle. The rocks in the subunit below the Olive Hill clay bed are similar in many respects to those in the subunit above the clay bed, and these two subunits cannot be distinguished where the clay bed is absent.

The varied rocks in the subunit below the Olive Hill clay bed consist of dark-gray shale, noncalcareous sandstone, and red, green, and yellow ocherous shale. These rocks occur as lenses and discontinuous beds, and their aggregate thickness ranges from 1 to 20 feet, though in most places their thickness is less than 6 feet. The dark-gray shale beds are typical Pennsylvanian shales and contain abundant tiny mica flakes and scattered imprints of plant fragments along bedding planes. The sandstone occurs in lenses as much as 10 feet thick. Crossbedding is common in the lower part; but the upper part, where in contact with the clay bed, is nonbedded, and *Stigmaria* are common. The varicolored ocherous shale beds ordinarily occur immediately below the clay bed. This ocherous shale is of particular interest because it is closely associated with the Olive Hill clay bed, and probably the two are related in origin. Unfortunately, information regarding the shale is incomplete, because natural exposures are rare, only portions of the shale are exposed in the floors of clay mines and mine access roads, and exploration drilling for clay is terminated when the shale is penetrated. Thickness of the varicolored shale ranges from about 1 foot to about 6 feet. Much of it contains abundant slickensides. Locally, bedding and laminations are absent, and except for its varied colors it is very similar in appearance to the semiflint and plastic clay in the Olive Hill clay bed (see p. F58). No orderly arrangement or layering of the red, green, and yellow colors was observed in any of the localities where the ocherous shale was seen in outcrop. In places the varicolored ocherous shale grades down into green shale of Mississippian age, but at other localities sandstone and dark-gray shale of Pennsylvanian age are present below the shale. Where the ocherous shale grades down into Mississippian shale, it could easily be interpreted as the geologic record of an ancient soil formed on the pre-Pennsylvanian erosional surface. The Pennsylvanian beds that occur locally below the ocherous shale, however, clearly establish its age as younger than the unconformity.

One sample of the sandstone and 7 samples of the ocherous shale from the subunit below the Olive Hill clay bed were investigated in the laboratory. The sandstone sample was taken from a bed about 10 feet thick at an exposure along the road in the Greenbriar Branch valley, Haldeman quadrangle (lat 38°12′28″ N.; long 83°16′28″ W.). From sieve and pipette analyses, this sample was found to contain 50 percent fine sand, 32 percent very fine sand, 12 percent silt, and 6 percent clay. More than three-quarters of the clay was kaolinite and the remaining part was illite. The sandstone is nearly pure quartz and no feldspar was present. The sample contained only a trace of heavy minerals, including tourmaline, rutile, and ilmenite. All 7 samples (table 2) of the ocherous shale consisted chiefly of varied amounts of kaolinite, illite, and mixed-layer clay minerals (mostly illite-montmorillonite). One pinkish-red clayey shale sample (No. 7, table 2) is very similar in mineral composition to semiflint clay (see p. 58). Other samples (Nos. 3 and 5, table 2) are very similar in mineral composition to typical shale of Pennsylvanian age.

TABLE 2.—*Estimates of mineral composition (in parts of ten) of red, green, and yellow ocherous shale in the Lee formation below the Olive Hill clay bed, of Crider, 1913, Haldeman quadrangle*

Sample	Illite	Kaolinite	Mixed layered clays[1]	Quartz
1	½	2–3	2–3	3–4
2	1	3	3	2–3
3	4	4	1	½
4	3	2–3	2	2
5	3–4	1	2	3–4
6	1–2	4–5	1–2	3
7	1	7	1	½

[1] Chiefly mixed layered illite-chlorite and vermiculite.

NOTE.—Source of Samples:
1. Weathered red and yellow ocherous shale below Olive Hill clay bed, exposed in tributary to Patties Lick Branch, lat 38°11′20″ N.; long 83°20′57″ W.
2. Green ocherous shale below Olive Hill clay bed, exposed along access road to strip mine lat 38°11′43″ N.; long 83°19′25″ W.
3. Yellow ocherous shale, same as No. 2.
4. Red ocherous shale below Olive Hill clay bed, exposed along access road to strip mine, lat 38°11′38″ N.; long 83°19′5″ W.
5. Green ocherous shale same as No. 4.
6. Red ocherous shale below Olive Hill clay bed, exposed in strip mine 900 feet northeast of road junction 961, Open Fork valley.
7. Pinkish-red ocherous clayey shale below Olive Hill clay bed, exposed in trail out of Greenbriar Branch valley lat 38°12′45″ N.; long 83°16′10″ W.

The second subunit, consisting of the Olive Hill clay bed and the thin coal bed which overlies it is discussed on pages F48–F79.

The third subunit, which overlies the thin coal above the Olive Hill clay bed, is an exceedingly varied unit (fig. 4), 20 to 40 feet thick, composed of discontinuous beds and interfingering lenses of dark-gray shale, siltstone, clayey sandstone, quartzose sandstone, thin coal beds and plastic underclays. The beds in this subunit commonly wedge in and out or grade from one lithologic type to another within a few yards, as, for example, from clay into clayey sandstone (fig. 4, e–e_2). In most places, the coal above the Olive Hill clay bed is overlain by a silty plastic clay (pl. 6), over which is another thin coal. In other places, the coal above the Olive Hill bed is overlain by dark-gray shale, and at one locality, in Open Fork valley in the Haldeman quadrangle, a zone in this shale, which is about 1½ feet above the clay, contained specimens of the genus *Lingula*. Dark-gray shale, thin underclay, and coal beds also occur higher in the subunit (pl. 4, secs. 3–4, 8), and at a few localities lenses of red and green vari-colored shale are present in the upper part of the subunit. Many of the sandstone beds occupy basin-shaped depressions in underlying strata (fig. 4, *g*), and at a few places lenses of sandstone cut sharply through

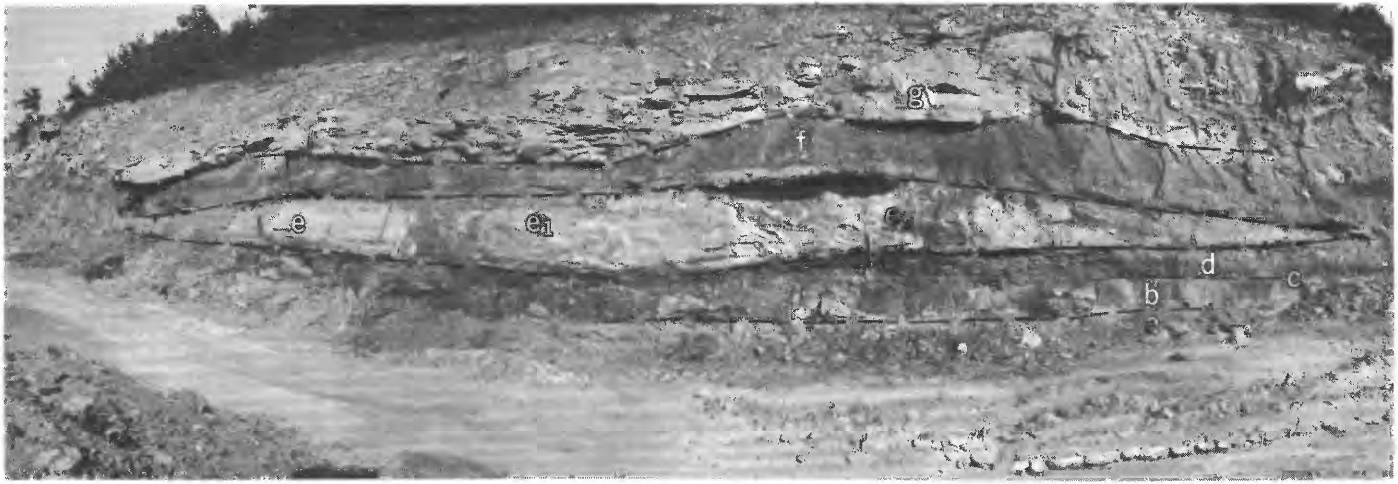


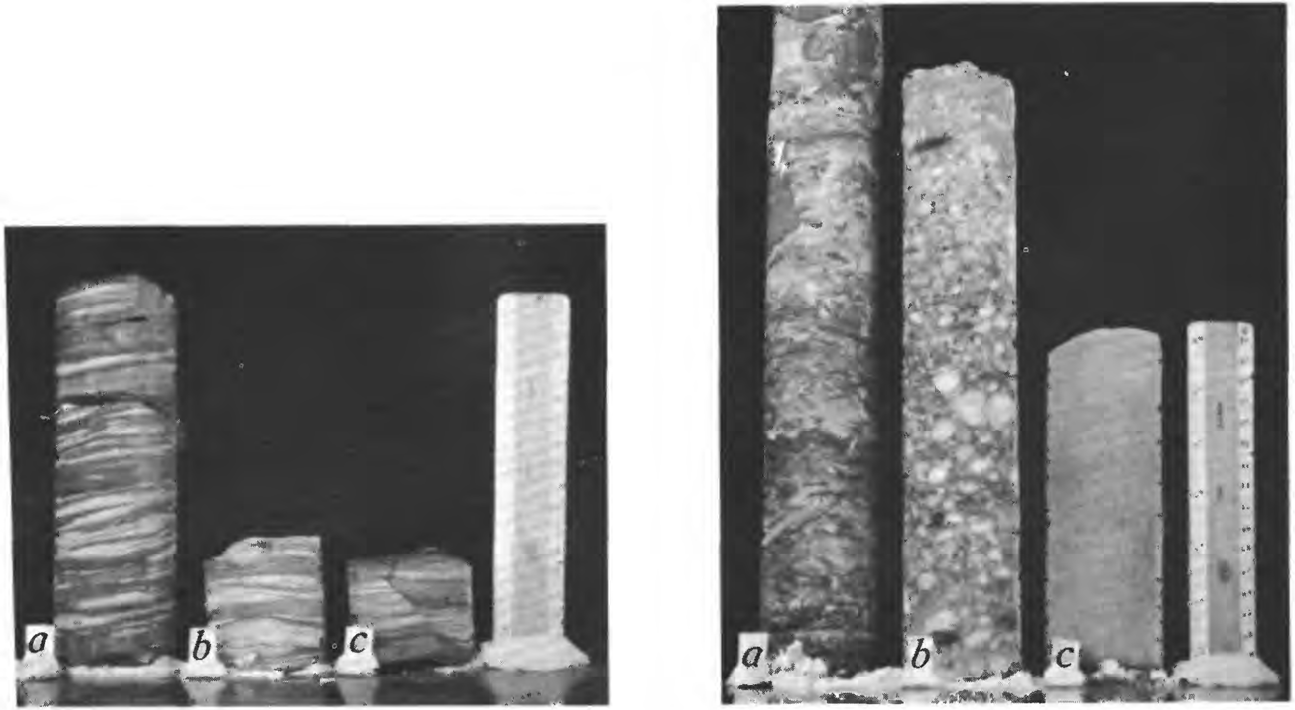
FIGURE 4.—Lower beds of the Lee formation in high wall of strip mine of Olive Hill clay bed of Crider, 1913, on the east side of the Open Fork valley, Haldeman quadrangle.

a, Semiflint clay, 1 to 2 feet thick.
b, Flint clay with thin carbon-rich pebble zone at top, 2 to 3 feet thick.
c, Coal, 5 to 9 inches thick.
d, Dark-gray shale lens, maximum thickness of about 1½ feet.
e, Clay, gray, plastic, 2½ to 5 feet thick; grades laterally into very sandy clay at e_1, and into clayey quartzose sandstone at e_2.
f, Shale, dark gray, 1 to 3 feet thick; contains at base a thin lens of sandy oolitic siderite.
g, Sandstone, quartzose, brownish-gray, medium-grained, 1 to 6 feet thick.

lower strata including the Olive Hill clay bed. Siderite concretions are common in this subunit and thin beds of oolitic siderite are present at a few localities. Except for carbonaceous films of *Stigmaria* rootlets in the underclays, fossils are rare in this subunit.

The rocks in the third subunit, notwithstanding their extreme variety, contain a few zones and general characteristics that extend throughout most of the area. In most places, the rock in the lower 10 to 15 feet of the subunit is dominantly clay, shale, and siltstone; sandstone beds are more abundant in the upper part. Perhaps the most persistent zone is a coal and underclay unit that rests on the coal above the Olive Hill clay or is separated from it by a thin wedge of shale or siltstone (fig. 4, bed *e*). The underclay is as much as 8 feet thick. Its composition is extremely varied, but it is mostly a brown plastic clay that consists of a mixture of illite and kaolinite with differents amounts of clastic quartz. This coal bed contains, at a few places, lacey carbonaceous residue films of the cortex of a plant. Specimens of this fossil—from the high wall above the Licking River limestone quarry, about 2 miles beyond the southwest corner of the Wrigley quadrangle—have been identified by Sergius H. Mamay of the U.S. Geological Survey as *Dictyoxylon*. This fossil, according to Mr. Mamay (written communication, Oct. 9, 1956) is regarded as indicative of Lower Pennsylvanian rocks, and it is not known to occur in any Mississippian beds.

The fourth subunit is composed chiefly of dark-gray shale that is typical of the shale facies, but it also contains a few thin quartzose sandstone beds, zones of interlaminated light-gray sandstone and dark-gray shale, and thin beds of coal, in association with underclays as much as 2 feet thick (pl. 4, sec. 4). Most of the interlaminated shale and sandstone is rippled bedded (fig. 5*A*, *a*, *b*, and *c*), but in some of these rocks the bedding is involute and highly distorted (fig. 5*B*, *a; A*), showing evidence of mudflow deposition. Trashy films of plant remains and impressions of *Lepidodendron* trunks are common on some bedding surfaces in the shale. A few specimens of a small species of *Lingula* were found in the shale in a face of a strip mine in the Open Fork valley, Haldeman quadrangle, but marine or brackish water fossils were not observed at any other locality. The shale consists chiefly of kaolinite, illite, and very fine grained quartz, but some mixed-layer clay minerals (chiefly illite and montmorillonite) are also present. Small muscovite flakes, oriented with their long dimensions nearly parallel with bedding planes, appear to be abundant because the shale splits along these planes. However, this mineral makes up an insignificant part of the bulk composition.



A *B*

FIGURE 5.—Drill core of Lee formation from holes on ridge extending along county boundary north of Route 173, near northeast corner of Wrigley quadrangle. (*A*.) *a*, *b*, and *c*, ripple-bedded interlaminated dark-gray shale and light-gray sandstone from shale facies. (*B*.) *a*, contorted bedded sandstone and shale from shale facies; *b*, conglomerate from lower one-third of cliff-forming sandstone facies; *c*, typical medium-grained sandstone of cliff-forming sandstone facies.

The fifth subunit is chiefly sandy shale interbedded with sandstone; it also contains three thin coal beds and their associated underclays. The coal beds are less than 12 inches in thickness, and the clays below them are also thin. The coal that overlies the top of the zone has been selected as the contact between the shale facies and the overlying Breathitt formation, as explained on page F27. The sandstone is chiefly in massive crossbedded lenses and discontinous beds. Some of the beds are tonguelike extensions of the cliff-forming sandstone facies; others, particularly in the area north of the Christy Creek Valley, were probably continuous with the sandstone facies before they were cut off during the formation of the present land surface. Some of these disconnected sandstone masses extend for 1 mile or more horizontally and are locally as much as 40 feet thick.

CLIFF-FORMING SANDSTONE FACIES

The cliff-forming facies is chiefly massive crossbedded quartzose sandstone that contains a few beds and lenses of dark-gray shale and quartz conglomerate. The facies, where present, generally range in thickness from 40 to 200 feet. It is thinnest in the central part of the Haldeman quadrangle where it grades into the shale facies, and it thickens in a southerly direction. Dark-gray carbonaceous shale lenses and tongues are common in the belt of gradation into the shale facies (pl. 4, section 9), and scattered large shale lenses are also present as far south as the southern part of the Wrigley quadrangle (pl. 5, section 9), where the sandstone facies is otherwise thick and persistent. Fresh rock from drill holes in the massive sandstone is loosely compacted and poorly cemented, but some case hardening is present in outcrops. Iron oxides are the chief cementing materials, but locally silica cement is present and the rock has sufficient strength to cause breakage across quartz grains. Most of the sandstone is brown or reddish brown in both weathered exposures and in the drill cores, and the color appears to result from the ferriferous cementing materials. The massive sandstone consists of crossbedded deltaic units stacked one above the other. The units range from 1 to 5 feet in thickness and contain both inclined or foreset beds and horizontal or topset and bottomset beds. The direction of inclination of prominent sets of crossbeds ranges from S. 20° W. to N. 30° W. at 2 dozen scattered localities in the Haldeman and Wrigley quadrangles where readings were recorded. The average direction of inclination is N. 87° W. and the angle of inclination ranges from 12° to 22°. Less prominent and local crossbeds are inclined in all directions, particularly where deltaic strata are cut by channel-fill deposits.

The rocks of the sandstone facies vary widely in grain size and degree of sorting. Two-thirds of the sandstone is composed of medium and fine grains in approximately equal proportions (table 3); about one-fourth of it is very fine sand, silt, and clay particles; and the remainder of the rock consists of very coarse sand, granules, pebbles, and cobbles. On outcrop surfaces of much of the unit, strings of milky quartz pebbles are scattered along bedding and crossbedding planes in fine- to medium-grained sandstone. Quartz pebbles and cobbles also form local beds and lenses of true conglomerate (fig. 5*B*, b; table 3, sample 20). Conglomerate beds in the sandstone facies are much more common in the Wrigley quadrangle than in the Haldeman quadrangle, indicating that the unit is coarser grained southward. Conglomerates are also most common in the lower part of the facies, and, in general, the sandstone tends to decrease in grain size from the base upward. Many of the conglomerate beds are crescent shaped and are no more than 25 feet wide and 8 feet thick where cross sections are exposed in cliff facies. Their shapes, together with prominent crossbedding, suggests that they are channel-fill deposits. Conglomerate beds are extremely porous and frequently cause loss of water circulation when penetrated during drilling.

All but 1 of the 22 samples of the sandstone facies (table 3) examined in the laboratory were quartz sandstone in which feldspar contents ranged from 0 to 5 percent, clay (less than 2-micron fraction) from 1 to 6 percent, and heavy minerals no more than 0.2 percent. One sample (table 3, sample 3) was distinctly arkosic and its sand fraction consisted of only 65 percent quartz, 34 percent feldspar, and 0.3 percent heavy minerals. None of the samples contained more than traces of rock fragments, and chert grains were rare. Nearly all of the quartz grains were subrounded to rounded (fig. 3*C*), and most of them were frosted. Most of the feldspar grains were also rounded and partially altered to clay minerals. Clusters of grains cemented by iron oxides were common in nearly all the samples, but no correlation between the amount or condition of the iron oxides and the brown and gray colors was observed.

The heavy minerals in the sandstones are tourmaline, muscovite, zircon, rutile, ilmenite, pyrite, and siderite in order of abundance and persistence (table 3). All these minerals are probably detrital, except pyrite and siderite. Many tourmaline and zircon grains show good crystal form, but the edges are rounded and sometimes the surfaces are frosted. Some rutile shows crystal forms, but most is in well-rounded lumps. Ilmenite occurs as very well rounded grains commonly altered to leucoxene on the surface. The muscovite is present as irregular flakes of all sizes; many flakes have rounded

TABLE 3.—*Particle size and mineral composition of sandstone beds in the Lee formation*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Particle size distribution, Wentworth (1922) scale, in percent																						
Cobble																				15		
Pebble																				27		
Granule	Tr.										4									14	1	
Sand:																						
Very coarse	Tr.									2	12									2	4	
Coarse	2	2					5	12	4	25	34			5	5	1			1	9	13	1
Medium	40	48	14	2	16	17	56	38	56	41	30	16	53	49	41	33	33	9	41	12	31	25
Fine	29	26	43	61	53	52	15	21	19	13	8	47	24	14	14	26	39	65	32	10	27	55
Very fine	8	8	14	15	10	10	7	7	6	5	3	18	5	7	7	12	9	11	7	4	9	9
Silt	15	12	17	14	14	16	13	18	12	12	5	14	13	18	26	24	15	12	13	6	11	5
Clay (<4 microns)	6	4	12	8	7	6	4	4	3	2	4	5	4	6	8	4	4	4	5	2	4	5
Total	100+	100	100	100	100	101	100	100	100	100	100	100	99	99	101	100	100	101	99	101	100	100
Composition of sand fraction, in percent																						
Quartz	100−	99.9	65+	98.8	94.8	99.9	99−	98−	99.9	100−	96−	100−	100−	97−	100	99.9	98.9	100−	100−	100−	99.9−	99−
Feldspar			34	1.0	5		1	2	Tr.		4			3			1		Tr.		Tr.	1
Heavy minerals	Tr.	.1	.3	.2	.2	.1	Tr.	Tr.	.1	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	.1	.1	Tr.	Tr.	Tr.	.1	Tr.
Percentage of rock <2 microns																						
	4	2	5	6	5	4	3	3	2	1	2	3	3	5	6	3	3	3	3	1	3	3
Composition of clay (<2 microns) fraction, in parts of 10																						
Illite	2–3	3–4	4–5	4–5	4–5	4–5	3	2–3	3–4	2–3	1–2	3–4	2	1–2	2–3	2	2–3	2–3	3–4	2–3	3–4	2–2½
Kaolinite	3–4	3–4	4–5	4–5	5	5	5–6	5	4–5	4	4	3–4	4–5	3–4	3	4	4	5	4	4–5	3–4	4
Chlorite	Tr.	Tr.	1	½	Tr.	Tr.	Tr.										Tr.	Tr.	Tr.	Tr.	Tr.	1½
Mixed-layer clay	1	1–2	Tr.	½	½	1	½–1	Tr.	1	1	2–3	1–2	1–2	2	1–2	1–2	2	½	1–2	1	1–2	½

Composition of heavy-mineral fraction

[A, abundant (50–100 percent); C, common (11–48 percent); P, present (1–10 percent); Tr., trace (<1 percent)]

Tourmaline	Tr.	C	Tr.	C	C	C	C	C	C	A	Tr.	A	C	A	C	C	C	A	C	A	C	C
Muscovite	C	C	A	C	A	C	C	C	C	C	A	------	C	------	C	P	------	C	------	Tr.	A	A
Zircon	Tr.	C	------	C	C	------	------	P	C	------	------	C	------	------	P	C	P	C	P	------	------	------
Rutile	------	C	------	P	P	------	C	P	------	------	------	C	P	------	C	C	C	------	P	------	Tr.	Tr.
Ilmenite	A	C	------	------	------	C	------	------	Tr.	P	------	------	------	------	------	P	A	------	A	------	------	C
Pyrite	------	------	Tr.	------	------	------	------	------	Tr.	------	C	------	------	------	C	------	------	------	------	------	------	------
Siderite	------	------	------	------	------	------	------	------	P	------	------	------	------	------	------	------	------	------	P	------	------	------

NOTE.—Source of samples:

1. Composite of surface samples of the sandstone facies of the Lee formation from section 57 feet thick exposed along road extending up steep hill at head of tributary to Dry Creek (pl. 4, section 11), Haldeman quadrangle (chemical analyses are given in table 8).
2. Composite of drill core samples of brown sandstone 114 feet thick forming the upper part of the sandstone facies of the Lee formation. Hole located on ridge between Laurel Fork and Laurel Creek (lat 38°09′18″ N.; long 83°16′23″ W.) Haldeman quadrangle.
3. Drill core sample near middle of gray sandstone 24 feet thick in the lower part of the sandstone facies of the Lee formation. Same hole as 2.
4. Drill core sample of sandstone facies of Lee formation, 11 feet below top of formation. Hole located near barn 500 feet west northwest of stream fork in Brown fork near northeast corner of Wrigley quadrangle.
5. Same as 4 except 21 feet below top of formation.
6. Same as 4 except 31 feet below top of formation.
7. Same as 4 except 41 feet below top of formation.
8. Same as 4 except 51 feet below top of formation.
9. Same as 4 except 61 feet below top of formation.
10. Same as 4 except 71 feet below top of formation.
11. Same as 4 except 75–76 feet below top of formation.
12. Same as 4 except 81 feet below top of formation.
13. Outcrop sample of brown sandstone 12 feet below the top of the sandstone facies of the Lee formation, exposed in trail 300 feet east of 4.
14. Same as 13 except 16 feet below top of formation.
15. Same as 13 except 21 feet below top of formation.
16. Same as 13 except 33 feet below top of formation.
17. Same as 13 except 41 feet below top of formation.
18. Drill core from brown sandstone 5 feet below the top of the sandstone facies of the Lee formation. Hole located 1000 feet south of 4.
19. Same as 17 except 77 feet below top of formation.
20. Same as 17 except sample is from gray conglomerate 131 feet below top of formation.
21. Composite of drill-core samples of sandstone facies of Lee formation, 89 feet thick. Hole located near road south of Elm Log Branch approximately 150 feet east of the western boundary of the Wrigley quadrangle (lat 38°01′26″N.; long 83°22′29″ W.).
22. Composite of drill-core samples of sandstone facies of the Lee formation, 117 feet thick. Hole located about 300 feet west of 20 (approximately 150 feet beyond the western boundary of the Wrigley quadrangle.)

edges and most of them have been bent by compression around sand grains. The clay minerals—kaolinite, illite, mixed layer, and chlorite (table 3)—are present in the sandstone facies in minor quantities. Kaolinite and illite occur in roughly equal amounts, and together they make up almost all of the clay fraction. A highly illitic variety of mixed-layer clay occurs in slightly more than traces; chlorite is less common than mixed layer.

CONDITIONS OF DEPOSITION OF THE LEE FORMATION

Sedimentary features of the Lee formation indicate that deposition took place in a coastal lowland characterized by periodic advances and withdrawals of shallow brackish or marine water. Well-developed crossbedding in the sandstone facies suggests deposition in large coalescing deltas. The crossbeds are inclined principally to the west in eastern Kentucky, indicating that the sand was introduced from the east. This conclusion, in general, conforms with those of students of Early Pennsylvanian sediment transport (Potter and Siever, 1956; Siever and Potter, 1956; Fuller, 1955; and Wilson and Stearns, 1957). The shale facies of the Lee formation seems to have been formed chiefly by the deposition of clay minerals and fine-grained sediments carried beyond the zones of deltaic sand accumulation. Much of these sediments was deposited in the outer peripheral areas of large deltas, in areas of quiet shallow water, possibly lagoons, and in large coastal swamps that were located between the large deltas. This speculation on the origin of the Lee formation is supported by the following observations: (1) the northward and westward decrease in grain size of the sandstone facies, and the gradation of the sandstone into the shale facies; (2) interfingering of tongues of sandstone and shale in the zone of gradation between the two facies; (3) occurrence of distorted (fig. 5*B*, *a*) and ripple-bedded interlayered (fig. 5*A*, *a–c*) sandstone and shale in parts of the shale facies; (4) evidence that the Olive Hill clay bed formed in swamps, presented by Patterson and Hosterman (1960, pp. 191–193) and summarized on pages F79–F81; (5) the likelihood that local channel and fill deposits in the shale facies were formed by shifting distributaries; (6) periodic submergence and emergence of the area, indicated by the interbedding of continental deposits with marine or brackish-water deposits. Thin coal beds and abundant plant remains, including root fossils, provide the evidence of continental environment; and sparse faunas, chiefly small *Lingŭla*, indicate marine or brackish water conditions of deposition.

The purity and roundness of the quartz grains and low content of heavy minerals in the sandstone of the Lee formation suggest that the source of the sand was a considerable distance away, and that perhaps it came from the erosion of older sediments. The presence of one bed of arkose in the sandstone at one locality is anomalous to all other evidence pertaining to the origin of the formation. However, this arkose occurs near the base of the sandstone facies at a point about 2 miles from where the sandstone grades into the shale facies. The arkose may represent sediment from a much smaller and closer source than that which provided most of the sand in the Lee formation.

BREATHITT FORMATION

The Breathitt formation includes all Pennsylvanian rocks in the Haldeman and Wrigley quadrangles above the Lee formation. The name Breathitt was introduced by Campbell (1893, p. 3), who failed to designate an upper boundary of the formation. According to a recent interpretation by Englund (1955, p. 5), who refers to previous regional correlations by Wanless (1939, p. 78; 1946, p. 10), the formation is presumed to include the youngest Pennsylvanian rocks in Breathitt County, which are considerably higher stratigraphically than the youngest rocks exposed in the area herein discussed. The Breathitt formation consists of shales, siltstones, sandstones, thin beds of coal and underclay, and a zone of dark-gray limestone and calcareous shale. The rocks of the Breathitt are for the most part soft and nonresistant, and inasmuch as they are truncated by the present land surface they support rolling uplands. Only about 50 feet of the lower beds in the formation are present in the northern third of the Haldeman quadrangle. The preserved section thickens progressively to the south and east, as the base of the formation descends in conformance with the gentle regional dip, and Breathitt strata are about 320 feet thick south and east of the village of Wrigley. Most of the rocks seem to represent deposition in a continental environment, but marine fossils are present in restricted zones.

TRANSITION BEDS

In most places, where the cliff-forming sandstone facies of the Lee is present, the lower 5 to 30 feet of the Breathitt formation consists of beds that are transitional between the two formations. The rocks in this transitional unit are interbedded quartz sandstones and sandy shales of varied thickness and distribution; the beds contain a thin discontinuous coal bed, the Zachariah (?) (p. F96), and a sandy underclay bed. Crossbedding is common in the sandstones of the transition zone, which tend to be very quartzose and low in feldspar, and similar to those of the cliff-forming sandstone facies of the Lee formation, whereas sandstone higher in the Breathitt for the most part contains abundant clay minerals, feldspar, and mica. Transition beds are not present where the cliff-forming sandstone facies of the Lee is missing, and the lower rocks of the Breathitt are similar to both the shale facies of the Lee formation and the rocks above the transition beds described under the following heading. Difficulties in recognition of the contact between the two formations where the cliff-forming sandstone facies of the Lee is missing are discussed on pages F27–F28.

STRATA BETWEEN TRANSITION BEDS AND MAGOFFIN BEDS OF MORSE (1931)

The rocks above the transition beds and below Morse's Magoffin beds are characterized by discontinuous beds and lateral gradations, but they contain a few persistent coal beds and a concretion zone. These rocks are about 275 feet thick in the southeastern part of the Wrigley quadrangle, where the section is most complete; they thin northwestward by truncation of the present land surface. The rocks in this sequence consist mainly of shale, siltstone, and sandstone but include subordinate amounts of coal and underclay. Individual beds vary greatly in thickness and lithologic composition within short distances, hence it is difficult to trace most of them from one outcrop to another. A few zones, however, are persistent and can be recognized throughout much of the area.

The lowermost persistent zone in the Breathitt formation is the Howard coal bed (pl. 5, sections 3, 7, 8, 11), 40 to 65 feet above the base of the formation. This coal bed has been recognized by Huddle throughout much of the West Liberty quadrangle, which joins the Wrigley quadrangle on the south. The Howard coal bed is exposed in many road cuts and small openings where coal has been secured for local consumption. The bed is 14 inches or more in thickness near Blairs Mills and north of Blaze (pl. 5, sections 3 and 8), but in most outcrops it is less than 6 inches thick. The underclay below the bed is thinner than the coal in most outcrops and it consists of the clay minerals kaolinite and illite, mixed-layered clay, and considerable amounts of quartz. This clay is not of sufficient thickness in the Haldeman or Wrigley quadrangles to be of economic value.

The persistent second zone is a resistant bed of platy canneloid shale and coal that ranges from 2 to 24 inches in thickness (48 inches have been reported) and in places contains a thin parting of plastic clay. This zone is believed to correlate with the Grassy coal (pl. 5, sections 3, 4, 7–12) described by Englund (1955, p. 7) from an area a few miles south of the Wrigley quadrangle. It is 105 to 120 feet above the base of the Breathitt. Most exposures of this bed are found in road cuts, but some natural exposures are located in the beds of small streams. Further information on this coal is given on pages F98–F102.

The third persistent zone consists of widely spaced, dark bluish-gray, unfossiliferous, calcareous, irregularly ovoid sandstone concretions (pl. 4, sections 8–10, 15, pl. 5, sections 4 and 8) as large as 3 by 10 feet. This zone, shown on plates 2 and 3, is located stratigraphically 75 to 100 feet below the Magoffin beds. The concretions crop out at or near the crests of high hills in the east central and southeastern parts of the Haldeman quadrangle and in the northeastern part of the Wrigley quadrangle.

The fourth persistent zone, the Fire Clay coal (pl. 5, sections 11 and 12) was recognized in only a few localities in the southeastern part of the Wrigley quadrangle. This coal was regarded by Wanless (1939, p. 55) as an important bed in regional correlations, and Robinson and Hudnall (1925) used it as their key bed in making a structure contour map of Morgan County. The Fire Clay coal is 28 to 38 feet below the Magoffin beds of Morse. This bed was mined at a point about a quarter of a mile south of State Route 7 and a few yards east of the Wrigley quadrangle boundary. The mine is now inaccessible, but the coal is reported to have exceeded 2 feet in thickness. The dump of this mine is littered with fragments of flint clay. This flint clay was probably from a parting in the Fire Clay coal bed, which is known to contain a flint clay parting at several localities a few miles south of the Wrigley quadrangle (Englund, 1955, pl. 3). A thickness of 2 to 3 inches for the flint clay in this inaccessible mine is indicated by lumps on the dump that have coaly layers on two sides; this thickness is about the same as that described by Englund.

The rock units enclosing the zones described above are similar and difficult to distinguish. They contain several thin coal and underclay beds, some of which can be correlated with thicker coal beds in the quadrangles to the south. Two of the coal beds have been correlated with the Tom Cooper and the Gun Creek (p. F102–F103). Nearly all underclays and some of the sandstones and siltstones subjacent to coal contain *Stigmaria;* many of the sandstones contain scattered and poorly preserved remains of *Lepidodendron;* and many of the bedding planes in the shales and siltstones are littered with a trashy film of carbonized plant fragments. Zones containing marine fossils are rare.

The rocks below the Howard bed, in most outcrops, are chiefly dark-gray shale interbedded with siltstone and fine- to medium-grained shaly sandstone, but at some places sandstone is more abundant than either the shale or siltstone. The sandstone in this zone is dark to medium gray where fresh and weathers rusty brown. Many of the sandstone beds are crossbedded, and ripple-bedding is common in the finer sediments, particularly where shale and siltstone are interlaminated. Beds tend to be discontinuous or to lens in and out, and lateral gradation from sandstone to shale is common. Rocks in the zone between the Howard coal bed and the Grassy coal are similar to those below the Howard coal bed; however, in all outcrops, shale is much more abundant than sandstone. Irregularly shaped ironstone (siderite) concretions are scattered sparsely throughout much of the shale. Fossil plant leaves occur in the silty beds 2 to 5 feet above Howard coal in outcrops in the village of Wrigley (pl. 5, section 11) and in a few other places, at approximately this stratigraphic position.

The unit between the Grassy coal bed and the calcareous concretion zones in the Haldeman quadrangle consists roughly of two-thirds dark-gray, brown-weathering shale and one-third loosely compacted sandstone and siltstone. The unit becomes more sandy to the south, and in the southern part of the Wrigley quadrangle the amount of sandstone and siltstone is about equal to the amount of shale. In this vicinity, some of the sandstone is sufficiently cemented to form small cliffs and prominent ledges in hillsides. Beds overlying the Grassy coal in the section along Route 7 south of Wrigley (pl. 5, section 11) contain *Lingula* and several other small brachiopods. A sandstone bed 14 feet above the coal in the section southwest of Blaze (pl. 5, section 7) is heavily cemented with hematite and contains several species of brachiopods. Calcareous sandstone concretions at the horizon of these fossils, between the Grassy and the Tom Cooper coal beds, are common in the West Liberty and Cannel City quadrangles.

The beds between the calcareous sandstone concretion zone and the Magoffin beds are about two-thirds sandstone and one-third dark-gray and brown shale, and these beds contain the Fire Clay coal and a thin coal questionably correlated with the Hamlin bed (p. F105). Sandstone in this unit caps the high hills along Routes 32 and 173 in the east-central and southeastern parts of the Haldeman quadrangle. It also is exposed in road cuts along Route 7 south of Wrigley (pl. 5, section 11), where it is 44 feet thick. The sandstone consists dominantly of loosely compacted, subrounded, fine- to medium-grained quartz. Flakes of muscovite make up 1 to 2 percent of the rock and are typically alined along normal and crossbedding planes. Small particles of light colored clay, which probably formed from altered feldspar grains, make up as much as 5 to 10 percent of the rock. Clay and shale are also more abundant in certain lenses and beds in the sandstone than in others. In places, the contact between the sandstone beds and subjacent strata is an undulating surface that suggests erosion prior to deposition of the sand. Locally, thick sandstone beds of this type occupy the stratigraphic interval of coal beds or the concretion zone, which are otherwise persistent.

MAGOFFIN BEDS OF MORSE (1931)

The name Magoffin was proposed by Morse (1931, 301–303) for thin fossiliferous limestone and shale strata that crop out in Magoffin County, Ky. Beds that are believed to represent this same unit crop out on many hillsides in the southeastern part of the Wrigley quadrangle (pl. 2). Most outcrops of the Magoffin beds form small shoulders in hillsides, and are littered with weathered fragments of dark-gray limestone, some of which weather bluish gray; but in a few outcrops, the beds are represented only by a unit of fossiliferous shale a few feet thick. The best exposure of the beds, in the area mapped, is in a road cut along Route 7, about two-tenths of a mile north of the southern edge of the Wrigley quadrangle. At this point the aggregate thickness of the Magoffin beds is 9 feet 7 inches. An excellent section (fig. 6) is also exposed along Route 173, three-quarters of a mile east

FIGURE 6.—Magoffin beds of Morse, 1931, exposed in road cut along Route 173 three-quarters of a mile east of Wrigley quadrangle. *a*, limestone 12 to 18 inches thick; *b*, dark-gray very calcareous shale 6 feet 2 inches thick with limestone bed; *c*, limestone 14 inches thick; *d*, limestone concretion, 20 inches by 4 feet; *e*, brown noncalcareous shaly siltstone 2 to 3 inches thick; and *f*, dark-gray shaly limestone 8 feet thick.

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of the Wrigley quadrangle. Faunal lists of the fossils in the Magoffin beds are given by Morse (1931, p. 302) who recognized 9 species of brachiopods, 3 of pelecypods, 1 of gastropods, and an unidentified crinoid.

The following section of the Magoffin beds of Morse (1931) was measured in a cutbank along Route 7, approximately two-tenths of a mile north of the southern boundary of the Wrigley quadrangle.

	Feet	*Inches*
1. Shale, brownish-gray, weathered	--	--
2. Limestone, very dark gray, argillaceous, and silty; contain scattered fossils; weathers platy (top of Magoffin beds)	2	--
3. Limestone, very dark gray, dense, argillaceous; contains abundant crinoids and brachiopods; weathers blocky	1	6
4. Limestone, very dark gray, argillaceous and silty, fossiliferous; weathers platy	2	4
5. Limestone, very dark gray, dense, argillaceous; contains crinoids and brachiopods; weathers blocky	--	9
6. Shale, dark-gray, lower one-third brownish-gray, soft, calcareous, fossiliferous; at base a zone of widely spaced dark-gray fossiliferous limestone concretion approximately 6 inches thick (base of Magoffin beds)	3	--
7. Shale, very dark gray, micaceous, soft, noncalcareous except in upper few inches	4	6
8. Coal, interlaminated with soft dark-gray shale	--	4
9. Shale, dark gray, soft	1	--
Cover.		

STRATA ABOVE THE MAGOFFIN BEDS OF MORSE (1931)

The Breathitt formation above Morse's Magoffin beds is limited in distribution and it consists of sandstone, siltstone, and shale. It also contains a few coal beds and calcareous sandstone concretions. These rocks are restricted to the structurally low area in the southeastern part of the Wrigley quadrangle, where a thick section of the Breathitt formation has been preserved. The maximum thickness of these rocks is about 125 feet. The most persistent bed in this unit is a massive, fine- to medium-grained, crossbedded sandstone that occupies broad channels. This sandstone bed is more than 50 feet thick in the section along Route 7 south of Wrigley (pl. 5, section 11) and probably is still thicker in high wooded hills west of the highway, where it appears to cut out the underlying Magoffin beds. Very irregular calcareous concretions are present in the upper part of the sandstone in the section along Route 7 and at several other localities. These concretions are as much as 10 feet thick and 12 to 15 feet in widest dimension. Whether or not the concretions all occur at the same stratigraphic position is not known. Presumably they were formed by calcite cement precipitated from ground water; the normal cross-bedding of the sandstone is preserved in them. The most prominent coal in the rocks above the Magoffin beds are correlated by Huddle with the Nickell coal of the West Liberty and Cannel City quadrangles (p. F106). This coal bed is exposed in a road cut along Route 7 at the top of the hill south of Wrigley (pl. 5, section 11) and south of Route 7 near the east edge of the Wrigley quadrangle (pl. 5, section 12). The clay below the coal at the top of the hill south of Wrigley is 1½ feet thick. Mineral composition and certain ceramic properties of this clay are discussed on pages F84–F87. Three other coal beds, correlated with the Haddix, Index, and Nickell beds by Huddle (p. F107), are present in outcrops near Route 7 south of Wrigley. In the Wrigley quadrangle, these coals are too thin to be of value and they are of little value as stratigraphic marker zones because of their limited extent.

PETROLOGY OF SANDSTONE BEDS IN THE BREATHITT FORMATION

Some of the sandstone beds in the Breathitt formation are very quartzose, others contain appreciable amounts of feldspar, and virtually all grains are medium sand or finer according to the Wentworth (1922) scale. The quartz content of the sand fraction (0.5 to 0.060 mm diameter) of eight samples examined in the laboratory (table 4) ranges from 73 to 99 percent, and feldspar from a trace to 26 percent. Most quartz grains were well rounded and frosted, and many of them were coated with iron oxide. Feldspar grains ranged from slightly altered, angular cleavage fragments to very thoroughly altered, rounded grains. The freshest and most abundant feldspar was from the two highest beds of the Breathitt sampled (table 4, samples 1, 2); whereas core samples from lower beds of the Breathitt contained less feldspar and it was more altered.

The heavy minerals of the sand fraction ranged from 0.1 to 1.7 percent of the eight samples examined in the laboratory. The heavy minerals present were: muscovite, tourmaline, zircon, rutile, ilmenite, siderite, and chlorite. Muscovite is by far the most abundant of these minerals. More than 50 percent of the heavy minerals was muscovite in the two samples from beds that were stratigraphically highest (table 4, samples 1, 2), and the proportions of this mineral present tends to decrease in lower beds. Muscovite occurs as rounded flakes and most of them are bent, due to compression around sand grains. Tourmaline was present in all 8 samples, zircon and rutile in 5 samples each, ilmenite and chlorite in 4 samples each. None of these minerals were distributed according to any regular stratigraphic pattern. Small amounts of siderite were present in the form of spheroidal aggregates in two samples (table 4, samples 2, 8). Presumably this mineral formed in place.

TABLE 4.—*Particle size and mineral composition of sandstone beds in the Breathitt formation*

	1	2	3	4	5	6	7	8
Particle-size distribution, Wentworth (1922) scale, in percent								
Sand:								
Coarse	Tr.	------	------	------	------	------	------	------
Medium	40	19	1	1	23	4	1	28
Fine	26	43	47	37	43	48	37	43
Very fine	9	10	20	25	10	19	44	7
Silt	19	20	24	26	18	21	15	14
Clay (<4-micron)	7	8	8	10	6	8	3	8
Total	101	100	100	99	100	100	100	100
Composition of sand fraction, in percent								
Quartz	84+	73	93+	90+	99+	94+	96+	94+
Feldspar	15	26	5	8	Tr.	5	3	5
Heavy minerals	.3	1.0	1.7	1.5	.1	.07	.2	.2
Percentage of rock <2 microns								
	4	5	5	7	4	5	2	6
Clay mineral composition of <2-micron fraction, in parts of 10								
Illite	4	3	3–4	4–5	4	4–5	2–3	2–3
Kaolinite	4	6	3–4	4–5	3–4	4–5	4	4
Chlorite	1	1	Tr.	1–2	1	½	1	1
Mixed-layer clay	Tr.	Tr.	1	Tr.	½	Tr.	Tr.	Tr.
Composition of heavy mineral fraction [A, abundant (50–100 percent); C, common (11–49 percent); P, present (1–10 percent); Tr., trace (<1 percent)]								
Tourmaline	C	P	Tr.	Tr.	C	C	Tr.	C
Muscovite	A	A	A	A	C	C	A	C
Zircon	P	P	------	------	P	P	------	C
Rutile	C	Tr.	Tr.	Tr.	------	------	------	P
Ilmenite	P	------	------	------	A	A	------	C
Siderite	------	P	------	------	------	------	------	P
Chlorite	------	C	C	C	------	------	------	C

NOTE.—Source of samples:

1. Surface sample from brownish-gray weathered sandstone enclosing calcareous concretion between Magoffin beds of Morse, 1931 and Nickell coal bed, exposed in road cut along Route 7, 1.1 miles south of Wrigley (pl. 5, section 11), Wrigley quadrangle.
2. Surface sample from basal beds of thick brownish-gray weathered sandstone unit above Gun Creek coal bed exposed in road cut along Route 7, three-quarters of a mile south of Wrigley (pl. 5, section 11), Wrigley quadragle.
3. Drill core sample from near middle of massive gray sandstone bed 32 feet thick, at a point 53 feet above the base of the Breathitt formation. Drill hole located near road south of Elm Log Branch, about 150 feet east of the west boundary of the Wrigley quadrangle (lat 38°1′26″ N.; long 83°22′29″ W.).
4. Composite sample of drill core from same hole as sample 3, includes core from several gray and brownish-gray sandstone beds in lower 70 feet of the Breathitt formation.
5. Drill-core sample from lower fourth of brown sandstone bed 37 feet thick, at a point 20 feet above the base of the Breathitt formation. Drill hole located about 300 feet west of drill hole 3, about 150 feet beyond the west boundary of the Wrigley quadrangle.
6. Drill-core sample from same hole as sample 5, from gray sandstone bed 10 feet thick, at a point 7 feet above the base of the Breathitt formation.

7. Drill-core sample from brown sandstone 3 feet thick, 31 feet above base of Breathitt formation. Hole located in drainage of west fork of Brown fork, near northeast corner of Wrigley quadrangle (lat 38°07'27" N.; long 83°15'34" W.).
8. Drill-core sample from brown sandstone 5½ feet thick in Breathitt transition beds, 10 feet above the base of formation. Hole is located in drainage of south fork of Brown fork, about 1,000 feet southeast of drill hole 7 (lat 38°07'24" N.; long 83°15'21" W.).

GEOLOGIC STRUCTURE

The Haldeman and Wrigley quadrangles lie within the broad crustal downwarp between the Appalachian Mountains and the Cincinnati arch, a low anticline whose axis plunges gently to the south across central Kentucky. Throughout these two quadrangles, Pennsylvanian strata dip between 30 and 50 feet per mile to the east and southeast. This structure is shown in a general way (pls. 2, 3) by contours based on the elevation of the Olive Hill clay bed of Crider. Local inclination of beds resulting from deposition on sloping surfaces are common in Pennsylvanian rocks. The apparent dips of beds of this type are locally as great as 30°, but such dips are not related to structure.

Regional dips of Mississippian rock in general conform closely to those of Pennsylvanian beds. At a few localities, however, Mississippian beds dip as much as 100 to 150 feet per mile, which is two to three times as great as the dip of the overlying beds. This slight difference in dip indicates that minor structural warping had taken place prior to the deposition of lowermost Pennsylvanian beds.

No large faults occur within the limits of the Haldeman and Wrigley quadrangles. Small faults with vertical displacements ranging from a few inches to 6 or 8 feet have been encountered in a few clay mines. Very little evidence of these faults can be observed at the surface and none of them has been shown on the accompanying maps.

The structural contours (pls. 2 and 3) are drawn on the base of the Olive Hill clay bed of Crider (1913). Where the clay bed is missing, the contact between rocks of Pennsylvanian and Mississippian age was arbitrarily used because of its close proximity to the clay in most places. Altitudes of the base of the clay were obtained from company drill-hole data and aneroid elevations recorded in the field. The structural contours in the Haldeman quadrangle show the relief of the clay bed in more detail than in the Wrigley quadrangle because the altitude of the clay was determined at many more places.

The surface represented by structural contours, (pls. 2, 3) has a number of highly irregular minor flexures that may be due to: (1) small-scale tectonic warping; (2) the irregular surface on which rocks of Pennsylvanian age were deposited; (3) irregular thickness, shape, and compaction of rocks of Pennsylvanian age below the clay; (4) irregularities in the depths to which clay alteration took place by methods outlined on pages F79–F81; or (5) minor errors in the method and data used in plotting the contours. Two domes in the Haldeman quadrangle, one northeast of Brinegar and one east of Craney Creek, are shown to have structural closure of more than 30 feet. These domes and other flexures may be explained by any of the possibilities outlined above.

MINERAL DEPOSITS

THE OLIVE HILL CLAY BED OF CRIDER, 1913

The name "Olive Hill fire clay" was introduced by Crider (1913, p. 594–595). The name is derived from Olive Hill, a village of about 1,300 inhabitants located 4½ miles northeast of the northeast corner of the Haldeman quadrangle. As explained by Waagé (1950, p. 45) the term "fire clay," commonly written "fireclay," has come to be applied in a stratigraphic sense to any clay that underlies a coal bed, and it has lost its original meaning of refractory clay. Accordingly, the term "fire clay" will not be used in this report, except as a proper name applied to a coal bed in the Breathitt formation.

The Haldeman and Wrigley quadrangles are in the southern part of a large refractory clay producing district in eastern Kentucky that has long been an important source of fire brick. The district is known as the Olive Hill district (Crider, 1913, p. 594), inasmuch as the fire brick industry is centered in the town of Olive Hill and in smaller communities scattered along the Chesapeake and Ohio railroad east and west of that town. The first clay was shipped from Olive Hill in 1883, according to Crider (1913, p. 592), who gives a brief historical review of the fire brick industry in eastern Kentucky. Bricks were first made in the area of this report at a plant built by the Kentucky Firebrick Co. in the village of Haldeman in 1903 (Crider 1913, p. 630), and this plant remained in operation until shortly after the close of World War II. Sometime prior to 1922 the same company built a second plant at Haldeman (Ries, 1922, p. 214), which was operated until 1955, when it was bought by the General Refractories Co. At the time of writing (1958), no firebricks are made at Haldeman or elsewhere in the Haldeman and Wrigley quadrangles, but production capacity of the district is maintained at a high level by increased plant facilities at Olive Hill. The clay mined in the Haldeman quadrangle each year amounts to several tens of thousands of tons. Most of it is trucked to the North American Refractories Co. plant at Hayward, Ky., and to the Harbinson-Walker Co. and the General Refractories Co. plants at Olive Hill, Ky. The Olive Hill district is one of the major producers of refractory brick in the United States and the finished brick is shipped to the steel producing centers of the United States and many foreign countries.

More than 90 percent of the raw materials used in the refractory products of the Olive Hill district are mined from the Olive Hill clay bed. The remaining small percentage of materials is added to enhance plasticity required for forming brick, or to increase density and resistance to high temperatures of brick for special uses. Some of these materials are: (1) local plastic underclays of Pennsylvanian age that occur several hundred feet higher stratigraphically than the Olive Hill clay bed, (2) diaspore from Missouri that has higher alumina content and refractory properties than the Olive Hill clay, and (3) soft kaolin of the type that is common in coastal plain deposits of Georgia, and that has essentially the same mineral composition as much of the Olive Hill bed but tends to increase density of the brick when added in small amounts.

MINING

At the time of the fieldwork (1957), several strip and underground clay mines were being worked in the Haldeman quadrangle, where clay had been mined for more than half a century. None of the clay deposits in the Wrigley quadrangle has been mined, and the only openings consist of about half a dozen hand-dug prospect pits.

The first mine in the area of this report was opened in 1903 (Crider, 1913, p. 594); the adit was only a short distance from the old Kentucky Firebrick Co. plant at Haldeman. A few years later, the Harbison-Walker Refractories Co. built the mining community of Brinegar, about 2 miles southeast of Haldeman, and has since mined clay extensively in that area almost continuously. Formerly, the clay was transported by steam locomotives operating on narrow-gage tracks. Narrow-gage tracks once extended along Mocabee Creek and Jacobs Fork from Brinegar to a point on the Chesapeake and Ohio Railroad near Lawton, a small settlement 2 miles beyond the northeast corner of the Haldeman quadrangle, where the clay was loaded on standard-gage cars and shipped to firebrick plants. Other narrow-gage tracks extended from mines at the head of Brushy Fork to the brick plant at Haldeman and from a mine in the Walker Branch valley along the Christy Creek valley to Morehead, a town 3.9 miles west of the Haldeman quadrangle. All these tracks are now abandoned and the clay is hauled by trucks.

At the time of writing (1958), the Harbison-Walker Refractories Co. operated a large underground mine at Brinegar and a smaller one on the Sparkman property, 1½ miles south-southwest of Brinegar. The General Refractories Co. operated the Sugartree mine in the Proctor Branch valley, approximately 0.9 mile upstream from the point where the Branch crosses the east boundary of the Haldeman quadrangle. This company also worked a small mine whose adit is about 1,000 yards N. 10° E. of the road junction near the mouth of

Open Fork. Underground operations were suspended in 1956 at the North American Refractories Co. mine in the valley of a small tributary to Mocabee Creek 1 mile northeast of Brinegar. The 3 refractory companies and 2 or 3 earth-moving contractors operate strip mines scattered through the Mocabee, Christy, and Craney Creek valleys.

The selection of clay deposits for mining is based on firing tests and analytical data from samples obtained by drilling. Exploratory diamond-drill holes are spaced on a grid having about 400-feet centers; supplemental holes for development are placed on much closer centers. The room-and-pillar method of mining is employed; in most mines pillars are robbed before the mine is abandoned. Because of inconsistencies in the quality of the clay, hand sorting is required to obtain high-quality clay; therefore, most companies sort the clay as it is loaded on mine cars. At the time of the fieldwork (1957), one mechanical loading device was in operation underground where the clay is unusually uniform. Mine adits are located in hillsides, and in many places main haulage ways are driven along the clay bed in an updip direction to provide drainage. In order to obtain nearly complete recovery, the haulage level is driven its full extent; thus all the deeply buried clay is mined. Mining operations are then extended toward the zone of shallow overburden in the direction of the portal until the workings reach the minimum roof stability zone, which is 60 to 80 feet of overburden. The underground workings are then abandoned, and the clay that remains between the workings and the surface is mined by stripping methods. Overburden as much as 60 feet is removed to mine high-quality clay 5 feet thick. Modern heavy earth-moving equipment, including bulldozers and power shovels, are used to remove the overburden. After the clay has been stripped, the upper surface is carefully cleaned to avoid undue contamination by shale, sandstone, and coal. The clay is then loosened with dynamite and loaded on trucks with power shovels. Hand picking of the clay in strip mines is necessary only when superior quality clay is required.

STRATIGRAPHIC POSITION, DISTRIBUTION, AND LITHOLOGY

The Olive Hill bed is an underclay that occurs near the base of the Lee formation, enclosed by an exceedingly variable sequence of beds (pl. 7). The coal that overlies the clay (pls. 6, 7; fig. 4) ranges from 0 to about 10 inches in thickness, but in most outcrops it is only 3 to 6 inches thick. The coal extends over more than three-quarters of the area of the clay, and in most places where it is absent, its stratigraphic position is marked by nearly black discoloration in the uppermost part of the clay or a thin zone of carbon-rich black shale above the clay. The clay bed occurs 1 to 8 feet above the base of the Lee formation at most places, but locally it is 20 feet above the base, and at one locality (pl. 5, section 2) a bed questionably identified as the Olive Hill bed is nearly 70 feet above the base of the Pennsylvanian rocks. Because the Lee formation rests on the truncated surface of 10 thin Mississippian formations, the Mississippian beds that occur a short distance below the clay vary considerably in lithology from place to place. This relation, together with the varied characteristics of the Pennsylvanian beds below the clay, has led to difficulties in prospecting for the clay and to differences in opinion regarding its age. However, the position of the clay above the unconformity clearly establishes its age as Pennsylvanian. The varied characteristics of the beds above and below the clay are shown in pl. 7 and described as part of the Lee formation (p. F28–F34).

The Olive Hill clay consists of irregular lenses (pl. 8) that rest on an undulating surface. Neither the lenses nor the areas in which the clay is missing show any regional alinement or preferred orientation. The maximum thickness of most lenses is less than 10 feet, but in one old mine, now inaccessible, the bed is reported to be 25 feet thick. The undulating surface on which the clay bed rests, shown by structure contours on the geologic maps (pls. 2, 3), has a local relief of as much as 30 to 40 feet. Although some of these undulations appear to reflect uneveness of the surface on which the clay was deposited, most of them probably formed after deposition of the clay, by differential compaction or other phenomena that caused slight warping of the rocks above and below the clay. Gentle warping of the same order of magnitude as the undulations is present in the uniformly bedded siltstones of the Brodhead formation in railroad cuts in the village of Haldeman and in a cut along U.S. Highway 60 at the west edge of the town of Olive Hill.

The Olive Hill clay bed is itself composed of three types of clay in irregular nonbedded lenses of variable thickness and shapes (pl. 7). About one-third of the bed is flint clay and the other two-thirds is chiefly semiflint clay with subordinate amounts of plastic clay, but all variations in hardness from flint to semiflint and from semiflint to plastic clay are present in different parts of the bed. Boundaries between one type of clay and another are ordinarily sharp. Such terms as "semihard," "hard-soft," "semiplastic," and "number 2 clay," are used by local miners for intermediate clays. Except for the superposition of one type of clay above another, the clay is essentially nonbedded. Typically, the flint clay overlies semiflint clay (pl. 6), but at many places the reverse is true and at a few places the flint and semiflint clay are irregularly interlayered. Where plastic clay is present it ordinarily occurs in the uppermost part of the bed, but there are many exceptions to this generalization.

Colors, nonclay minerals, soluble salts, organic materials, and fossils are similar in all three types of clays; the types of clay differ, however, in the type and crystallinity of the clay minerals and in certain physical properties such as resistance to high temperatures, hardness, plasticity, resistance to erosion, and spacing of slickensides. Most of the clay is medium gray to brownish gray, but colors range from very light gray to almost black. Rusty iron stains are common along joints and in weathered outcrops. The content of nonclay mineral ranges from trace amounts to more than 50 percent of very sandy portions of the bed; lateral gradations from sand-free clay to very sandy clay within a few yards are common. Gypsum is the principal soluble salt present, and most of it is localized in crusts along joints. The plant-root fossil *Stigmaria* is commonly preserved in all three types of clay in the form of carbonaceous films. Locally the main rootstock with rootlets attached (fig. 7) is preserved in flint clay but commonly only the detached rootlets remain. The carbonaceous films rarely make up as much as 2 percent of the clay. The clay minerals in the clay are chiefly kaolinite, illite, and mixed-layer clays.

TYPES OF CLAY

The Olive Hill clay bed contains three types of clay—flint, semiflint, and plastic. A discussion on the physical, mineralogical, and chemical properties of the three clays and the differences between them follows.

FLINT CLAY

The flint clay in the Olive Hill clay bed is a hard, resistant, nonplastic refractory clay consisting chiefly of kaolinite. It possesses flintlike characteristics of homogeneity and conchoidal fracture, but it is distinctly softer than true flint (SiO_2). Most high-grade flint clay has a Mohs-scale hardness slightly greater than 3; the clay intermediate between flint and semiflint clay is slightly softer. Flint clay will not slake in water and has no plasticity unless very finely ground, and then plasticity is developed to approximately the same degree as similarly prepared quartz. Flint clay is sufficiently resistant to erosion to form small benches in stream beds. It weathers to angular blocks which, in turn, break down into shardlike fragments having sharply curved knife edges and pointed corners. Slickensides are extremely rare in flint clay. Oolites are very abundant in some of the flint clay but are not present in all deposits. The best flint clay is composed of more than 90 percent kaolinite, and some illite or mixed-layer clays are always present. This statement is based on mineralogical evidence discussed on the following pages and on chemical analyses (table 5). According to these analyses, flint clays are very similar in composition to theoretical kaolinite (SiO_2, 46.54 percent; Al_2O_3, 39.50 percent;

FIGURE 7.—*Stigmaria* from the Olive Hill clay bed of Crider, 1913, showing main rootstock with rootlets attached (at right angles) and nodular root scars; pocket knife is 2½ inches long.

and H_2O, 13.96 percent), but some of the alkali constituents of illite and mixed-layer minerals are always present. Pyrometric cone equivalents (PCE) of high-grade flint clay range from 34 to 36 (1,760°–1,810°C.).

TABLE 5.—*Mineral composition and chemical analyses of clays from the Olive Hill bed of Crider (1913) arranged in order of pyrometric cone equivalents*

[Location of these samples on pls. 2 and 3 is indicated on table 6]

Sample No.	25	7	8	13	2	5	16	17	33	38
U.S.G.S. laboratory No.	------	150135	150136	148113	148114	------	148118	148119	150142	150139
Type of clay	Flint	Flint	Semi-flint	Flint	Flint	Composite	Flint	Semi-flint	Flint	Composite
Pyrometric cone equivalent (PCE)	36	35	34+	34+	34	34−	34−	34−	34−	34−

Clay minerals

[Numbers, parts of 10; E, excellent; VG, very good; G, good; P, poor; VP, very poor]

	25	7	8	13	2	5	16	17	33	38
Kaolinite	9–9½	9–9½	9–9½	9–9½	9–9½	8½	9	9–9½	9	9–9½
Illite	Tr.	------	Tr.	------	Tr.	½	------	¼–½	¼–½	Tr.
Chlorite	½	------	------	------	------	------	------	------	------	------
Mixed-layer clay minerals	Tr.	½	½	¼	½	½	½	¼–½	¼–½	½
Crystallinity of kaolinite	VG	VG	VG	E	E	VG	E	G	VG	E

Nonclay minerals, in parts of 10

	25	7	8	13	2	5	16	17	33	38
Quartz	------	Tr.	------	------	------	------	------	Tr.	------	------
Anatase	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Siderite	------	------	------	------	------	------	------	------	------	------
Iron oxide minerals	------	------	------	------	------	------	------	------	------	------
Pyrite	------	------	------	------	------	Tr.	------	------	------	Tr.
Organic material	------	Tr.	------	Tr.	------	------	------	------	------	------
pH index	6.0	4.8	4.8	4.9	5.6	4.6	4.7	4.8	5.5	5.6

Chemical analyses

[In weight percent. Samples 1 and 10 analyzed by Mr. E. L. Prew, Alfred University, Alfred, N.Y., using standard methods; all other samples analyzed by Messrs. P. L. D. Elmore, S. D. Botts, M. D. Mack, and J. H. Goode under supervision of Mr. W. W. Brannock, using methods like those of Shapiro and Brannock (1956). Summations rounded to nearest whole number. Samples for which TiO_2 only is given analyzed by Patterson and Hosterman according to method of Shapiro and Brannock (1953). Asterisk (*) indicates samples contain organic matter that may cause FeO percentage to be in error]

	25	7	8	13	2	5	16	17	33	38
SiO_2	------	44.6	44.7	45.0	45.1	------	44.7	44.7	45.5	44.2
Al_2O_3	------	37.8	37.6	38.2	37.8	------	38.0	37.4	36.0	36.9
Fe_2O_3	------	.50	.59	.46	.45	------	.57	1.0	.8	.7
FeO	------	.20*	.22*	.19	.48	------	.09	.03	.38*	.55*
MgO	------	.06	.16	.13	.09	------	.10	.18	.36	.15
CaO	------	.04	.06	.06	.16	------	.06	.07	.08	.38
Na_2O	------	.12	.09	.06	.09	------	.06	.11	.10	.09
K_2O	------	.34	.41	.30	.64	------	.36	.97	1.0	.31
TiO_2	0.9	2.0	1.5	1.9	2.1	1.8	2.0	1.9	2.0	2.1
P_2O_5	------	.00	.03	.01	.01	------	.01	.01	.05	.42
MnO	------	.00	.00	.00	.01	------	.00	.01	.00	.00
H_2O	------	14.0	14.0	13.8	13.4	------	13.5	13.4	13.0	13.3
CO_2	------	.09	<.05	.05	.07	------	.05	<.05	.12	.12
Sum	------	99.	99.	100.	100.	------	100.	100.	99.	99.
SO_3	------	------	------	.20	<.03	------	<.03	<.03	------	------
S (total)	------	------	------	------	------	------	------	------	------	------
Ignition loss	------	------	------	------	------	------	------	------	------	------

TABLE 5.—*Mineral composition and chemical analyses of clays from the Olive Hill bed of Crider (1913) arranged in order of pyrometric cone equivalents*—Continued

[Location of these samples on pls. 2 and 3 is indicated on table 6]

Sample No.	15	9	22	27	30	14	12	20	26
U.S.G.S. laboratory No.	148111								
Type of clay	Flint	Flint	Flint	Semi-flint	Flint	Semi-flint	Semi-flint	Com-posite	Flint
Pyrometric cone equivalent (PCE)	33–34	33+	33+	33+	33+	33	33−	33−	33−
Clay minerals—Continued [Numbers, parts of 10; E, excellent; VG, very good; G, good; P, poor; VP, very poor]									
Kaolinite	9	8	7–8	7–8	8–8½	8	8½	8½–9	8
Illite		½–1	½–1	Tr.	½	¼–½	Tr.	Tr.	1
Chlorite		Tr.							
Mixed-layer clay minerals	½	½	Tr.	1–1½	½	1	½–1	½–1	½
Crystallinity of kaolinite	E	VG	E	VP	VG	P	G	VG	VG
Nonclay minerals, in parts of 10—Continued									
Quartz		½–1	1–2	Tr.	Tr.	½	¼–½	Tr.	Tr.
Anatase	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Siderite									
Iron oxide minerals									
Pyrite		Tr.			Tr.+		Tr.		Tr.+
Organic material							Tr.		
pH index	5.7	4.3	4.8	5.5	5.9	7.7	6.0	4.3	4.4
Chemical analyses—Continued [In weight percent. Samples 1 and 10 analyzed by Mr. E. L. Prew, Alfred University, Alfred, N.Y., using standard methods; all other samples analyzed by Messrs. P. L. D. Elmore, S. D. Botts, M. D. Mack, and J. H. Goode under supervision of Mr. W. W. Brannock, using methods like those of Shapiro and Brannock (1956). Summations rounded to nearest whole number. Samples for which TiO_2 only is given analyzed by Patterson and Hosterman according to method of Shapiro and Brannock (1953). Asterisk (*) indicates samples contain organic matter that may cause FeO percentage to be in error]									
SiO_2	44.6								
Al_2O_3	33.0								
Fe_2O_3	.78								
FeO	.08								
MgO	.22								
CaO	.08								
Na_2O	.13								
K_2O	.71								
TiO_2	1.6	2.0	2.0−	1.5	1.5	2.0+	2.5	1.5	2.0
P_2O_5	.07								
MnO	.01								
H_2O	13.6								
CO_2	$<.05$								
Sum	100.								
SO_3	$<.03$								
S (total)									
Ignition loss									

TABLE 5.—*Mineral composition and chemical analyses of clays from the Olive Hill bed of Crider (1913) arranged in order of pyrometric cone equivalents*—Continued

[Location of these samples on pls. 2 and 3 is indicated on table 6]

Sample No.	29	1	3	6	32	35	4	23	11	21
U.S.G.S. laboratory No.	--------	--------	148115	150134	--------	150143	148116	--------	--------	148117
Type of clay	Flint	Flint	Semi-flint	Plastic	Flint	Flint	Semi-flint	Composite	Composite	Semi-flint
Pyrometric cone equivalent (PCE)	33−	32½	32½	32+	32+	32+	32	32	32−	32−

Clay minerals—Continued

[Numbers, parts of 10; E, excellent; VG, very good; G, good; P, poor; VP, very poor]

Sample No.	29	1	3	6	32	35	4	23	11	21
Kaolinite	8–8½	7½–8	8	7	7–7½	7–7½	7–7½	6½–7	7–7½	7–7½
Illite	1	Tr.	1½–2	1½–2	1½–2	--------	2	1	1	1½
Chlorite	--------	--------	--------	--------	--------	--------	--------	--------	--------	½
Mixed-layer clay minerals	½	1–2	Tr.	½–1	½–1	½–1	Tr.	1	Tr.	Tr.
Crystallinity of kaolinite	VG	VG	P	VP	VG	VG	P	G	VG	P

Nonclay minerals, in parts of 10—Continued

Sample No.	29	1	3	6	32	35	4	23	11	21
Quartz	Tr.	Tr.	--------	Tr.	¼–½	1–2	--------	1	1	1
Anatase	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Siderite	--------	--------	--------	--------	--------	½–¼	--------	--------	--------	--------
Iron oxide minerals	--------	--------	--------	--------	--------	Tr.	--------	--------	--------	--------
Pyrite	--------	Tr.	--------	--------	--------	--------	Tr.	--------	Tr.	--------
Organic material	--------	Tr.+	--------	Tr.	Tr.	Tr.	Tr.	--------	--------	--------
pH index	7.0	4.1	5.6	4.4	5.4	6.9	5.8	4.5	4.6	4.2

Chemical analyses—Continued

[In weight percent. Samples 1 and 10 analyzed by Mr. E. L. Prew, Alfred University, Alfred, N.Y., using standard methods; all other samples analyzed by Messrs. P. L. D. Elmore, S. D. Botts, M. D. Mack, and J. H. Goode under supervision of Mr. W. W. Brannock, using methods like those of Shapiro and Brannock (1956). Summations rounded to nearest whole number. Samples for which TiO_2 only is given analyzed by Patterson and Hosterman according to method of Shapiro and Brannock (1953). Asterisk (*) indicates samples contain organic matter that may cause FeO percentage to be in error]

Sample No.	29	1	3	6	32	35	4	23	11	21
SiO_2	--------	39.0	45.1	46.4	--------	47.2	46.6	--------	--------	45.8
Al_2O_3	--------	34.2	36.4	34.0	--------	33.3	35.1	--------	--------	35.1
Fe_2O_3	--------	3.4	1.0	1.4	--------	.9	1.1	--------	--------	1.6
FeO	--------	--------	.23	.41*	--------	2.3*	.16	--------	--------	.34
MgO	--------	.55	.52	.69	--------	.30	.54	--------	--------	.45
CaO	--------	.32	.10	.11	--------	.20	.18	--------	--------	.06
Na_2O	--------	.44	.18	.24	--------	.15	.22	--------	--------	.19
K_2O	--------	2.57	1.8	3.1	--------	.75	2.0	--------	--------	2.4
TiO_2	2.7	2.17	2.4	1.4	1.5	1.5	2.4	2.0−	2.0+	1.5
P_2O_5	--------	.24	.05	.02	--------	.06	.10	--------	--------	.01
MnO	--------	--------	.01	.00	--------	.03	.01	--------	--------	.01
H_2O	--------	--------	12.3	11.6	--------	11.9	12.1	--------	--------	12.4
CO_2	--------	3.54	.07	.26	--------	1.4	<.05	--------	--------	<.08
Sum	--------	--------	100.	100.	--------	100.	101.	--------	--------	100.
SO_3	--------	.72	<.03	--------	--------	--------	<.03	--------	--------	<.03
S (total)	--------	.29	--------	--------	--------	--------	--------	--------	--------	--------
Ignition loss	--------	17.39	--------	--------	--------	--------	--------	--------	--------	--------

TABLE 5.—*Mineral composition and chemical analyses of clays from the Olive Hill bed of Crider (1913) arranged in order of pyrometric cone equivalents*—Continued

[Location of these samples on pls. 2 and 3 is indicated on table 6]

Sample No.	37	10	19	34	18	31	24	28	36
U.S.G.S. laboratory No.	--------	--------	148110	150141	148112	--------	--------	--------	150140
Type of clay	Flint	Semi-flint	Com-posite	Semi-flint	Com-posite	Flint	Plastic	Semi-flint	Flint
Pyrometric cone equivalent (PCE)	32−	31+	31	30–31	30	30−	29−	29−	20+

Clay minerals—Continued

[Numbers, parts of 10; E, excellent; VG, very good; G, good; P, poor; VP, very poor]

Kaolinite	6	6	6	4–5	5–5½	5½	5½–6	5½	7
Illite	Tr.	1	1	2	2–3	¼	2	1½	--------
Chlorite	--------	--------	--------	--------	½	--------	--------	Tr.	--------
Mixed-layer clay minerals	Tr.	¼–½	¼–½	Tr.	½	½	1	½	½
Crystallinity of kaolinite	E	G	P	VP	G	VG	VP	VP	VG

Nonclay minerals, in parts of 10—Continued

Quartz	3–4	2	2–3	3–4	1	3–4	½	2–3	½
Anatase	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Siderite	--------	--------	--------	--------	--------	--------	--------	--------	1
Iron oxide minerals	--------	--------	--------	--------	--------	--------	--------	--------	½
Pyrite	--------	Tr.	--------	--------	--------	--------	--------	--------	--------
Organic material	--------	Tr.	--------	--------	--------	Tr.	--------	--------	--------
pH index	7.0	5.7	4.2	5.4	4.3	6.4	4.8	6.5	6.8

Chemical analyses—Continued

[In weight percent. Samples 1 and 10 analyzed by Mr. E. L. Prew, Alfred University, Alfred, N.Y., using standard methods; all other samples analyzed by Messrs. P. L. D. Elmore, S. D. Botts, M. D. Mack, and J. H. Goode under supervision of Mr. W. W. Brannock, using methods like those of Shapiro and Brannock (1956). Summations rounded to nearest whole number. Samples for which TiO_2 only is given analyzed by Patterson and Hosterman according to method of Shapiro and Brannock (1953). Asterisk (*) indicates samples contain organic matter that may cause FeO percentage to be in error]

SiO_2	--------	54.3	54.6	66.7	52.8	--------	--------	--------	36.2
Al_2O_3	--------	28.5	29.9	21.0	30.7	--------	--------	--------	31.2
Fe_2O_3	--------	3.2	1.7	1.4	1.4	--------	--------	--------	1.1
FeO	--------	--------	.12	.40*	.72	--------	--------	--------	11.9
MgO	--------	.45	.42	.29	.78	--------	--------	--------	.54
CaO	--------	.24	.05	.11	.13	--------	--------	--------	.41
Na_2O	--------	.27	.10	.11	.22	--------	--------	--------	.10
K_2O	--------	1.50	1.3	1.1	2.5	--------	--------	--------	.26
TiO_2	1.8	1.97	1.4	1.4	1.3	1.5+	1.0	0.5	1.6
P_2O_5	--------	.22	.05	.01	.01	--------	--------	--------	.30
MnO	--------	--------	.00	.00	.01	--------	--------	--------	.08
H_2O	--------	--------	10.6	7.3	10.	--------	--------	--------	11.4
CO_2	--------	.21	.05	.12	.06	--------	--------	--------	4.2
Sum	--------	--------	100.	100.	101.	--------	--------	--------	99.
SO_3	--------	.45	<.03	--------	<.03	--------	--------	--------	--------
S (total)	--------	.25	--------	--------	--------	--------	--------	--------	--------
Ignition loss	--------	10.34	--------	--------	--------	--------	--------	--------	--------

SEMIFLINT CLAY

Semiflint clay is intermediate between flint and plastic clay in physical characteristics and clay-mineral composition. It has a Mohs-scale hardness between 2 and 3, and it possesses very little natural plasticity except when finely ground. Nearly all semiflint clays contain abundant diversely oriented slickensides. Parting occurs mostly along the slickensides; and commonly, when fresh semiflint clay is subjected to a single rainfall, it breaks down into a rubble of irregular polyhedra having a slickenside on each face. Semiflint clays are rarely seen in natural outcrops except where they are protected by overlying flint clays or other resistant beds. However, some of the harder semiflint clays, which are gradational into the flint clays, are remarkably resistant to weathering. A good example is the semiflint clay that for many years has supported the footing of the bridge on State Route 32, one-quarter mile west of Elliotville, Haldeman quadrangle.

The semiflint clays consist chiefly of mixtures of kaolinite, illite, and mixed-layer minerals, and the kaolinite present generally ranges from 60 to 80 percent or a little more. The PCE's of semiflint clays are mostly in the range 31–33 (1,680°–1,745°C.), and these clays are distinctly lower in heat-resisting properties than good quality flint clay. In a few places, semiflint clays are very refractory, and PCE's are as high as 34+ (table 5). The refractory properties of most semiflint clays are lower than in flint clays chiefly because of higher contents of alkali-bearing clays such as illite and mixed layer minerals.

PLASTIC CLAY

Plastic clay consists of mixtures of kaolinite, illite, and mixed-layer minerals. Weathered plastic clay readily develops considerable plasticity when wet, but some grinding is required to develop maximum plasticity in the fresh clay. Abundant slickensides are present in the fresh plastic clay, but as weathering progresses the slickensides are sealed and the clay becomes a homogeneous mass. Natural exposures of plastic clay are exceedingly rare because it is soft and lacks resistance to weathering. Only a small amount of plastic clay is present in the Olive Hill clay bed. The few samples examined were very similar in mineralogical composition to the poorer quality semiflint clays. The content of illite and mixed-layer clay minerals was high; accordingly, the alkali content should be high and refractory properties should be relatively low.

MINERALOGY

CLAY MINERALS

ANALYTICAL PROCEDURE

Investigations of clay minerals were based primarily on X-ray diffraction of oriented and randomly oriented clay slides prepared from whole samples and the less than 2-micron fraction of the samples. The clay was ground and dispersed in distilled or deionized water, and sodium metaphosphate was used as required to prevent flocculation. After approximately 6 hours settling time the less than 2-micron fraction was siphoned off. Oriented aggregates were made on porous ceramic tile, using the techniques described by Kinter and Diamond (1956). Randomly oriented slides were obtained by pressing the less than 2-micron clay that had been oven dried into aluminum sample holders. A standard X-ray diffraction unit with copper radiation was used. A 1° beam slit, a soller slit, and a 0.1° detector slit with nickel filter were used in conjunction with a proportional counter X-ray detector. The goniometer was run at a speed of 2° per minute. The chart was driven at the speed of 24 inches per hour, so that the X-ray diffraction trace was recorded at the rate of 5° per inch.

The clay minerals were determined and their proportions estimated by X-ray techniques, based on the measurement of characteristic basal spacings which, in turn, reflect the number of silica-tetrahedral and alumina- or magnesia-octahedral sheets contained in the unit cell of the mineral. A unit cell with two sheets, one of silica and one of alumina, is about 7 A thick (an example is kaolinite); a unit cell with three sheets, two of silica with one of alumina between, is about 10 A thick (an example is illite); and a unit cell with four sheets, two of silica and two of magnesia or alumina, is about 14 A thick (an example is chlorite). The unit of measure is the angstrom (A), which is 10^{-8} centimeters. The thickness between layers (d) in angstrom units is calculated from the Bragg equation $d=\frac{\lambda}{2\sin\theta}$, where λ is the X-ray wavelength (which for $CuK\alpha_1$ radiation is equal to 1.54050 A) and 2θ is the angle measured on the goniometer and marked off on the X-ray diffraction trace. Values of d, in A units, corresponding to measured values of 2θ are readily determined from published tables. The height and area of the peaks on the X-ray diffraction traces are a function of the amount and crystallinity of the clay minerals present, which provides some basis for estimating the proportions of the various clays present. The techniques employed in interpreting differences in crystallinity and of making quantitative

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estimates from X-ray diffraction traces are described in detail by L. G. Schultz (1960).

Clay samples were also examined by means of differential thermal analysis, electron microscope, and petrographic microscope; and chemical analyses were made of selected samples. The differential thermal analysis equipment used was similar to that described by Grim and Rowland (1944, p. 6–9). Both carbon-replica and powder techniques were employed in preparation of samples for electron microscope examination. The carbon replicas were prepared by the authors in the manner described by Bates and Comer (1955, p. 1–25). Miss Marie Lindberg examined the samples by means of the electron microscope and took the electron micrographs. Chemical analyses (table 5) were made in the laboratories of the Geological Survey by Messrs. S. D. Botts, M. D. Mack, J. H. Goode, and P. L. D. Elmore under the supervision of Mr. W. W. Brannock, and by Mr. Elmer L. Prew of Alfred University, Alfred, N.Y. The rapid analysis method (Shapiro and Brannock, 1956) was used for the analyses made in the Geological Survey laboratories. Analyses by Mr. Prew were by standard methods. Analysis of titanium on samples for which complete chemical analyses are not given in table 5 were made by the authors employing the method described by Shapiro and Brannock (1953).

KAOLINITE

Kaolinite $(OH)_8Si_4Al_4O_{10}$ is by far the dominant clay mineral in the Olive Hill clay bed, and in places it makes up as much as 90 to 95 percent of the bed. The kaolinite in the flint clay is predominantly well crystallized. In the plastic clay and in some semiflint clay, the kaolinite has a poor degree of crystallinity similar to the "fireclay" kaolinite mineral of Brindley and Robinson (1947). Intermediate stages of crystallinity are present in most semiflint clays. Recognition of well-crystallized kaolinite is based on the narrow basal (001) reflection at 7.1 A and the sharp resolution of reflections from the pyramidal and prismatic planes (fig. 8). Poorly crystallized kaolinite gives a broad basal (001) reflection at slightly greater than 7.1 A and the reflections from the pyramidal and prismatic planes are diffuse. The degree of crystallinity of the kaolinite varies with the proportions of other clay minerals present in the clay. The well-crystallized kaolinite occurs only in clays that contain only small amounts of other clay minerals, and therefore it is restricted to the flint clays. Poorly crystalline fireclay kaolinite occurs only where appreciable amounts of illite and mixed-layer clays are also present. Kaolinite having intermediate crystallinity occurs in both the flint and semiflint clays that contain small amounts of illite and mixed-layer min-

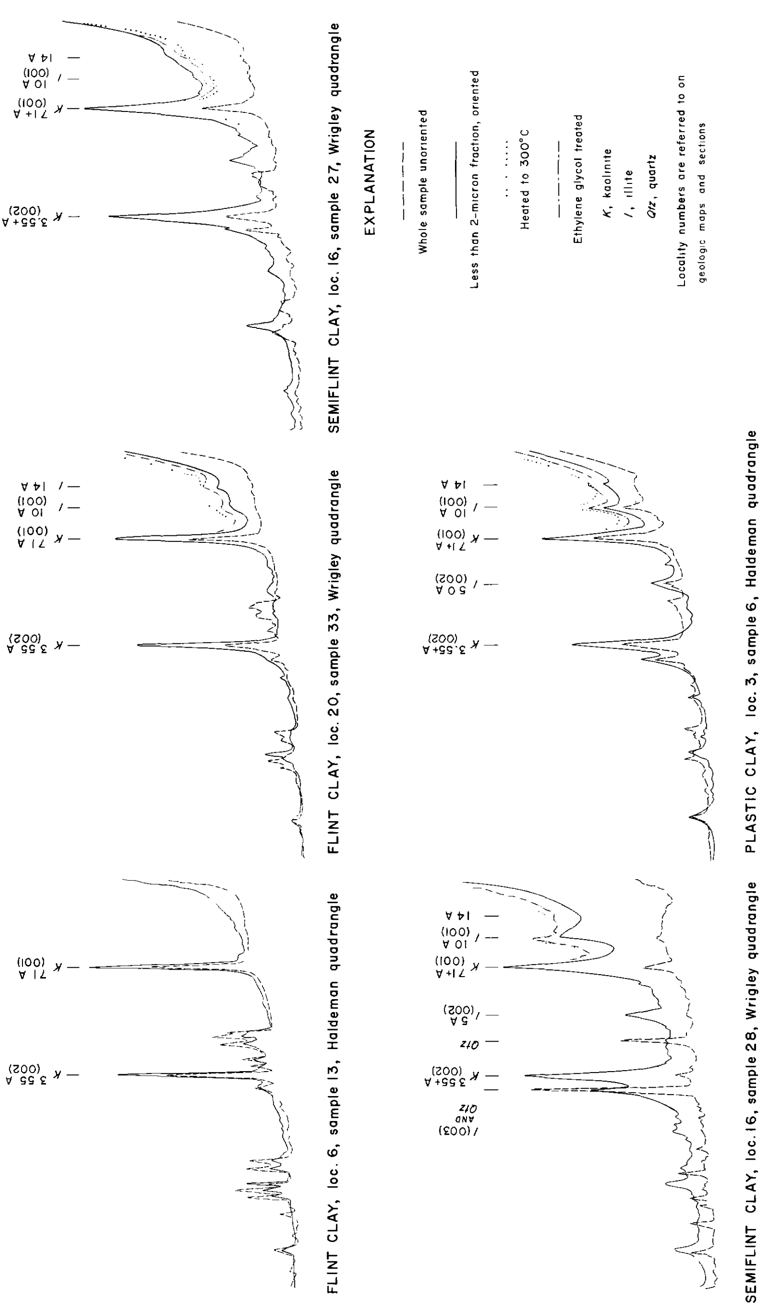

FIGURE 8.—X-ray diffractometer traces (CuK-α_1 radiation, of flint, semiflint, and plastic clays from the Olive Hill clay bed of Crider, 1913.

erals. The conclusions regarding the crystallinity of the kaolinite are based on the criteria outlined by Brindley (1951, p. 46, 50–52). Our conclusions closely parallel those of Keller and others (1954, p. 19) and McConnell and others (1956, p. 279), who studied similar clays. The proportion of nonclay minerals bears no relation to the crystallinity of the clay, and well-crystallized kaolinite occurs in parts of the bed that contain as much as 50 percent quartz.

Differential thermal analysis curves of samples from the Olive Hill bed (fig. 9) appear to support the conclusion that kaolinite is the dominant clay mineral present and that the kaolinite in flint clay is more perfectly crystallized than in plastic clay. The prominent endothermic peak resulting from the loss of hydroxyls is at approximately 600°C. for flint clay (fig. 9, sample 25) and at only 580°C for plastic clay (fig. 9, sample 24). Also, the exothermic reaction at about 975°C is intense and is completed within a temperature range of 25°C, whereas this reaction for plastic clays is much less intense and takes place over a temperature range of approximately 75°C. The differential thermal-analysis curves for semiflint clay, not illustrated in this report, are intermediate between plastic and flint clay. The higher energy required to drive the hydroxyl ion of the clay mineral structure from the flint clay suggests that in the flint clay the hydroxyl ion is more tightly bound than it is in plastic clay. The exothermic peak at approximately 975°C probably indicates the final breakdown of the structure remaining after the hydroxyls have been driven off. If so, the broad peak for plastic clay suggests that bonds of varying strength are present and the sharp peak for flint clay may mean that the bonds are all of essentially the same strength.

ILLITE

The term "illite" [$(OH)_4K_y(Si_{8-y}\cdot Al_y)(Al_4\cdot Fe_4\cdot Mg_4\cdot Mg_6)O_{20}$, where y is less than 2] in this report is applied to a dioctohedral clay-size mica commonly referred to by some authors as hydrous mica in part. Illite is the second most common clay mineral in the Olive Hill clay bed. The proportion ranges from a trace in the flint clay to about 40 percent in the plastic and the softer semiflint clays. Illite is recognized in X-ray diffraction traces by its basal (001) spacing at approximately 10 A (fig. 8). Weak second-order (002) reflections at 5 A and third-order (003) at 3.3 A are also present in diffractometer traces of some samples. Only the material that does not expand when treated with ethylene glycol is considered to be illite; if there is some expansion, the material is considered to be mixed-layer clay. In differential thermal-analysis curves, the presence of small amounts of illite is suggested by broad weak endothermic reactions between 100° and 200°C

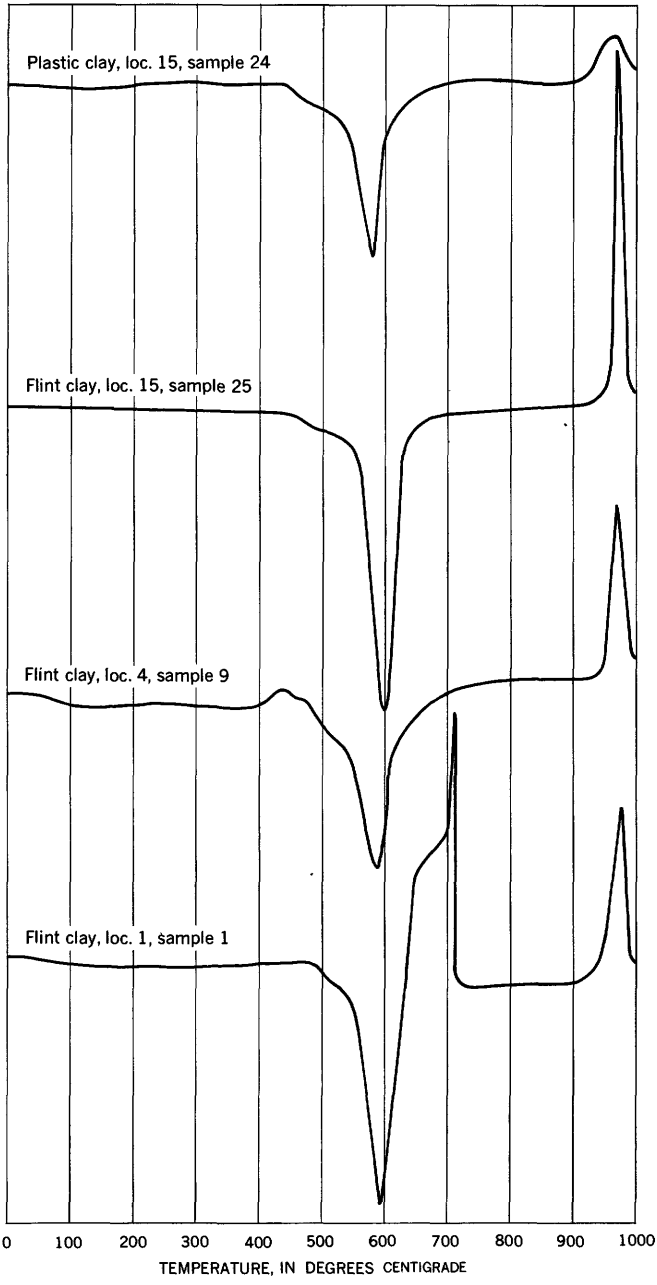

FIGURE 9.—Differential thermal analysis curves of clays from the Olive Hill clay bed of Crider, 1913. Locality numbers are referred to on plates 2–4 and on table 6.

(fig. 9, samples 9 and 24) and by small endothermic reactions beginning between 450° and 500° C.

MIXED-LAYER CLAY MINERALS

Complex mixed-layer minerals are closely associated with the illite. Some of these minerals resemble montmorillonite in that X-ray diffraction traces show a slight increase in 14 A reflections when samples are treated with ethylene glycol. Montmorillonitelike layers are most common in plastic clays and softer semiflint clays (fig. 8). Other mixed-layer clays consist of heterogeneous mixtures of minerals resembling chlorite, montmorillonite, and probably vermiculite. X-ray traces of these clays have broad irregular bulges in 10 A to 14 A range, and reflections are changed very little by heat or ethylene glycol treatments. Efforts to improve the mineral structure of mixed-layer minerals by treatment with potassium ions were not successful. The structure of these minerals appears to be far more complex than that of some mixed-layer clays that are mostly potassium-deficient illites. Heterogeneous mixed-layer assemblages occur only in small amounts. They are probably present in all types of clay in the Olive Hill area, but they are most abundant, or at least most easily recognized, in the softer flint and harder semiflint clays. Mixed-layer clay minerals are not recognizable in differential thermal analysis curves of samples from the Olive Hill bed (fig. 9). The reactions caused by heating these minerals are probably similar to reactions that take place in illite, and, no doubt, part of the small reactions attributed to illite are caused by mixed-layer minerals.

The Olive Hill clay bed contains a very small amount of a clay mineral that is probably chlorite. In X-ray diffraction traces, this mineral has a fundamental basal spacing of 14 A, and it does not swell when treated with ethylene glycol or collapse when heated to 300°C. Some doubt regarding the correct identification of this mineral remains, however, because it was neither destroyed nor enhanced by heat treatment at 650°C, and it was not destroyed by 3*N* hydrochloric acid treatment as are most chloritic clay minerals. Possibly the clay mineral here reported to be chlorite is a highly aluminous variety. Chlorite is most abundant in the softer flint clays and harder semiflint clays (fig. 8, samples 33, 27), but in none of the clay did the estimated amounts exceed 5 percent (table 5).

NONCLAY MINERALS

The material other than clay minerals in the Olive Hill clay bed includes allogenic minerals that were introduced during deposition of the clay, authigenic minerals that formed after deposition of the clay, and organic matter in the form of thin carbonaceous films. The allogenic minerals are quartz, SiO_2; zircon, $ZrSiO_4$; tourmaline, (H, Li, Na, K, Ca)$_9Al_3(B{\cdot}OH)_2Si_4O_{19}(+Fe_2O_3$, FeO, MgO, MnO); garnet, which in the Olive Hill bed is probably almandite having the composition $Fe_3Al_2(SiO_4)_3$; ilmenite, $FeTiO_3$; and magnetite, $FeFe_2O_4$. Quartz occurs in proportions ranging from traces to aproximately 50 percent. The other allogenic minerals are present only in trace amounts. The most abundant authigenic mineral is siderite, Fe CO_3, and it occurs in amounts as great as 10 percent (table 5, sample 36). Other authogenic minerals, present in minor amounts in samples studied in the laboratory, are pyrite, FeS_2; iron oxide minerals such as limonite, goethite, lepidocrosite, and hematite; and the soluble salts gypsum, $CaSO_4{\cdot}2H_2O$, and iron sulfate. Traces of galena, PbS, and sphalerite, ZnS, have also been reported in the clay bed; they are probably authigenic. Anatase, TiO_2, is present in small amounts throughout the Olive Hill clay bed, but whether or not it was introduced at the time of deposition or formed after deposition is not known.

The allogenic minerals vary considerably in grain size, roundness, and amount of alteration. Quartz occurs as both rounded and angular grains; most of the rounded grains are frosted and most of the angular ones are clear. Locally quartz grains are coated with an iron oxide mineral that is probably limonite. Grain size of the quartz ranges from very fine silt to medium sand. The quartz in plastic and semi-flint clay is essentially unaltered, but many of the grains in flint clay are serrated and etched and partially replaced by clay minerals (fig. 11, *c*). Most of the allogenic minerals other than quartz occur as rounded grains. Garnet and zircon grains are essentially unaltered. Most of the magnetite, however, is partly altered to limonite or hematite, and most of the ilmenite is coated with leucoxene.

The authigenic minerals occur in a variety of crystal forms, and they apparently were formed at two different times. Pyrite and siderite are scattered throughout the clay, and hematite, limonite, gypsum, and soluble salts are closely associated with joints in the clay. Probably the pyrite and siderite formed long before the other minerals, which may be still forming by precipitation from ground water. Siderite occurs commonly as oolites, spherulites, and euhedral crystals, and at the locality where it makes up 10 percent of the bed it is in the form of nodular concretions that are as much as one-fourth inch in diameter and one-half inch in length. Many of the siderite concretions contain irregular inclusions of white kaolinite. Some of the pyrite occurs locally as small euhedral crystals disseminated throughout the clay, but most of it is in the form of small irregular nodular concretions. Most of these pyrite concretions are closely associated with carbonaceous films of *Stigmaria*, and presumably the pyrite was concentrated in the space originally occupied by a plant rootlet. Pyrite, in very fine particles, gives an exothermic reaction between 400° and 500°C in differential thermal analysis (fig. 9, sample 9). The iron oxide minerals limonite and hematite occur as films along joints in the clay and as finely disseminated particles causing red, brown, and yellow discoloration of the clay adjacent to joints. The gypsum and soluble iron sulfate salts are chiefly in the form of films along joints. Iron oxide minerals, gypsum, and soluble iron sulfate salts are present only in small amounts in most of the Olive Hill clay bed. The differential thermal-analysis curves give no indication that these minerals were present in any of the samples investigated, and the percentages of iron, calcium, and sulfur are low in the chemical analyses of most samples of these clays (table 5).

Anatase occurs in all samples of the Olive Hill clay bed examined in the laboratory (table 5), and appears to be present in essentially all parts of the bed; it probably contains nearly all of the titanium present in the clay. Anatase was identified by the strongest X-ray reflection at 3.51 A. Inasmuch as this reflection is masked by the second-order basal reflection (002) of kaolinite, it was necessary to heat the clay to 550°C for half an hour to destroy the kaolinite structure in order to recognize the presence of anatase. The strongest reflection of anatase was weak for all samples, but the proportion of anatase indicated on the X-ray diffraction traces was probably sufficient to account for nearly all of the titanium which ranges from 0.9 to 2.7 percent shown in the chemical analyses (table 5).

Anatase appears to be in very fine particles uniformly distributed throughout large bodies of the clay. The less than 2-micron fractions contained essentially the same proportions of anatase as the whole clay in samples investigated by X-ray methods. This observation together with the absence of recognizable anatase in thin sections indicates that the mineral is present in very fine particles. The distribution of titania in the clay was investigated by chemical analyses of the type outlined by Shapiro and Brannock (1953). Samples were taken from opposite sides of blocks of flint clay and semiflint clay approximately 1½ feet in diameter. Samples from the same block contained essentially identical amounts of titania for each type of clay, though blocks from different localities differed within the range indicated in table 5.

The Olive Hill clay bed in one mine near Olive Hill, Ky., is reported by Greaves-Walker (1907, p. 470) to contain nodules and oolites of uncommonly high alumina content. He referred to the material as "aluminite," and it was later identified as gibbsite, $Al_2O_3 \cdot 3H_2O$, by Galpin (1912, p. 324–329). Greaves-Walker reports as much as 48.5 percent alumina, and a low content of alkali and iron. Accordingly, the so-called aluminite was more valuable for refractory purposes than parts of the bed that contain only kaolinite. During the present investigation a special effort was made to locate samples of gibbsite-bearing clay in the Haldeman and Wrigley quadrangles, but without success. The efforts included X-ray examination of concentrated oolites from the clay bed at several localities. In all samples, the oolite concentrates contained only kaolinite that was of essentially the same composition as the enclosing nonoolitic clay.

Coaly organic matter appears to be abundant in the Olive Hill clay bed because black films and specks are conspicuous in hand specimens, but the total content of organic matter in the clay is low. Most of the carbonaceous films and specks are remains of detached rootlets of *Stigmaria*, but locally nearly complete root systems are preserved by such films (fig. 7). The presence of organic matter is also indicated in some differential thermal analysis curves by a sharp exothermic reaction between 650° and 720°C (fig. 9, sample 1). Of all samples investigated, sample 1 contained the most organic matter, and the exothermic peak shown by the curve of that sample is of the same order of magnitude as peaks obtained from a 2-percent mixture of coal from the bed overlying the Olive Hill clay in clay that contains essentially no organic matter. No indication of organic matter was present in the differential thermal-analysis curves of most of the clays investigated, and organic matter probably makes up considerably less than 1 percent of most parts of the Olive Hill bed.

TEXTURE AND HARDNESS OF THE CLAY

The textures of the three types of clays were examined by petrographic and electron microscope and by X-ray diffraction of slices of clays. Electron micrographs were taken of powder samples of plastic, semiflint, and flint clays and of carbon replicas (Bates and Comer, 1955, p. 3) of flint and impregnated semiflint clays. The slices for mounting in the X-ray diffractometer were cut from samples on which the field orientation had been recorded. Slices of flint clays were cut parallel to the horizontal, vertical east-west, and vertical north-south field directions. Slickenside surfaces of semiflint clay and slices cut at angles to slickensides were also examined. Interpretation was based on the assumption that orientation parallel to the basal planes of the clay minerals would give intense basal (001) and subdued prism reflections similar to those from mounts prepared by settling, and that random distribution of the clay minerals would give intense prism and subdued basal reflections.

The kaolinite grains in flint clay lack preferred orientation; some of the kaolinite grains in semiflint clays are alined parallel to slickenside surfaces, and much of the illite and mixed-layer clays in semiflint and plastic clay is partially oriented. The evidence for lack of orientation of kaolinite in flint clay is based on the X-ray diffraction traces of oriented slices. In the traces, the basal reflections of kaolinite are no higher in slices from one direction than from any other, and the prism reflections are resolved equally well in traces of slices in all directions. Lack of orientation is also shown in the electron micrograph of flint clay (fig. 10). X-ray diffraction traces of semiflint clay slices cut at angles to slickensides are similar to those from flint clay showing general haphazard orientation. Also, no evidence of orientation of kaolinite is present in an electron micrograph of semiflint clay shown by Patterson and Hosterman (1960, p. 191). However, basal reflections from kaolinite are more intense in X-ray diffractometer traces from slickenside surfaces of semiflint clay than from slices cut at angles to the slickenside. Apparently some of the kaolinite grains are oriented parallel to slickensides.

In a general way the hardness of the clay varies directly with the amount of recrystallization of the kaolinite. In flint clay, recrystallization of kaolinite is indicated by light-colored kaolinite grains sufficiently large to be seen with a petrographic microscope. These grains occur in the centers of oolites and scattered throughout an extremely fine grained groundmass (fig. 11, *A*). A small amount of light-colored kaolinite occurs in vermicular or wormlike crystals. Electron micrographs of flint clays (fig. 10) indicate that the kaolinite grains are interlocking and angular, forming a texture somewhat similar to the texture of certain igneous rocks. In semiflint clays, thin sections show no evidence of recrystallization of kaolinite (fig. 11, *B*), and electron micrographs show the kaolinite grains to be much less angular and interlocked than in flint clays. No typical hexagonal kaolinite crystals were observed in either the carbon replicas or the powder electron micrographs.

Some of the illite and mixed-layer clays in thin sections of semiflint clays appear to be partly oriented into wavy distorted bands (fig. 11, B). Some of these bands of partly oriented illite and mixed-layed clay extend along slickensides, and others are enclosed in clay that shows no evidence of parting or movement. Apparently, some slickensides form along zones of weakness caused by partial orientation of clay grains, and very little force and movement are required to form a parting with a shiny surface. Little geologic evidence pertaining to the origin of the bands is available, but they may represent mineral

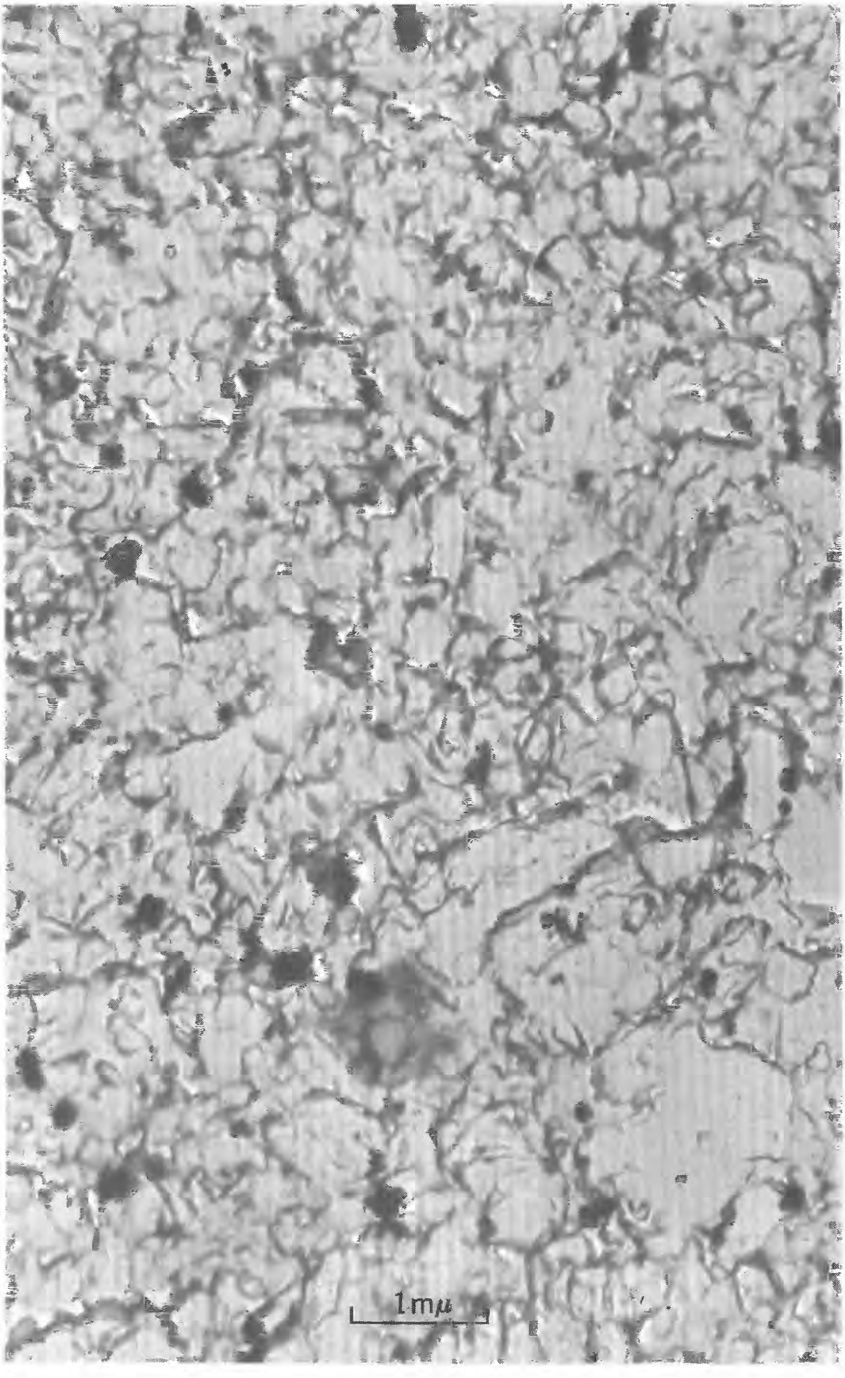

FIGURE 10.—Electron micrograph of carbon replica of flint clay.

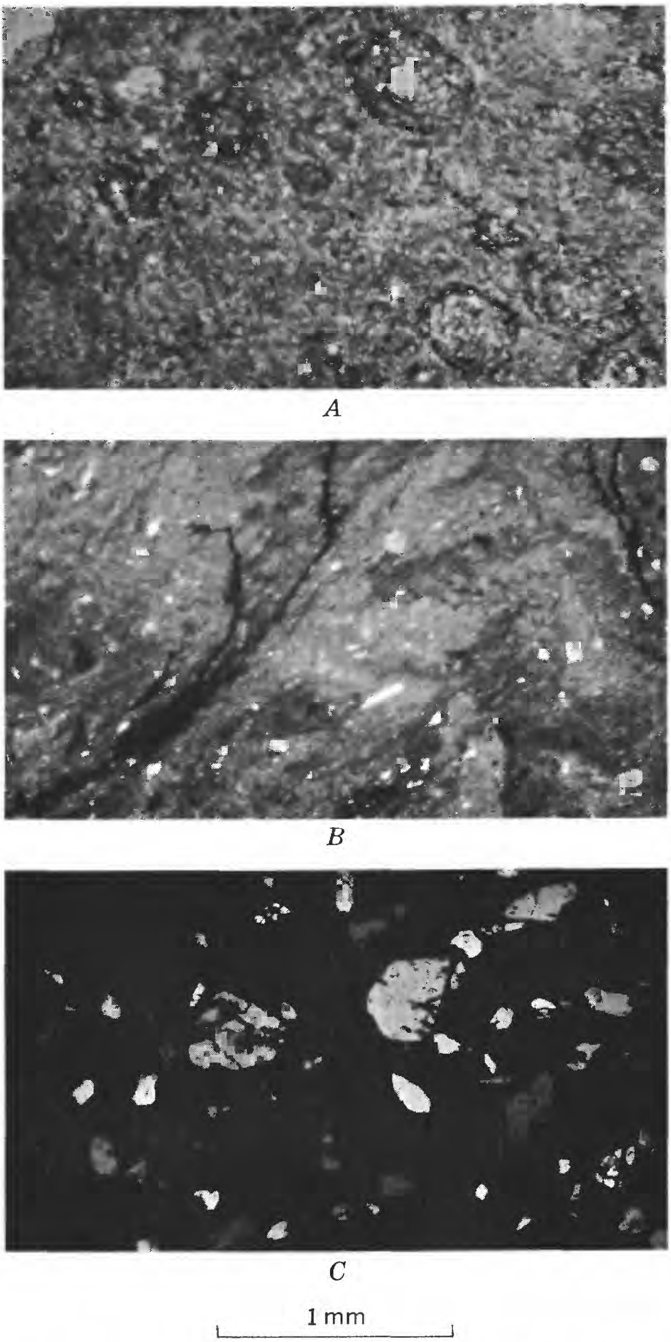

FIGURE 11.—Thin-section photomicrographs. *A*, oolitic bint clay; *B*, silty semiflint clay; *C*, etched and replaced quartz sand grains in flint clay.

orientation by pressures related to the churning action of roots or plastic flowage.

REFRACTORY TESTS

Tests were made (table 6) on 38 samples from the Olive Hill clay bed at 24 localities in the Haldeman and Wrigley quadrangles to evaluate their refractory properties. The tests were made by Richard West and Leon B. Coffin, Ceramic Research Department, Alfred University, Alfred, N.Y. In general, accepted testing procedure such as is outlined by Klinefelter and Hamlin (1957, p. 29–35) was followed; however, some modification of accepted procedure was required because flint clays have no plasticity and cannot be made into test brick without the addition of bonding agents. Ceramic tests of brick made from flint clays to which bonding agents have been added are of questionable value because of the variable effect of the bonding agent on the refractoriness of different samples. Practical procedures for testing the refractory properties of flint clays by using coarsely crushed clay instead of test brick were devised by Messrs. West and Coffin, which are now regarded as standard procedure in the department. In their procedure, the sample is crushed to $3/8$–$1/2$ inch in size and quartered. One portion was used for firing tests and another was ground to pass 70 mesh and used for pyrometric cone equivalent (PCE) tests and chemical analysis. Firing tests were run on three 200-gram portions of the coarse fraction of each sample. Each portion was placed in an alumina crucible of known weight and volume. The specimens were dried overnight at 100° C, cooled, and weighed on an analytical balance. The crucibles and specimens were immersed in kerosene overnight, then the weights of the saturated sample in air and suspended in kerosene were determined to the neareest 0.01 gram. The volumes were calculated from these weights. The specimens were heated in a gas fired kiln to 1,000°, 1,200°, 1,400°, and 1,600° C, and weights were taken and volumes calculated after each firing. Several empty crucibles were heated for control purposes; their volume changes were negligible after heating to all four temperatures. Percentage change in weight and volume, bulk density, and apparent specific gravity were calculated from weights recorded after each firing; all calculations of weight or volume change were based on dry measurement. Pyrometric cone equivalent (PCE) tests were made according to procedure outlined in Designation 24 by the American Society for Testing Materials (1948). The PCE test as stated by Klinefelter and Hamlin (1957, p. 29) is "a standard determination universally used to evaluate the refractoriness of both clays and refractory bodies," and it is probably the best measure of the refractory properties of clays given in table 6. The PCE of a clay is deter-

TABLE 6.—*Refractory tests of samples from the Olive Hill clay bed of*

[Tested by Richard W. West and Leon B. Coffin, Department of Ceramic Research, Alfred University,

Locality No. on plates 2–4	Sample No.	Pyrometric cone equivalent	Percent volume change after heating				Apparent specific gravity after air drying and heating				
			1,000°C	1,200°C	1,400°C	1,600°C	Air dried	1,000°C	1,200°C	1,400°C	1,600°C
Haldeman											
1	1	32½	−15.16	−22.11	−8.17	--------	2.46	2.58	2.48	2.27	--------
	2	34	−15.62	−19.73	−17.43	−6.08	2.50	2.58	2.64	2.57	2.30
	3	32½	−4.22	−16.89	−8.61	+8.10	2.61	2.57	2.56	2.52	2.08
	4	32	−6.67	−12.18	−10.85	+13.68	2.56	2.55	2.53	2.47	2.06
2	5	34−	−11.39	−16.85	−15.56	−13.48	2.54	2.57	2.55	2.58	2.26
3	6	32+	−4.4	−15.7	−11.3	+12.8	2.66	2.62	2.64	2.5	1.93
	7	35	−16.1	−22.1	−19.8	−17.7	2.59	2.72	2.75	2.68	2.53
	8	34+	−14.2	−20.0	−17.2	−11.2	2.55	2.64	2.68	2.66	2.36
4	9	33+	−9.26	−7.10	−4.21	--------	2.54	2.51	2.45	2.28	--------
	10	31+	−4.9	−6.05	−5.72	−7.85	2.51	2.53	2.51	2.50	2.37
	11	32−	−6.98	−6.33	−3.08	--------	2.49	2.56	2.45	2.31	--------
5	12	33−	−8.16	−13.70	−8.16	+18.43	2.50	2.51	2.56	2.39	1.69
6	13	34+	−16.33	−21.41	−19.6	−17.42	2.53	2.64	2.56	2.68	2.53
7	14	33	−10.99	−6.91	+0.71	+16.31	2.55	2.46	2.34	2.23	1.90
8	15	33−34	−16.92	−23.17	−22.23	−19.20	2.51	2.58	2.63	2.63	2.49
9	16	34−	−27.36	−25.20	−22.05	−15.58	2.51	2.92	2.75	2.66	2.48
	17	34−	−9.71	−19.42	−15.33	+13.28	2.53	2.56	2.59	2.61	1.53
10	18	30	−6.89	−11.37	+6.73	--------	2.42	2.35	2.24	1.88	--------
11	19	31	−3.47	−8.68	−8.68	--------	2.56	2.54	2.53	2.45	--------
12	20	33−	−8.44	−8.11	−8.94	+19.86	2.56	2.52	2.47	2.48	2.16
13	21	32−	−16.13	−17.93	−12.76	+7.59	2.56	2.50	2.50	2.45	2.03
	22	33+	0	−2.77	−6.07	−3.81	2.54	2.58	2.55	2.64	2.42
14	23	32	−17.58	−13.32	−3.37	+14.20	2.58	2.57	2.52	2.41	2.02
Wrigley											
15	24	29−	−2.6	−15.8	−6.0	+14.4	2.68	2.62	2.57	2.18	1.71
	25	36	−12.8	−18.9	−17.3	−13.5	2.57	2.66	2.70	2.70	2.50
16	26	33−	−11.6	−14.4	−5.3	+19.9	2.61	2.64	2.64	2.47	1.83
	27	33+	−9.0	−14.4	−9.8	+16.7	2.59	2.64	2.64	2.54	1.88
	28	29−	+4.0	+3.4	+7.2	+29.8	2.61	2.66	2.64	2.52	1.90
17	29	33−	−7.7	−11.5	−10.7	−6.2	2.59	2.73	2.70	2.67	2.42
	30	33+	−9.8	−14.4	−10.0	+10.0	2.59	2.68	2.68	2.54	1.99
18	31	30−	−6.0	−9.0	−9.0	−8.3	2.59	2.70	2.68	2.68	2.46
19	32	32+	−6.2	−12.3	−10.7	−4.6	2.59	2.65	2.69	2.64	2.33
20	33	34−	−10.4	−15.9	−13.5	−4.4	2.59	2.66	2.70	2.64	2.29
	34	30−31	0	−3.0	−.73	+10.8	2.61	2.67	2.70	2.59	2.14
21	35	32+	−7.7	−12.3	−12.9	−4.0	2.63	2.71	2.75	2.66	2.33
22	36	20+	−14.2	−20.4	−12.3	−11.8	2.77	2.98	3.01	2.67	2.01
23	37	32−	−3.0	−3.0	−2.4	−9.3	2.59	2.71	2.70	2.70	2.52
24	38	34−	−13.5	−16.5	−16.1	−11.3	2.59	2.72	2.68	2.62	2.28

Crider (1913) Haldeman and Wrigley quadrangles, Kentucky

Alfred, N.Y. Colors determined by comparison with "Rock Color Chart" (Goddard and others, 1948)]

Percent weight loss after heating				Bulk density of clay after drying and heating					Color of test brick fired at 1,600°C
1,000°C	1,200°C	1,400°C	1,600°C	Air dried	1,000°C	1,200°C	1,400°C	1,600°C	
quadrangle									
16.49	16.83	16.92	--------	2.20	2.17	2.35	1.99	--------	--------
12.94	13.02	13.05	10.90	2.31	2.39	2.51	2.44	2.21	Light olive gray 5Y6/1.
11.63	11.71	11.00	10.57	2.52	2.32	2.46	2.45	2.04	Moderate olive brown 5Y4/4.
11.20	11.28	11.30	12.05	2.45	2.33	2.47	2.44	1.99	Yellowish gray 5Y 7/2.
12.96	13.04	13.06	15.82	2.30	2.26	2.40	2.37	2.18	Light olive gray 5Y 6/1.
10.25	10.75	10.75	11.0	2.38	2.24	2.52	2.39	1.87	Moderate brown 5YR 4/4.
13.25	13.75	13.5	13.5	2.32	2.40	2.58	2.51	2.44	Pale yellowish brown 10YR 6/2.
13.0	13.5	13.5	13.5	2.36	2.39	2.55	2.47	2.30	Pale yellowish brown 10YR 6/2.
12.28	12.32	13.66	--------	2.36	2.28	2.24	2.13	--------	--------
9.48	9.55	9.61	9.16	2.37	2.26	2.27	2.27	2.34	Pale yellowish brown 10YR 6/2.
10.92	11.10	11.02	--------	2.43	2.33	2.31	2.23	--------	--------
12.35	12.42	13.44	15.09	2.41	2.28	2.43	2.26	1.65	Light brown 5YR 6/4.
13.41	13.48	13.35	13.16	2.33	2.41	2.57	2.51	2.45	Very light gray N8.
11.94	11.96	12.39	12.92	2.41	2.37	2.27	2.08	1.79	Light brown 5YR 5/6.
12.80	12.88	12.90	12.13	2.32	2.44	2.64	2.60	2.53	Very pale orange 10Y 8/2.
13.38	13.42	13.43	12.22	2.29	2.74	2.66	2.55	2.58	Very light gray N8.
12.64	12.73	11.25	--------	2.41	2.33	2.61	2.52	1.44	Light brown 5YR 5/6.
9.87	9.96	11.08	--------	2.24	2.17	2.25	1.06	--------	Moderate brown 5YR 4/4.
10.06	9.92	10.07	--------	2.48	2.32	2.45	2.44	--------	--------
12.68	12.77	12.91	12.60	2.44	2.33	2.32	2.41	1.94	Yellowish gray 5Y 7/2.
11.12	11.26	11.30	11.36	2.18	2.06	2.36	2.21	1.80	Pale brown 5YR 5/2.
11.19	11.01	11.03	10.90	2.46	2.20	2.25	2.33	2.28	Very light gray N8.
11.10	11.14	11.17	11.06	2.44	2.63	2.50	2.25	1.95	Light olive gray 5Y 5/2.
quadrangle									
8.5	9.0	9.0	9.25	2.10	1.97	2.27	2.03	1.66	Moderate yellowish brown 10YR 5/4.
13.15	13.75	13.75	13.75	2.38	2.37	2.53	2.48	2.37	Very light gray N8.
13.0	13.0	13.0	13.0	2.42	2.37	2.45	2.22	1.75	Moderate yellowish brown 10YR 5/4.
12.0	12.25	12.25	12.25	2.40	2.31	2.45	2.33	1.80	Moderate yellowish brown 10YR 5/4.
4.75	4.5	4.5	4.5	2.49	2.28	2.30	2.22	1.83	Medium light gray N6.
12.0	12.0	12.0	12.0	2.43	2.31	2.42	2.40	2.28	Pale yellowish brown 10YR 6/2.
12.5	12.5	12.5	12.5	2.40	2.32	2.45	2.32	1.91	Moderate yellowish brown 10YR 5/4.
10.5	11.0	11.0	11.0	2.40	2.28	2.34	2.34	2.32	Medium light gray N6.
10.0	11.5	11.5	11.5	2.43	2.31	2.45	2.41	2.26	Pale yellowish brown 10YR 6/2.
12.5	13.0	13.0	13.0	2.40	2.34	2.48	2.41	2.18	Pale yellowish brown 10YR 6/2.
7.0	7.5	7.5	7.5	2.43	2.26	2.32	2.27	2.03	Medium light gray N6.
12.5	13.0	13.0	13.75	2.47	2.34	2.45	2.41	2.22	Pale yellowish brown 10YR 6/2.
15.0	15.25	15.5	16.0	2.47	2.45	2.63	2.38	2.36	Blackish red 5R 2/2.
10.0	10.5	10.25	10.5	2.43	2.26	2.24	2.24	2.40	Medium light gray N6.
13.75	14.25	14.0	14.0	2.38	2.37	2.44	2.45	2.28	Moderate yellowish brown 10YR 5/4.

mined by preparing a pyramidal cone of certain dimensions and heating it along with standard cones in a specified manner until deformation takes place. The PCE is the number of the standard cone whose tip would touch the supporting plaque at the same time as that of the clay cone tested.

The ceramic properties of 38 samples tested (table 6) varied considerably. On the basis of pyrometric cone equivalents, 16 samples were in the superheat duty range (cone 33 or greater, 1,745°C or higher), 15 samples were in the high heat duty range (cone 31 to 33, 1,680°+ to 1,745°C), 6 samples were in the intermediate heat duty range (cone 26 to 31, 1,595° to 1,680°C), and 1 sample was low heat duty (cone 20+, 1,530°C). The volume change, specific gravity, weight loss, and bulk density of the samples also cover broad ranges. However, only extreme changes in these properties cause the clay to be unusable, because shrinkage and bloating can be controlled to some extent by such techniques as (1) adding grog when making brick, and (2) by gradually elevating the temperature during firing to allow the escape of evolving gases.

In a general way the refractoriness of the clay varies directly with the amount of kaolinite and inversely with the proportions of other minerals that are present. All five samples having PCE's in the range 34 to 36 (table 5) are estimated to contain 90 to 95 percent kaolinite, whereas samples consisting of about half kaolinite have PCE's in the range 29 to 30. Theoretically, kaolinite consists of 39.5 percent Al_2O_3, and it is this alumina that gives the clay its refractory properties. The increase in PCE as the alumina content increases toward the composition of theoretical kaolinite is shown for the samples tested in figure 12. Minerals other than kaolinite have variable effects on the refractory properties of clays. Appreciable amounts of quartz are present in some clays used for refractory brick. This mineral apparently acts primarily as a diluent and samples containing as much as 30 to 40 percent quartz have pyrometric cones greater than 30 (table 5, samples 34 and 37). The iron-bearing minerals, such as siderite, pyrite, and iron oxides, act as fluxes and greatly reduce the refractory properties of the clay. None of the samples having PCE's of 34 or more contained as much as 1 percent iron oxide (fig. 12), and the PCE of the one sample in which the amount of siderite was estimated to be 10 percent (table 5, sample 36) was only 20+. Potassium, sodium, and calcium-bearing minerals also act as fluxes and small amounts of these minerals will greatly reduce the refractoriness of the clays (fig. 12). Most of the potassium, sodium, and calcium is probably contained in or closely associated with the illite and mixed-layer clay minerals, and none of the samples having PCE of 33 or greater con-

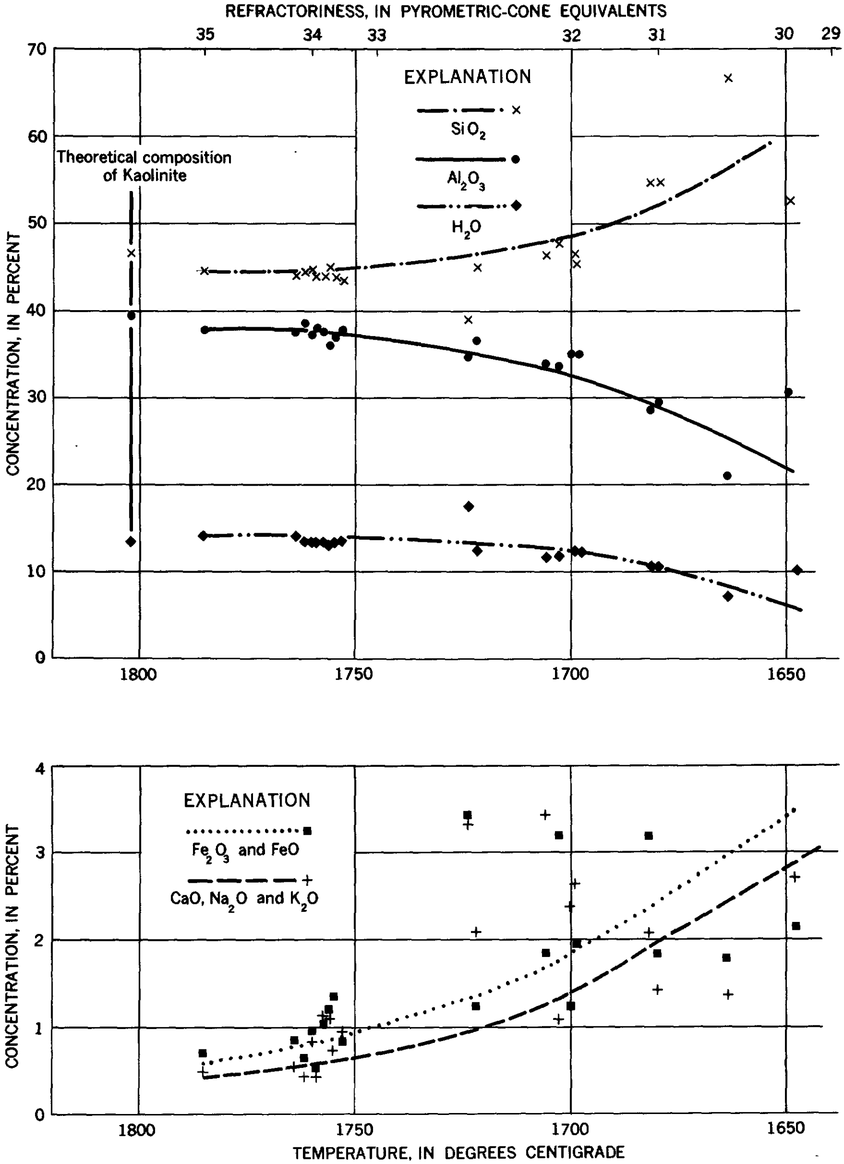

FIGURE 12.—Graphs showing the influence of variations in content of alumina and other oxides on the refractory properties of clay in the Olive Hill clay bed of Crider, 1913.

tained more than an estimated 10 percent of these clay minerals (table 5). However, the true effect of illite and mixed-layer clay minerals on the refractory properties is somewhat obscure because the proportion of illite and mixed-layer clays tend to vary directly with the amount of iron present. Organic matter burns off during firing of the brick and has little or no effect on the refractory properties, if the evolving gases are allowed to escape gradually before the exterior of the brick vitrifies.

Color of the fired clay is of minor importance for use in refractory products, but some of the clay in the Olive Hill bed may eventually be used in products such as face brick, for which fired color is critical; chiefly for this reason, the colors of the fired samples are recorded in table 6. Light color is indicative of refractory products because, in a very general way, the color darkens as amounts of certain components, chiefly iron compounds, that reduce refractoriness increase. For example, the most iron-rich sample tested (sample 36, tables 5, 6) is blackish red and had very low refractory properties, whereas samples which are low in iron are very light shades of gray and brown and had good or excellent refractoriness. In addition to the samples listed in table 6, four samples, for which data are not given in this report, were tested for possible use in face brick. Of these, 1 sample, which was from semiflint clay, fired very light cream buff and had the plasticity and other properties required for making face brick; and 2 samples, which were from flint clay, fired sufficiently light colored but lacked the plasticity required for face-brick manufacture.

RESOURCES OF CLAY IN THE OLIVE HILL BED

The available information on which to calculate tonnages of clay in the Olive Hill bed in the Haldeman and Wrigley quadrangles varies considerably from place to place; because of this variability, estimates of the amount of clay present were calculated in different ways in three areas. The areas are designated, for purposes of discussion only, as Haldeman A, Haldeman B, and Wrigley.

Haldeman A is the irregularly shaped area, mostly in the eastern half of the Haldeman quadrangle, in which thicknesses and shapes of clay bodies are shown by isopach lines on plate 8. Several hundred logs of drill holes and many measurements of the clay from mine workings and from natural exposures were available in this area. Calculations of tonnages of clay in the Haldeman A area are, in effect, measured tonnages, whereas those in the other two areas are much less accurate.

Haldeman B is that portion of the Haldeman quadrangle occupied by the Lee formation; it contains clay for which sufficient information is not available on the thickness of clay to permit construction of isopach lines (pl. 8). A fair amount of information regarding thicknesses of the clay was available, however, from the logs of many scattered drill holes and prospects, as well as from numerous natural outcrops. Tonnages of clay in Haldeman B area are inferred, but the basis for the inferences was reasonably sound.

The third area is the entire Wrigley quadrangle except those portions from which the Lee formation has been eroded. The information available for the estimation of the amount of clay present in the Wrigley area was by far the least. The clay and the rocks that enclose it are covered in all but a few places in the Wrigley quadrangle, and only 20 natural exposures were located during fieldwork. The clay has been explored by drilling only in a few properties in the northeast, north-central, and southwest parts of the quadrangle. The resource estimates for the Wrigley quadrangle are all in the inferred category, and the basis for the inference is, in large measure, speculative.

Estimates of the amount of clay in the Olive Hill bed in the two quadrangles were made by calculating the clay for the Haldeman A area, determining the average amount of clay per square mile, and projecting this average figure to the Haldeman B and Wrigley areas. Inasmuch as the clay bed occurs in the lower part of the Lee formation, the areas where this formation has been eroded (shown as rocks of Mississippian age in pls. 2, 3) were excluded from all calculations. Also, all clay less than 2 feet thick was considered too thin to be mined profitably and was excluded from the calculations. Areas between successive isopach lines (pl. 8) were measured in square miles with a polar planimeter, and the number of cubic feet of clay underlying each area was calculated and weight in tons was estimated on the assumption that 12.8 cubic feet of clay weighs approximately 1 ton. The 12.8 figure is based on specific gravity measurements (table 6) of air-dried clay, and all figures are on air-dried basis. So many assumptions were necessary in calculating tonnages of clay in the Olive Hill bed that the figures given may be in error as much as 50 percent.

The original tonnage of clay in the Haldeman A area is calculated to have been 85 million tons, and the average per square mile, 3½ million tons. Approximately 19.1 square miles is occupied by the Lee formation in the Haldeman B area, and this area is estimated to contain 65 million tons of clay. Clay has been mined in the Haldeman A area since 1903. Approximately one-half of the high-grade clay in this area has been mined or lost in mining, and much of the remaining clay is of too low grade for use. Accordingly, the clay in this area can be reduced by one-half, or to about 40 million tons, and thus the total resources of clay in the Haldeman quadrangle are about 100 million tons. Of this figure, only about one-fifth, or 20 million tons, is probably suitable for use in refractory products, and only a fraction of this amount is of the quality required for superheat duty refractory products.

The Lee formation occupies approximately 49.8 square miles in the Wrigley quadrangle; as much as 175 million tons of clay may be present in this quadrangle. Approximately one-half of this clay is below local drainage levels and at such depths that vertical shaft mining would be required. The clay probably could not be mined profitably under economic conditions that will exist in the foreseeable future, and for most purposes the resources of clay in the Wrigley quadrangle can be reduced by one-half. Furthermore, the proportion of high-quality clay in the Olive Hill bed is probably lower in the Wrigley than in the Haldeman quadrangle, because sand and siderite are abundant in much of the clay in the Wrigley quadrangle (pl. 6) and several of the samples from the Wrigley quadrangle tested (table 6) were of low-quality clay. Probably no more than 8 to 10 million tons of the clay in the Wrigley quadrangle can be considered to be reserves of refractory clay.

Much of the clay in both quadrangles that is unsuitable for use in high-grade refractory products may eventually be used for some purpose other than refractory products. Some of the low-refractory clay is very light colored after firing (table 6) and would be suitable for face brick on low-heat duty refractory products. Also, much of the clay may some day be used as a source of alumina. Probably much of the clay that is unsuitable for refractory products because of high iron contents could be used for extraction of alumina at costs only a few cents a pound higher than ores currently used.

Information available to the authors regarding the extent of areas in which the clay in the Olive Hill bed has been mined underground was incomplete and only areas mined by stripping are illustrated in this report (pl. 2). Essentially all the large clay bodies in the northeast quarter of the Haldeman quadrangle have been mined underground except the deposits in the Greenbrier Creek valley. Most of the high-grade clay in bodies that have been mined is depleted except in areas where underground mining is active (see p. F49). In addition to deposits in the northeast quarter of the quadrangle, the bodies shown by isopach lines (pl. 8) in an area east of Buffalo Branch southwest of Haldeman on Walker Branch, and in a small stream valley 1.1 miles due west of Elliottville (pl. 2) are depleted of high-grade clay. Clay deposits east of Cold Spring Branch (not shown on the isopach map) were mined many years ago; they also are probably exhausted. Large tonnages of low-grade clay are still present in areas in which the high-grade clays are exhausted. Appreciable tonnages are also present at sites suitable for strip mining, but much of this near-surface clay is high in iron content and is unsuitable for use in refractories.

ORIGIN OF THE CLAY

Stratigraphic, paleontological, mineralogical, and chemical evidence all support the conclusion that the clay deposits in the Olive Hill clay bed were formed by the alteration of ordinary fine-grained Pennsylvanian sediments in acid swamps. Some of the facts and observations pertaining to the origin of the clay are as follows:

1. The clay is a true underclay as indicated by (a) the thin overlying coal bed, (b) abundant fossil plant roots, *Stigmaria* (fig. 7), in the clay, including main root stocks with rootlets attached, (c) lack of bedding in the clay, (d) abundant slickensides in semiflint and plastic clays.
2. Root fossils indicate that the clay supported plant growth and, therefore, served as a subaqueous soil; however, evidence for a soil profile in the clay is lacking.
3. The clay bed is discontinuous and consists of irregular lenses having no preferred orientation.
4. Essentially all of the clay is acid according to pH measurements of 40 samples (table 5). Two of these samples were neutral and 38 were acid ranging down to pH 3.9
5. The kaolinite, illite, and mixed-layer clay minerals in plastic clays are similar to clay mineral assemblages in Pennsylvanian shales enclosing the clay bed. Schultz (1958, p. 363, 377, 378) also observed close mineralogic relationships between several plastic underclay beds and enclosing shales.
6. Proportions of kaolinite increase gradually from plastic to flint clay, and this increase is accompanied by a corresponding decrease in the amounts of illite and mixed-layer clays present.
7. Recrystallization of the kaolinite in flint clay is indicated by interlocking grains and by comparatively light colored large kaolinite grains in a dark-colored, very fine grained groundmass. Semiflint and plastic clays show little evidence of recrystallization.
8. Some of the quartz grains in sandy flint clays are fresh, but others show evidence of solution and replacement by clay (fig. 11, *c*).
9. The clay bed contains virtually no feldspar.
10. The titania content of most flint clays is about 2.0 percent, of semiflint about 1.5 percent, and of plastic clay 1.0 to 1.5 percent. Titania is one of the most stable of all chemical components, and if it

has not migrated the increase in percentage from plastic to flint clay indicates a residual enrichment.

The shapes of the irregular lenses of clay, the relation of lithologic units within the bed, the presence of fossil roots, the absence of a soil profile, the lack of bedding, overlying coal, and marine or brackish-water fossils in the dark shale above the clay—all point toward an origin of the clay in coastal swamps. Clearly the irregular-shaped lenses of clay lack the orientation, continuity, and bedding that would be expected if they (1) were formed by dissection of a blanket of sediment, (2) accumulated in channels, as in certain kaolin deposits of Tertiary age in Mississippi (L. C. Conant, unpublished data, 1958), or (3) formed in cutoff stream meanders as has been suggested by Kesler (1956, p. 553) for the kaolin deposits in Georgia. The irregular shapes and lack of orientation of the clay lenses, however, would be expected if the deposits accumulated in swamps in which bodies of water were irregular in shape and depth. Further evidence that the clay deposits formed in swamps lies in the root fossils in the clay and the overlying coal; this relation is remarkably in accord with the invasion of modern swamps by plants and with the accumulation of peat in modern swamps, as described by Twenhofel (1950, p. 81–84). The best explanation for the absence of a soil profile seems to be that none developed because the clay was water logged at the time it served as a soil. The lack of bedding in the clay is probably due to the churning action of roots and to plastic flowage. The later gradation from virtually pure clay to very sandy clay appears to be similar to the decrease in grain size away from shore in sediments in modern swamps diagramed by Twenhofel. A sparse fauna, chiefly small *Lingula*, in the shale a short distance above the clay, and the conformable relation of the shale and clay suggest that only slight subsidence was required to lower the clay below sea level. This, in turn, suggests that the swamps were located along coastal lowlands, a possibility that seems in accord with the evidence for deltaic deposition in the sandstone facies of the Lee formation.

The clay appears to have formed by the leaching and alteration of ordinary fine-grained Pennsylvanian sediments in acid swamps, a theory similar in some respects to those proposed by Keller and others (1954) and by McMillan (1956). Inasmuch as the clay minerals in plastic clay do not differ greatly from those in the Pennsylvanian shales enclosing the clay bed, there is no reason to assume that special sedimentary sorting processes were involved. The three types of clay—plastic, semiflint, and flint clay—can be explained as representing progressive stages of leaching. According to this theory kaolinite formed concurrently with the removal of alkalies and silica from illite and mixed-layer clays and certain non-clay minerals. Leaching of the clay is indicated by both direct and indirect evidence, but unfortunately there is little evidence to support the idea that kaolinite formed from other clay minerals, and nothing to reveal what happened to the dissolved materials. The etched quartz grains and their replacement by clay minerals are convincing evidence that leaching took place. Also, the absence of feldspars, which are present in many plastic underclay beds, is suggestive of leaching. The 50-percent increase in titania from plastic clay to flint clay seems to represent an expected increase in resistates with leaching. The root fossils provide still another line of indirect evidence, for they clearly indicate that the clay supported plants; and alkalies and perhaps silica would be removed from any material that served as a soil. Perhaps most of the leaching took place while the rotted roots of many generations of plant growth provided channels for the acid waters to circulate through the sediments lying on the floors of the swamps. The materials removed by the leaching process and by upward diffusion into the overlying body of water were flushed away by sluggish movement of water through the swamps. The acidity of the swamps is indicated by the present acid characteristics of the clay, by the overlying coal, and by organic materials scattered throughout the clay. A suggestion that kaolinite formed from other clay minerals lies in the relation of crystallinity of the kaolinite and its proportions to other clay minerals in the three types of clay. The kaolinite in plastic clay is a poorly crystallized fireclay variety, and its proportion to other clay minerals is low. The flint clay is essentially pure kaolinite that is well crystallized. In the semiflint clay, the perfection of the kaolinite structure as well as the proportions present are intermediate betwen plastic and flint clay. This progressive increase in the perfection of the kaolinite structure accompanying a decrease in the amount of other clay minerals seems more than a coincidence, and it may represent a tendency for the crystal structure of kaolinite to become more perfect as the alkalies and silica are leached.

CLAYS AND SHALES EXCLUSIVE OF THE OLIVE HILL CLAY BED OF CRIDER, 1913

Large deposits of shale and considerable amounts of underclay, exclusive of the Olive Hill bed, are present in the Haldeman and Wrigley quadrangles, and very large tonnages of these rocks are probably suitable for use in certain ceramic products. None of these rocks has been mined for ceramic raw materials, but some of them could be used for sewer pipe, drain tile, and structural clay products, and some of the shales are probably suitable for making lightweight aggregate. Underclay beds occur in the shale facies of the Lee formation and in the Breathitt formation of Pennsylvanian age. Shale is present in several formations, but only the Muldraugh formation, the Haney limestone of McFarlan and Walker (1956) of Mississippian age, and the shale facies of the Lee and Breathitt formations contain beds of sufficient thickness to be considered as possible sources of ceramic materials.

Much of the red and green shales in the Muldraugh formation of Mississippian age would probably be satisfactory for use in structural clay products. Although this formation is rarely more than 20 feet thick, there are many localities where considerable tonnages of clay could be mined in the Haldeman quadrangle. In most outcrops in the Wrigley quadrangle, this formation is too thin to be considered as a potential source of ceramic raw materials. Investigations of samples of shale from the Muldraugh formation at three localities by X-ray and petrographic microscope revealed that the shale is composed chiefly of illite, kaolinite, and mixed-layer clay minerals (table 7, 10–12). Red and green shale samples from the same locality (table 7, 10–11) gave essentially identical X-ray diffraction patterns, and presumably the difference in color is due to variations in the oxidation condition of the iron. The amount of fine-grained quartz sand and silt varies a great deal from place to place. One sample of green shale from the Muldraugh formation was analyzed chemically (table 8, sample 3) and tested for possible use as a bloating clay. This channel-type sample was taken at an outcrop of shale 13 feet thick at a point along the road at the head of the Dry Creek valley, Haldeman quadrangle (pl. 4, section 11).

The one sample of shale from the Muldraugh formation tested at the U.S. Bureau of Mines Electrotechnical Experiment Station had very poor bloating properties; however, it is probably suitable for use in common brick and tile. This shale is smooth working, requiring 25 percent water for plasticity and drying with 3 percent shrinkage without defects. An estimate of the mineral composition of this sample is given in table 7 (No. 12) and a chemical analysis in table 8 (sample 3). Firing characteristics of this shale are given below.

Temperature (degrees F)	Color	Hardness	Apparent specific gravity
1,800	Buff	Fairly hard	2. 63
2,000	Orange buff	Very hard	2. 62
2,100	Red brown	Steel hard	2. 49
2,200	Brown	do	2. 36
2,300	do	Expanded	2. 14
2,400	do	do	1. 75

TABLE 7.—*Estimated mineral composition (in parts of ten) of clays and shales, exclusive of the Olive Hill clay bed of Crider (1913), in the Haldeman and Wrigley quadrangles, Kentucky*

[*Chemical analyses given in table 8. **Chiefly mixed-layered illite and montmorillonite]

Sample No.	Type of rock	Formation	Quartz	Clay minerals			
				Illite	Kaolinite	Mixed-layer**	Chlorite
1*	Plastic underclay.	Breathitt	2–3	3–4	4–5	Tr.	
2	Flint clay	do	1		9	Tr.	
3	Plastic underclay.	do	3–4	1	3–4	1	1
4*	Dark-gray shale	Lee	3–4	2–3	2–3	1–2	
5	do	do	2–3	3–4	3–4	½	½
6	Plastic underclay.	do	2	1–2	5	1–2	
7	Sandy plastic underclay.	do	5	2	2	1	
8	Plastic underclay.	do	3–5	2	4	½	
9	do	do	1	2–3	6	2	
10	Red shale	Muldraugh	1	5	1	3	
11	Green shale	do	2	3–5	1	2–5	
12*	do	do	2	4	½	3–4	
13	Purplish-gray shale.	Haney limestone of McFarlan and Walker.	Tr.	9		Tr.	

NOTE.—Source of samples:
1. Plastic underclay 1 foot 10 inches thick below Nickell coal bed in upper part of Breathitt formation, at a point along Route 7, Wrigley quadrangle (pl. 5, section 11).
2. Flint clay, sample obtained from dump of old mine in Fire Clay coal bed, at a point 50 feet east of the Wrigley quadrangle and 1,000 feet south of Road Fork.
3. Plastic underclay 2 feet thick in lower part of Breathitt formation, North of Blaze (pl. 5, section 8).
4. Dark-gray shale, Lee formation, composite of chip samples from beds 20 feet thick exposed in high wall of strip mine east of road junction 961 in Open Fork valley, Haldeman quadrangle.
5. Dark-gray shale, Lee formation, composite of chip samples of beds 25 feet thick exposed in high wall of strip mine on south side of Mocabee Creek valley near east edge of Haldeman quadrangle.
6. Plastic underclay 2 feet thick exposed along road near head of west fork of Buffalo Branch, Haldeman quadrangle (pl. 5, section 1).
7. Plastic underclay 1 foot 4 inches thick, same location as 6.
8. Plastic underclay 2½ feet thick exposed along road between Bearskin Branch and Jones Branch, Haldeman quadrangle (pl. 3, section 3).
9. Brown plastic underclay 5 feet thick above the Olive Hill clay bed, Sugartree mine (pl. 6, No. 7), Haldeman quadrangle.
10. Red shale, Muldraugh formation, grab sample, from exposures along mine access road near cemetery on west side of Open Fork valley, Haldeman quadrangle.
11. Green shale, same as 13.
12. Green shale, Muldraugh formation, channel sample from beds 13 feet thick, at a point along road at head of the Dry Creek valley, Haldeman quadrangle (pl. 4, section 11).
13. Purplish-gray shale, Haney limestone of McFarlan and Walker, channel sample of beds 18 feet thick in high wall of overburden stripped above limestone at Kentucky Road Oiling Co. quarry, Christy Creek valley, Haldeman quadrangle.

The Haney limestone of McFarlan and Walker (1956) in some places grades laterally into a calcareous shale that may have some slight potential for use in making light-weight aggregate. One locality where this limestone formation is represented by shale is at the limestone quarries along the north side of the Christy Creek Valley, Haldeman quadrangle. Approximately 90 percent of one sample of this shale (table 7, sample 13) examined in the laboratory was composed of illite, and the other 10 percent was chiefly calcite and mixed-

TABLE 8.—*Chemical analyses of shales, sandstones, and a siltstone from the Haldeman quadrangle, and a sample of plastic underclay from the Wrigley quadrangle, Kentucky*

[Analyses by P. L. D. Elmore, S. D. Botts, and M. D. Mack under the supervision of W. W. Brannock, employing methods similar to those of Shapiro and Brannock (1956). Summations rounded to nearest whole number. *Sample contains appreciable organic matter, which may have caused inaccuracy in the value of FeO]

	1	2	3	4	5	6	7
SiO_2	93.6	92.7	66.4	56.3	74.6	55.6	62.3
Al_2O_3	3.1	3.8	16.2	21.9	9.6	16.2	22.3
Fe_2O_3	1.1	1.0	4.2	1.6	1.5	5.9	1.4
FeO	.07	.07	.76	3.4	4.4	.81	.40
MgO	.18	.26	1.5	1.2	1.0	2.0	.42
CaO	.11	.09	.26	.37	.64	4.2	.08
Na_2O	.14	.15	.18	.19	.72	.11	.21
K_2O	.63	.78	4.0	2.9	2.4	4.2	2.5
TiO_2	.16	.21	.91	1.1	.76	.64	2.1
P_2O_5	.00	.00	.00	.24	.22	.08	.04
MnO	.02	.01	.03	.08	.04	.01	.00
H_2O	.58	1.0	5.3	6.3	2.4	7.6	7.3
CO_2	.05	.05	.05	1.5	1.4	2.5	.12
Sum	100	100	100	*97	100	100	99

NOTE: Source of sample—

1. Sandstone, Lee formation, composite of chip sample from exposures 57 feet thick along graveled road extending up steep hill at head of tributary to Dry Creek, Haldeman quadrangle (pl. 4, section 11) (lab. No. 148098).
2. Sandstone, Lee formation, composite of chip samples taken at 1 foot intervals of 106 feet of diamond-drill core, hole located on ridge east of head of Minor Creek, Haldeman quadrangle (samples obtained through courtesy of General Refractories Co.) (lab. No. 148099).
3. Green shale, Muldraugh formation, channel sample from exposure 13 feet thick along graveled road extending up steep hill at head of a tributary to Dry Creek, Haldeman quadrangle (pl. 4, section 11) (lab. No. 148100).
4. Dark-gray shale, Lee formation, composite of chip samples from beds 20 feet thick exposed in high wall of strip mine east of road junction 961 in Open Fork valley, Haldeman quadrangle (lab. No. 148101).
5. Siltstone, Brodhead formation, composite of chip sample from outcrops 20 feet thick on north side of Route 32, ⅛ mile west of Pattys Lick, Haldeman quadrangle (lab. No. 148102).
6. Purplish-gray shale, shaly facies of Haney limestone of McFarlan and Walker, channel sample of beds 14 feet thick which form the overburden above the limestone at Kentucky Road Oiling Co. quarry, Haldeman quadrangle (pl. 4, section 6) (lab. No. 148103).
7. Underclay, light- to medium-gray, 1½ feet thick, below Nickell coal bed, exposed along Route 7 south of Wrigley, Wrigley quadrangle (fig. 3a, section 11) (lab. No. 150138).

layer clay minerals. The calcium content of this shale virtually rules it out as a possible source of raw materials for structural clay products, but some of it may be suitable for use in making light-weight aggregate. No bloating-test data are available for this shale.

Very large reserves of dark-gray shale are present in the Lee formation above the Olive Hill clay bed outside the area investigated, and shale in this stratigraphic position is used as ceramic raw material. The largest deposits of dark-gray shale are in the shale facies of the Lee formation in the northern half of the Haldeman quadrangle, but some shale is also present above the Olive Hill bed in the southern half of the Haldeman and in the Wrigley quadrangles. In many places the dark-gray shale forms most of the overburden that is stripped from the Olive Hill clay bed. Both the Olive Hill clay bed and the shale above it are mined at Clack Mountain, 2 miles beyond the western boundary of the Haldeman quadrangle, by the Lee Clay Products Co., Morehead, Ky. The clay and the shale are mixed and made into sewer pipe, drain tile, and certain structural clay products. Ceramic tests of two samples of very similar shale from the Lee formation at points northeast of the Haldeman quadrangle are given by Floyd and Kendall (1955, p. 42–43). Both samples slaked readily, were plastic, and worked well in an extrusion machine. They had fair air-dried strengths, and their firing range was 1,125° to 1,210°C. Possible use for sewer pipe and structural clay products was suggested.

Mineralogical investigations and bloating tests were made on two samples of dark-gray shale in the Lee formation. A chemical analysis was also made of one of the samples (table 8, sample 4). Both samples were composite chip samples from strata several feet thick exposed in high walls of a strip mine in the Haldeman quadrangle. These two samples consisted chiefly of the clay minerals illite and kaolinite and fine-grained quartz; they contained appreciable amounts of mixed-layer clay minerals, and a small amount of chloritic clay was present in one sample. Bloating tests were made at the U.S. Bureau of Mines Electrotechnical Experiment Station, Norris, Tenn. Both samples were dark-gray shale that had been crushed and seived. Only the fraction that passed through number 2 and was retained on number 4 mesh seive was tested. The tests show that some of the shale is potentially good bloating material; however, complete evaluation for this purpose would require pilot plant testing. Firing characteristics of these two samples of shale are given in table 9.

Dark-gray shales that are similar in appearance to those in the Lee formation occur at several different stratigraphic positions in the Breathitt formation. None of these shales have been used in the vicinity of the area investigated, and neither mineralogical, chemical, nor ceramic test data are available.

Variable plastic underclay beds occur at several stratigraphic positions in the shale facies of the Lee formation above the Olive Hill clay bed (pl. 4), but none of these clays serve as sources of ceramic raw materials. These underclays range in thickness from 0 to nearly 10 feet, and commonly they wedge out from their maximum thickness within a few hundred yards. At many places, the underclays grade laterally into sandstone or siltstone. The most promising of these underclay beds overlies the thin coal bed above the Olive Hill clay bed.

This clay has been tested at many places by refractory companies to determine if it could be mined in conjunction with the Olive Hill bed. It has been found to be exceedingly variable, and attempts to use it

TABLE 9.—*Firing characteristics of dark-gray shale in the Lee formation*

Sample	Temperature (degrees F)	Bulk specific gravity	Absorption (percent)	Remarks
1	1, 800	1. 72	10. 6	No bloating.
	1, 900	1. 37	16. 0	Slight bloating.
	2, 000	1. 39	14. 7	Do.
	2, 100	1. 13	17. 8	Fair bloating, sticky.
	2, 200	1. 05	19. 1	Fair bloating, very sticky.
	2, 300	. 90	17. 0	Overbloated, very sticky.
	2, 400	. 85		Do.
2	1, 800	1. 29	18. 6	Slight bloating.
	1, 900	1. 19	21. 5	Do.
	2, 000	1. 02	26. 1	Fair bloating.
	2, 100	. 84	28. 8	Good bloating.
	2, 200	. 66	31. 7	Good bloating, slightly sticky.
	2, 300	. 48	32. 1	Overbloated, very sticky.
	2, 400	. 45	36. 8	Overbloated, melted and viscous.

NOTE. Source of sample:
1. Dark-gray shale, Lee formation, composite of chip samples from beds 20 feet thick exposed in high wall of strip mine east of road junction 961 in Open Fork Valley, Haldeman quadrangle.
2. Dark-gray shale, Lee formation, composite of chip samples of beds 25 feet thick exposed in high wall of strip mine on south side of Mocabee Creek Valley near east edge of Haldeman quadrangle.

have not been successful. All of the plastic underclays in the Lee formation (table 7, samples 6–9, consist chiefly of mixtures of the clay minerals kaolinite and illite, with varying amounts of mixed-layer clays and clastic quartz. The high proportions of illite and mixed-layer clay minerals in these clays indicate rather high content of alkalies, and probably none of the clays have high refractory properties.

Underclays also occur at several stratigraphic positions in the Breathitt formation, (pl. 4). Most of these underclay beds are thin and discontinuous and are similar to those in the Lee formation. None of them has been worked for ceramic raw materials and there is little likelihood that they will ever be developed.

Mineral compositions of samples of three underclays in the Breathitt formation were estimated in the laboratory, and ceramic tests and a chemical analysis were made of one of the samples. (1) The first sample was taken from a bed in the lower part of the Breathitt formation at an outcrop north of Blaze, Wrigley quadrangle (pl. 5, section 8). Approximately one-third of this sample was quartz (table 7, sample 3). Kaolinite was the most abundant clay mineral, but mixed-layer and chloritic clay minerals were also present. (2) The second sample was of dark-gray flint clay from the parting in the Fire Clay coal bed and was taken from the dump of the old Clearfield Co. mine (p. F104), a short distance east of the Wrigley quadrangle. This flint clay bed is probably no more than 2 or 3 inches thick, but it is of interest because it is the only flint clay in the Haldeman and Wrigley quadrangles in rocks younger than the Olive Hill clay bed. The sample was composed of approximately 90 percent well-crystallized kaolinite and 10 percent angular, very fine grained quartz sand and silt. Traces of mixed-layer clay minerals were also present. The dark-gray color of this flint clay no doubt reflects a higher content of finely disseminated carbon that is common in most of the Olive Hill clay (p. F52 and F67). (3) The third sample was taken from the underclay below the Nickell coal bed at a point along Route 7 at the top of the hill south of Wrigley (pl. 5, section 11). The underclay at this point is 1½ feet thick and consists of light- to medium-gray plastic clay with abundant slickensides. It consists chiefly of kaolinite and illite (table 7, sample 1), but a small amount of mixed-layer clay is also present. Quartz of silt and fine sand size makes up about one-quarter of the bed. The clay has low-grade refractory properties (PCE 27+) as compared to high-grade refractory clay of the Olive Hill bed (table 5). The color of the test brick was grayish orange after firing at 1,000°C, yellowish gray in the range 1,200° to 1,400°C, and yellowish brown after firing at 1,600°C. The sample fired maintained satisfactory density characteristic at the lower temperatures, but it bloated excessively when fired at temperatures above 1,400°C. The chemical analysis of this clay (table 8, sample 7) indicates that it contains 2.5 percent K_2O, which is probably the cause of the low refractory properties of the clay. Most of it is no doubt contained in the illite. The large content of silica shown in the analysis is due to the high content of clastic quartz.

LIMESTONE

The rocks in the Haldeman and Wrigley quadrangles contain large quantities of marketable limestone. Though it is chiefly in beds less than 15 feet thick, large quantities lie under light overburden in narrow belts along outcrops and can be easily stripped and quarried. Nearly all of the limestone that is produced is used as road metal, agricultural lime, and concrete aggregate. Some of it has been shipped for use as flux in steel mills, and small amounts of dolomitic limestone are reported to have been dug from small prospect type openings in the Warsaw(?) formation for carving or ornamental stone.

Several hundred thousand tons of limestone have been taken from three quarries in the Haldeman quadrangle, and favorable sites for additional quarries are present at several localities. At the time of the field investigations (1955–57) the only active quarry in this quadrangle was operated by the Kentucky Road Oiling Co. on the north side of Christy Creek, between Seas Branch and Open Fork. Abandoned quarries are located near the Christian Cemetery, on the north side of Christy Creek, and on a branch of Craney Creek in the south-central part of the quadrangle. The Beech Creek limestone of Malott, 1919 and St. Louis limestone, the only two formations from which limestone has been quarried, have been worked at all three quarries. The Beech Creek is a high-calcium (95 percent or more calcium carbonate) limestone that is nearly white in color and has rather uniform purity and chemical composition. The calcium carbonate content of three samples analyzed ranged from 97.1 to 98.1 percent (table 1, samples 7, 8, and 9). The St. Louis limestone is dark to medium gray and is much less consistent in composition than the Beech Creek, principally because of variation in the amount of chert (SiO_2). The calcium carbonate content of three samples taken from the St. Louis ranged from 87.6 to 97.1 percent (table 1, samples 2, 3, and 4). In the Haldeman quadrangle, the thickness of the limestone formations varies considerably within short distances; therefore, careful exploration is required to locate good quarry sites. The presence of several outcrops suggests that good sites for quarries in the St. Louis and Beech Creek limestone are located at several places on both north and south sides of the Christy Creek Valley, between the two quarries described above. Large amounts of limestone that have not been developed are also present in the Mocabee, Greenbriar, and Proctor valleys in the northeast part of the quadrangle. Throughout most of the quadrangle the Beech Creek limestone is overlain by incompetent shales; therefore, the cost of roof support would be too great to permit profitable underground quarrying.

Limestone production in the Wrigley quadrangle at the time of the field investigations (1956–57) was limited to a series of long, narrow workings at the quarry along the North Fork of the Licking River operated by the Kentucky Road Oiling Co., but large deposits are present elsewhere in the southern half of the quadrangle. The quarry is located along the North Fork of the Licking River ¾ to 1¾ miles downstream from Leisure. Yearly production of crushed stone ranges from 70 to 100 thousand tons. Stone is taken from the St. Louis, Beech Creek, and Glen Dean limestones. Of these three formations, only the Beech Creek is sufficiently pure to be classified as high-calcium limestone (table 1, samples 10, 11); it is the source of nearly all rock sold for agricultural purposes. Road metal, the principal product of the quarry, is taken from all three formations. Large reserves of limestone are present under light overburden in the valleys of Yocum Creek and its tributaries, as well as downstream from the present quarry workings. Very large deposits could be worked by underground methods in the vicinity of the present quarry and elsewhere.

Rock of sufficient competency to support roofs of underground workings is present in most places.

SILICA SAND

At the time of the field investigation (1955–57) there was no utilization of sandstone in either the Haldeman or Wrigley quadrangles. A small amount of silica sand was once mined from a point near the Kentucky Firebrick Co. plant (Crider, 1913, p. 639). Crider described the deposit as follows:

> At a point about 90 feet above the clay [Olive Hill clay bed near the base of Pennsylvanian rocks] is a ledge of comparatively pure sandstone which is mined by the company, ground and mixed with plastic clay, and burned into silica brick.

Neither chemical analyses nor information concerning the dimensions of this deposit are available.

Considerable amounts of silica sand have been mined from deposits at Lawton, Ky., about 1¾ miles from the northeast corner of the Haldeman quadrangle. Sand was formerly shipped from this locality for use in window glass manufacture (Crider, 1913, p. 683), and the deposit is now worked intermittently to satisfy local needs. McGrain (1956, p. 11) reports that the sand is used at nearby refractory plants, where it is sprinkled on the floors of kilns and between green bricks to prevent them from sticking during firing. Sandstone deposits that are very similar to the one at Lawton occur in large lenses throughout the northern half of the Haldeman quadrangle. Presumably the composition and grain size of these deposits is similar to that given by McGrain (1956, p. 11) in analyses reproduced below.

"Chemical analysis (percent):	*Unwashed*	*Washed*
SiO_2	96.700	98.840
Fe_2O_3	.118	.050
Al_2O_3	2.537	.890
$CaCO_3$	.035	.030
$MgCO_3$	.090	.020

"Sieve analysis (percent):	*Unwashed*	*Washed*
Retained on 20 mesh	3.72	2.44
Retained on 30 mesh	2.82	5.94
Retained on 40 mesh	7.23	11.95
Retained on 50 mesh	13.64	20.77
Retained on 70 mesh	20.99	45.73
Retained on 100 mesh	30.22	11.91
Retained on 140 mesh	13.62	[1]1.26
Retained on 200 mesh	3.32	----
Through 200 mesh	4.44	----
	100.00	100.00

The percentage of loss through washing was not determined."

[1] Through 100 mesh.

Very large amounts of sandstone are present in the cliff-forming sandstone facies of the Lee formation in the southern half of the Haldeman and throughout the Wrigley quadrangles. Chemical analyses of this sandstone from two localities (table 8, samples 1 and 2) indicate high iron contents. Most of the iron is in the form of hematite cement and coatings on the quartz grains, and it would be difficult to wash out. Information on grain size, clay mineral, and heavy mineral content of this sandstone is given in table 4. This sandstone has never been mined within the limits of the Haldeman and Wrigley quadrangles; apparently it is of little value.

ASPHALT

A deposit of asphalt along a branch of a large tributary to Jones Branch, half a mile south-southwest of road junction 1136 near the center of the north boundary of Haldeman quadrangle, was described by Crider (1913, p. 682). The deposit occurs in the lower part of the Lee formation, a few feet above the stratigraphic position of the Olive Hill clay bed. At the time of the field work (1956), prospect openings in this deposit were covered by slump and alluvial materials, and the only asphaltic rock observed was in a small dump. Crider, however, described the deposit as 4 to 6 feet in thickness and consisting of coarse-grained sandstone completely saturated with oil.

Several similar deposits of asphaltic sandstone are known in the area north of the Haldeman quadrangle. Efforts to mine the asphalt have been made from time to time, but a profitable outlet has never been found. The prospects for future use of this material are also dim. Though no test data or analyses are at hand, the oil contents of the deposits are probably too low to permit profitable extraction of petroleum products, and more suitable bituminous road surfacing materials can be obtained at lower costs from other sources.

OIL AND GAS

Several test wells have been drilled in the Haldeman and Wrigley quadrangles in search for oil and gas. Shows of both oil and gas have been reported in a few of the holes, but there has been no commercial production up to the date of writing (1959). Sufficient gas was present in one well to furnish domestic supplies for one farm home for several years. Data for this well and other selected dry holes are given in table 10.

No favorable traps for petroleum are indicated on the rocks exposed at the surface; however, the possibility of buried anticlines, fault traps resulting from pre-Pennsylvanian crustal movement, or sedimentary traps in pre-Pennsylvanian rocks cannot be ruled out. In a few

TABLE 10.—*Data on selected dry holes drilled in Haldeman and Wrigley quadrangles, Kentucky*

[From information on file in the State Geologist's office, Lexington, Ky.]

No. on pls. 1, 2	Operator	Location	Drilling ceased	Total depth	Surface formation	Lowest unit reached	Remarks
			Haldeman quadrangle				
1	Gulf Refining Co.	Patties Lick Branch	1943	1, 150	Brodhead (near top) (Mississippian).	Richmond group (Ordovician).	Small shows of oil at 826, 853, 1,150 ft. Small show of gas at 826 ft.
2	Ashland Oil and Refining Co.	do	1940's(?)	3, 721	Brodhead (lower part) (Mississippian).	Bonneterre dolomite equivalent (Cambrian).	
3	Jack Cecil	John L. Lewis farm, Christy Creek valley.	1940's(?)	2, 778(?)	Brodhead (upper part) (Mississippian).	Knox dolomite equivalent (Cambrian?).	Provided gas for household use for nearby farmhouse for several years.
4	Jack Cecil	Near limestone quarry on north side of Christy Creek valley.	1940's(?)	3, 100	Muldraugh(?) (Mississippian).	(?)	Show of oil at 2,909, 3,032, 3,041, 3,051, and 3,100 ft. Show of gas at 3,100 ft.
5	Gulf Refining Co.	Possum Trot Branch	1943	1, 055	Brodhead (Mississippian).	Richmond group (Ordovician).	
			Wrigley quadrangle				
6	Gulf Refining Co.	Jones Branch of Slabcamp Creek.	1943	964	Lee (near base?) (Pennsylvanian).	Clinton formation equivalent (Silurian).	Small show of oil at 867 ft.
7	Gulf Refining Co.	Ralph Perkins farm, 1.2 miles southeast of Perkins School.	1943	1, 509	Breathitt (lower part) (Pennsylvanian).	Richmond group (Ordovician).	Show of gas at 710 ft.
8	Raymond Long	Ollie Sargent farm, 860 ft north-northeast of Blairs Mill School.	1954	1, 315	Breathitt (lower part) (Pennsylvanian).	"Corniferous" (Devonian?).	Show of oil 1,157 ft.
9	Raymond Long	Ernie Perry farm 4,050 ft south-southwest of Blairs Mill School.	1955	1, 315	Breathitt (lower part) (Pennsylvanian).	"Corniferous" (Devonian?).	Show of oil at 1,166 ft.
10	Northwestern Oil Co.	0.8 mile below waterfall at head of Yokum Creek.	1920	1, 080	Pennington(?) (Mississippian).	"Corniferous" (Devonian?).	

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places the dip of Mississippian strata is slightly greater than of overlying beds, indicating some structural warping before the deposition of Pennsylvanian beds. Conceivably, low closed structural domes could exist in Mississippian and older formations where they are completely covered by Pennsylvanian strata. Also, the two quadrangles lie in a belt in which geologic conditions are somewhat favorable for the formation of stratigraphic traps. The rocks dip gently to the east and southeast, and they contain many lens-shaped sandstone deposits and several small unconformities. Any porous rock unit pinched out updip by impervious beds might serve as a trap for petroleum. Porous beds may wedge into tight enclosing beds where truncated by an unconformity or by normal termination of lens-shaped units. Unfortunately both buried structural sedimentary type traps are difficult and expensive to locate, and therefore the prospects of finding petroleum in the Haldeman and Wrigley quadrangles are difficult to assess. Only 2 of the 10 wells drilled in the Haldeman and Wrigley quadrangles for which records are available were more than 3,000 feet deep (table 10), and the area is essentially untested.

COAL BEDS AND COAL RESOURCES

By JOHN W. HUDDLE

The coal reserves of the Wrigley and Haldeman quadrangles are very small. As shown in the stratigraphic sections (pls. 4–5), the Lee formation contains 3 or 4 thin coal beds, and the Breathitt formation contains 9 widespread but generally very thin coal beds. Only very locally do any of the beds exceed 14 inches in thickness, and only 2 beds, the Grassy and Fire Clay of the Breathitt formation, contain pockets of coal thicker than 14 inches that are of sufficient extent to class as recoverable reserves, according to definitions currently used (Averitt and others, 1953). Many of the coal beds that are thin and unimportant in this area are important producing coal beds in nearby areas or in other parts of the eastern Kentucky coal field (Huddle and others, in 1962).

Coal reserves are reported by thickness, reliability, and overburden categories. The thickness categories used in coal reserves studies by the U.S. Geological Survey in eastern Kentucky are 14 to 28 inches, 28 to 42 inches, and more than 42 inches. Coal in beds less than 14 inches thick is not included. The reliability of an estimate depends on the amount of information available to the estimator. Because very little information was available on coal in the Wrigley and Haldeman quadrangles, the estimated reserves are classed as inferred. All coal beds in the two quadranges are thinner than 14 inches at several localities, and they thin rapidly in all directions from the few observation points where coal thicker than 14 inches was measured or reported. All estimated coal reserves lie under less than 1,000 feet of overburden.

Commercial varieties of bituminous and subbituminous coals include common banded, splint, cannel, and boghead coal (American Society for Testing Materials, 1954). Common banded coal consists of irregularity alternating layers of a bright vitreous material (vitrain), less brilliant attrital material, and soft, powdery material called fusain or mineral charcoal. Splint coal has a dull luster and includes very thin irregular bands of vitreous material. It is hard and tough, and it breaks with an irregular fracture, sometimes splintery. Cannel and boghead are nonbanded varieties of bituminous coal with uniform, compact, aphanitic texture, are black or dark gray in color, and have a greasy to dull luster and conchoidal fracture. They ignite easily and burn with a yellow smoky flame. In thin sections cannel coal and boghead coal are distinguished by the presence of resinous spore coats in cannel and algal remains in boghead coal, but in hand specimens they are indistinguishable.

Information concerning the character of the coal in the Haldeman and Wrigley quadrangles was obtained principally from observations in roadcuts, natural exposures, limestone quarries, clay pits, and cores from holes drilled for refractory clay. In 1955 and 1956 there were no active coal mines in the area, but at locality 10 (pl. 3) and a few other localities, small amounts of coal have been mined from the Howard and other beds for household use and for farm forges. Because of the lack of active mines, it was impractical to obtain unweathered coal for analysis, but analyses of the coals from nearby areas indicate that most of the coal is probably of high-volatile bituminous rank. Most beds are composed of bright, common banded coal; fusain partings are usually present; and visible pyrite is common. Nonbanded coal, probably cannel, occurs in at least two stratigraphic positions in the Breathitt formation—the Grassy and the Fire Clay coal beds.

COAL BEDS OF THE LEE FORMATION

The Lee formation in the Wrigley and southern half of the Haldeman quadrangles consists of a lower unit composed of shale, thin-bedded sandstone, coal, and underclay and an upper massive sandstone unit. These units locally grade into each other laterally and vertically, and the sandstone grades into a dark shale facies in the northern half of the Haldeman quadrangle. Wherever the massive sandstone member of the Lee formation is absent, coal beds may be present. Several diamond-drill holes in the Wrigley, Haldeman, and adjacent quadrangles penetrated three coal beds in the shale unit below massive sandstone, but in some holes neither coal beds nor underclays were found. Probably there are at least three and perhaps four, coals in this part of the Lee formation, but the number of beds is uncertain because they are not persistent or easily correlated. Three thin coal beds are present in the shale facies that is laterally equivalent to the massive sandstone, as shown in sections 1, 2, 3, 8, and 9, plate 4.

The unconformity at the base of the Lee formation of Pennsylvanian age is an irregular surface, and the base of the massive sandstone unit also is an irregular surface, so that neither of these two surfaces can be used as a datum plane for correlating the coal beds of the Lee formation. As a result, the continuity and identification of the coal beds are in question in many places. Wherever the Olive Hill clay bed is present, the coal bed immediately above it can be recognized, and this and other coal beds both above and below the Olive Hill clay bed can also be correlated. A second thin coal bed, 2 to 8 feet above the coal bed overlying the Olive Hill clay bed, contains a peculiar lacelike imprint of bark tissue in the fusain layers of the coal. This fossil has been identified as *Dictyoxylon* by S. H. Mamay; inasmuch as it has not been found in other coal beds in the area, it is probably useful for correlation purposes, particularly where the Olive Hill clay bed and overlying coal are absent.

Coals in the Lee formation associated with the Olive Hill clay bed (pls. 4, 5) have been mined locally in the Haldeman quadrangle for household or forge coal at places where the clay is mined. No coal samples fresh enough for analysis were obtained in the Wrigley quadrangle, but three samples of Lee formation coals were collected from cores drilled by the General Refractories Co. about 3 miles east of Dan, Ky., in the northern part of the Ezel quadrangle (about 3.3 miles southwest of the southwestern corner of the Wrigley quadrangle). These analyses show that the coals above the Olive Hill clay bed are high in heat value, low in ash, but contain relatively large amounts of sulfur (table 11). It is unlikely that anywhere in the Wrigley and Haldeman quadrangles any of the coal beds of the Lee formation is thick enough to mine commercially; the coal above the Olive Hill clay bed is too thin even to be mined profitably in conjunction with the clay. Most of the reports of thick coal found in holes drilled in the search for oil and gas probably are due to mistaking black shale for coal, or to erroneous reports of thickness due to sample contamination caused by coal caving down the hole. Exploration for coal in the Lee formation anywhere in the quadrangles is not justifiable because the chances of finding a large pocket of thick coal are remote. This is true in spite of the fact that pockets of thick coal in the shale below the massive sandstone of the Lee formation were mined in the vicinity of Frenchburg for a number of years, where Crandall (1910) and Miller (1910) reported the coal to have a maximum thickness of 40 inches.

TABLE 11.—*Analyses of coals of the Lee formation*

[Analysis by U.S. Bureau of Mines. Condition of sample: A, as received; B, moisture- and ash-free]

Bureau of Mines laboratory No.	Condition of sample—	Proximate analysis (percent)				Ultimate analysis (percent)					Heat value (Btu)
		Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	
F-61507	A	3.6	41.4	48.2	6.8	4.4	5.5	71.7	1.4	10.2	13,170
	B		46.2	53.8		4.9	5.7	80.1	1.6	7.7	14,720
F-61508	A	2.6	44.6	48.1	4.7	2.3	5.9	76.0	1.6	9.5	13,860
	B		48.1	51.9		2.5	6.0	82.0	1.7	7.8	14,940
F-61509	A	3.3	40.1	47.3	9.3	5.6	5.3	69.9	1.4	8.5	12,800
	B		45.8	54.1		6.4	5.6	80.0	1.6	6.4	14,650

Measurements of coal beds in the Lee formation in the Haldeman and Wrigley quadrangles are shown graphically in plates 4 to 6, and additional measurements of these coals are listed in the sections measured at the following localities (pl. 3):

Location 1:

Altitude at top of coal bed: 1,146 feet.	*Feet*	*Inches*
Sandstone	51	0
Concealed	7	0
Coal	--	6
Shale, black	11	0

Location 2:

Altitude at top of coal bed: 1,013 feet.		
Sandstone	55	0
Concealed	51	0
Coal	--	9
Semiflint clay	3	0
Sandstone	1	0
Shale, silty	23	6

Location 3:

Altitude at top of coal bed: 1,042 feet.		
Sandstone, massive, cliff-former	--	--
Concealed	60	0
Coal	--	3
Semiflint clay, silty	2	0
Cover	10	0

Location 4:

Altitude at top of coal bed: 902 feet.	Feet	Inches
Sandstone, massive, cliff-former	--	--
Coal	0	3
Shale, black	6	0
Semiflint clay	3	0
Sandstone	3	0
Shale, red and green (Mississippian)	10	0

Location 5:

Altitude at top of coal bed: 898 feet.		
Sandstone, massive, cliff-former	--	--
Coal	1	0
Shale, black	2	0
Coal	1	0
Underclay	1	6

Location 6:

Altitude at top of coal bed: 900 feet.		
Sandstone, massive, cliff-former	--	--
Coal	0	8
Shale, black	10	0
Shale (Mississippian) Brodhead formation	--	--

Location 7:*

Sandstone, massive, cliff-former	--	--
Coal	0	6±
Underclay	2	0
Sandstone	--	10
Siltstone, with plant rootlets	2	8
Coal	--	4
Underclay	1±	0

*Section from diamond-drill core; drill hole only approximately located on plate 3.

COAL BEDS OF THE BREATHITT FORMATION

ZACHARIAH(?) COAL BED

A coal bed (shown in secs. 2, 4, 8, 9, pl. 4; and secs. 19, 23, and 25, pl. 5) occurs in the base of the Breathitt formation immediately above the sandstone member of the Lee formation. This coal bed is discontinuous and coal is absent in many sections. At a few sections as much as 5 inches of coal is present, but at most places the coal horizon is represented only by a bloom or an underclay. The coal is probably equivalent to the Zachariah coal (Briggs, 1957), the Lily coal, and the No. 1 coal reported by Crandall (1910, pl. 1, p. 35). No reserves are present in the Wrigley and Haldeman quadrangles.

HOWARD COAL BED

The name "Howard" was proposed by Browning and Russell (1919, p. 28) for a thin coal in northern Magoffin County. In the Wrigley and Haldeman quadrangles a coal bed at this stratigraphic position ranges in thickness from 3½ to 14 inches where it was observed. The coal generally lies between 40 and 65 feet above the top of the massive sandstone unit of the Lee formation. In most localities the roof rock is a dark gray or black fissile shale, and commonly the coal is underlain by siltstone or very fine grained sandstone. The bloom of this coal was seen in a number of places throughout the area, and it was fresh enough to be measured at the following localities (pl. 3):

Location 8:

Altitude at top of coal bed: 1,217 feet.	*Feet*	*Inches*
Shale	22	0
Coal	1	0
Underclay	6	0
Shale	26	0

Location 9:

Altitude at top of coal bed: 998 feet.		
Shale	19	0
Coal	--	10
Underclay	--	7
Shale	20	0

Location 10:

Altitude at top of coal bed: 940 feet.		
Siltstone	2–3	0
Coal, laminated in top and bottom 4 in	---	12–13
Shale, abundant plant rootlets	---	3

The thickness of the Howard coal is shown graphically in sections 3, 7, 8, and 11, plate 5. It is unlikely that there are any thick pockets of coal or any coal resources in the Wrigley and Haldeman quadrangles. Thick coal also is unknown at this horizon in Morgan, Menifee, Elliott, and Magoffin Counties, Ky. No exposures of unweathered coal were found to sample for coal analysis. The bed is composed of common banded, bright attrital coal, generally with thin vitrain bands, but at some places, as at section 8, plate 8, thick vitrain bands are present. The top and bottom 4-inch benches of coal are laminated at location 10, and only the middle 4 inches is common banded, bright, cleated coal. The laminated coal probably contains a high percentage of ash. The presence of visible pyrite at all localities indicates that the coal is probably high in sulfur.

GRASSY COAL BED

The name "Grassy" was applied by Englund (1955, p. 7) to a coal bed in the lower part of the Breathitt formation in the Cannel City quadrangle, where it has been mined locally. Nowhere in the Wrigley or Haldeman quadrangles is the coal known to be thicker than 24 inches, and locally its position is occupied by a canneloid shale or nonbanded coal. Throughout most of the Wrigley quadrangle the Grassy coal is split, the upper and lower splits being separated by 12 to 18 feet of shale and sandstone. The lower split is commonly a bright, banded attrital coal ranging in thickness from 6 to 14 inches. In the section measured near Blairs Mills School (sec. 3, pl. 5), the lower split of the Grassy appears to be split again into two benches separated by 6½ feet of siltstone and underclay.

The upper split of the Grassy coal is generally a canneloid shale or a nonbanded coal having a slaty cleavage and conchoidal fracture. That the shale represents the stratigraphic position of a coal is clear from the fact that at several locations (see sections, p. F101) it is associated with common banded coal or overlies a shale siltstone or sandstone containing plant roots. This coal bed is thickest in the vicinity of location 14 (pl. 3 and p. F101), where 22 to 48 inches of nonbanded coal (probably cannel) in a local pocket is reported. Cannel coal was seen in the spring north of the road at this locality. The top of the bed was clearly a canneloid shale with slaty fracture, and even the central part of the bed, which had a strong conchoidal fracture, had a slight tendency to fracture parallel to the bedding. No samples were obtained for analysis, but the coal seemed heavy and probably had a fairly high ash content. The material in the dump at location 16 (pl. 3 and p. F102) also was relatively heavy and had a slaty fracture.

Impure nonbanded coal with a slaty fracture occurs in the Grassy coal bed at a number of places near Wrigley. This coal was called canneloid shale in the field, but thin sections and an ash determination show that it should be classified as impure coal. Ash ranges from 34 to 39.7 percent. A grab sample of coal at location 14 (pl. 3 and p. F101), selected for light weight and apparent purity, was thin sectioned and studied by James M. Schopf of the U.S. Geological Survey. He reports that the sample is a cannel coal, containing a considerable amount of humic matter, opaque matter, some waxy spore coat material, and scattered grains of quartz and mica. A block sample of the entire coal bed was collected at location 20 (pl. 3 and p. F102). Thin-section studies by Schopf show it to be impure, nonbanded coal, containing a large percentage of humic and opaque organic matter, and abundant crystals, spherules, and aggregates of siderite a ferrous carbonate ($FeCO_3$). This specimen contained 39.7 percent ash.

East of Wrigley, along Road Fork and its tributaries, the Grassy coal is represented by impure cannel coal which is widespread but generally less than 14 inches thick. A column sample was collected in the creek bed at the base of a bluff northwest of road junction 830 on State Route 7, location 19 (pl. 3 and p. F102). This sample was also studied by Schopf. He reports that the top block, 1.5 inches thick, has a slaty fracture, 3–4 percent spore coats, 30–40 percent humic matter, and sufficient opaque matter to class the rock as cannel shale. It contains 51.8 percent ash. The lower part of this sample contains 3–4 percent oil algae, sufficient to justify the term "boghead cannel" shale. The middle block, 3.5 inches thick, was analyzed by the U.S. Bureau of Mines as follows:

	As-received (percent)	Moisture-free (percent)	Moisture- and ash-free (percent)
Moisture	1. 6		
Volatile matter	37. 5	38. 1	57. 9
Fixed carbon	27. 3	27. 7	42. 1
Ash	33. 6	34. 2	
Total	100. 0	100. 0	100. 0
Sulfur	1. 1	1. 1	1. 6
Heat value (Btu)	9, 480	9, 630	14, 630

It is an impure cannel coal containing abundant disseminated siderite, which probably accounts for some of the ash reported by the U.S. Bureau of Mines. The bottom block, which is 3.5 inches thick, is similar to the middle block but contains abundant pyrite veins, more disseminated siderite, and probably more ash than the middle block. The plant matter in this block is compressed. Uncrushed plant tissues commonly are preserved by siderite, but here apparently the siderite was added to the peat too late to preserve uncompressed plant material. A 1-inch bed immediately below the coal contains mainly siderite and pyrite, with minor amounts of organic matter. This basal bed contains uncrushed specimens of pelecypods, probably *Naidites* sp., and the brachiopod *Lingula* sp. The presence of these fossils suggests that the impure cannel and boghead cannel coals were deposited in brackish waters.

Two samples of impure cannel coal and one sample of cannel shale from the Grassy bed were ashed and analysed by semiquantitative spectrographic techniques (table 12). Iron seems to be the most abundant element in the coal, and most of it is contained in siderite, which is very abundant in this coal. The concentrations of germanium, gallium, and beryllium in this coal are not sufficiently great to constitute a possible source of these trace elements.

TABLE 12.—*Semiquantitative spectrographic analyses of the ash of cannel coal and cannel shale from the Grassy bed*

[M indicates a major constituent greater than 10 percent. The following elements were looked for but not found: P, As, Au, Bi, Cd, Ce, Co, Cs, Dy, Er, Eu, Gd, Hf, Hg, Ho, In, Ir, La, Lu, Nd, Os, Pd, Pr, Pt, Rb, Re, Rh, Ru, Sb, Sn, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Yb. Analyzed by Katherine V. Hazel, U.S. Geological Survey]

	Coal, impure cannel, 3 in. thick (location 19)	"Roof" shale, dark gray, fissile, 3 in. thick (location 19)	Coal, impure cannel (location 20)
Si	7.0	3.0	3.0
Al	3.0	1.5	1.5
Fe	M	M	M
Mg	.15	.15	.15
Ca	.3	.3	.3
Na	.3	.3	.3
K	3.0	3.0	3.0
Ti	.15	.07	.07
Mn	.03	.07	.07
Ag	.00003	.00015	.00003
B	.015	.015	.015
Ba	.03	.015	.015
Be	.0007	.0003	.0003
Cr	.003	.0015	.0015
Cu	.07	.015	.015
Ga	.0007	.0007	.0007
Ge	.0015	.0003	.0015
Li	.007	.003	.003
Mo	.0003	.0007	.0003
Nb	.007	.015	.007
Ni	.003	.0015	.0015
Pb	.007	.007	.007
Sc	.0015	.00015	.0015
Sr	.003	.003	.003
V	.007	.003	.007
Y	.0003	.003	.0007
Zn	.007	.015	.007
Zr	.015	.015	.015

The estimated coal resources of the Grassy coal bed in the Wrigley and Haldeman quadrangles are inferred from geologic evidence and reported thicknesses. Approximately 360,000 tons of nonbanded coal (probably cannel) is present, but prospecting will be necessary to prove the exact quantity and quality. North of Blaze the coal is common banded and, although it was mined for forge coal at location 15 (pl. 3 and p. F102), it is not thick enough in a large-enough area to constitute coal resources.

According to D. B. Reger (written communication, 1929) the following section was exposed in 1929 at a small mine on a branch of Minor Creek about half a mile west of Blairs Mills at an altitude of 1,155 feet (aneroid barometer):

Shale, dark gray
Coal, about 2 feet, concealed by water, mostly splint coal with a little cannel

Apparently, in this area the coal is thicker than 14 inches, but at section 18, plate 4, it is split into three benches and no other outcrops of thick coal were found nearby. Prospecting of this bed might reveal a small area of bright, common banded coal thicker than 14 inches.

The Grassy coal probably is an equivalent of the Elkhorn No. 1 or Elkhorn No. 2 of the Big Sandy coal district. These coals are extensive and important in eastern Kentucky, but in Wrigley quadrangle they appear to be near the feather edge of the beds (or bed) and contain no important coal resources. The thickness of the Grassy coal at measured sections 3, 7, 8, 10, and 12 is shown in plate 5, and other thicknesses were measured at the following localities:

Location 11:

Altitude at top of coal bed: 1,028 feet.	*Feet*	*Inches*
Shale	--	--
Coal	0	1
Underclay	2	0
Shale	8	0

Location 12:

Altitude at top of coal bed: 1,025 feet.		
Shale	--	--
Coal	0	9
Underclay	--	6
Shale	--	--

Location 13:

Altitude at top of coal bed: 886 feet.		
Shale and siltstone	6	0
Siltstone	3	0
Coal	--	6
Underclay	--	4
Sandstone	1	6
Siltstone	6+	0

Location 14:

Altitude at top of coal bed: 1,039 feet.		
Siltstone and sandstone	2	0
Coal, cannel, and canneloid shale	2	0
Underclay, plastic	1±	0
Concealed	14	0
Sandstone	1±	0
Coal	--	8–12
Underclay	--	--

Location 15:

Altitude at top of coal bed: 1,052 feet.		
Sandstone	6	0
Coal (reported)	1	6
Underclay	--	6

Location 16:

Altitude at top of coal bed: 1,024 feet.	Feet	Inches
Siltstone	4±	0
Coal, cannel (reported)	--	22–48

Location 17:

Altitude at top of coal bed: 912 feet.		
Siltstone	10±	0
Sandstone	4±	0
Shale, canneloid	1	4
Coal bloom	--	2
Underclay	--	6
Siltstone	2	6

Location 18:

Altitude at top of coal bed: 861 feet.		
Shale, canneloid	0	5
Coal	--	3–4
Underclay	--	10
Sandstone	1+	0

Location 19:

Altitude at top of coal bed: 842 feet.		
Coal bloom	0	3
Underclay, sandy, dark-gray	--	8
Siderite, bed or large lens	--	3
Coal, impure cannel	--	3
Coal, impure cannel, shaly	--	4½
Cover	--	--

Location 20:

Altitude at top of coal bed: 890 feet.		
Alluvium	--	--
Coal, impure cannel	0	6
Shale, medium-gray; contains abundant *Stigmaria*	--	4
Shale, light-gray, contains abundant *Stigmaria*	--	4

TOM COOPER COAL BED

The name "Tom Cooper" was proposed by Browning and Russell (1919, p. 29–31) for a coal bed in northern Magoffin County, lying between the Grassy and the Gun Creek coal beds. It has been traced northward by mapping through the Dingus and Cannel City quadrangles to the Wrigley quadrangle. It is probably the marginal portion of the Upper Elkhorn No. 3 coal, which is the most important producing coal in eastern Kentucky. The area of outcrop is essentially confined to the southeastern portion of the Wrigley quadrangle (sec. 11, pl. 5). Elsewhere in the quadrangle it either has been removed by erosion or was never deposited. The fact that marine shales and sandstone occupy the general position of the Tom Cooper coal (secs. 7 and 8, pl. 5) suggest that it was never deposited. The coal is 7 inches thick in section 11, plate 5, and ranges from 5 to 8 inches in thickness in the following sections from Blair Branch (pl. 3), where it was formerly mined for local use:

Location 21:

Altitude at top of coal bed: 856 feet.	*Feet*	*Inches*
Sandstone	2	9
Coal	--	5
Siltstone, with plant roots	1±	0

Location 22:

Altitude at top of coal bed: 857 feet.		
Shale, black	3	0
Coal	--	8
Bone	--	1
Underclay	1±	0

GUN CREEK COAL BED

The name "Gun Creek" was proposed by Browning and Russell (1919, p. 32–33) for a coal bed mined along Gun Creek east of Royalton in Magoffin County. This is the same bed that was called Cannel City by Englund (1955, p. 8), and it is probably the Amburgy coal of the Hazard coal field. The Gun Creek coal is generally thin, and nowhere in the Wrigley or Haldeman quadrangles is it thick enough to contain reserves of minable coal. It crops out only in the SE¼ of the Wrigley quadrangle, where it is common banded coal. No non-banded (cannel or boghead) coal was found at this horizon in the Wrigley quadrangle. The following sections were measured in creek bed exposures (pl. 3):

Location 23:

Altitude at top of coal bed: 874 feet.	*Feet*	*Inches*
Sandstone	1±	0
Coal	--	6–8
Shale, with plant roots	2±	0

Location 24:

Altitude at top of coal bed: 953 feet.		
Siltstone	2±	0
Coal	--	7
Shale	1	3
Coal	--	3
Shale	--	1
Coal	--	5
Shale, with plant roots	--	2

Location 25:

Altitude at top of coal bed: 945 feet.

	Feet	Inches
Sandstone	20±	0
Coal	--	7
Shale, with plant roots	3±	0

FIRE CLAY COAL BED

The Fire Clay coal bed, named by Hodge (1908, p. 40–41), is the most widespread and widely known coal in the eastern Kentucky coal field. It occurs 25 to 50 feet below the Magoffin beds. Throughout most of eastern Kentucky it contains a parting of flint clay that ranges in thickness from 0 to 6 inches, but in the Wrigley and Haldeman quadrangles this flint-clay parting is generally absent and the bed is difficult to recognize. Where the coal was seen and measured (fig. 3a), it is 8 to 12 inches thick. Elsewhere it is thicker than 14 inches, as it was mined by the Clearfield Coal Co. at location 26 (fig. 2), and at a point 50 feet east of the Wrigley quadrangle and 1,100 feet south of Road Fork. At these localites the coal is reported to be 22 to 28 inches thick, and fragments of flint clay, typical of the parting in the Fire Clay bed, are abundant in the dump. At location 29 it was reported to be 22 inches thick. Crandall (1910, p. 6) reported coal at Judge Blair's farm on Blair Fork as being 40 inches thick, under a slate roof, 55 feet above the creek bed. The section described by Crandall could not be located in the field, but it may be at the old adit in the Fire Clay coal, in a tributary of Blair Branch at aneroid elevation 913 feet, location 30.

The Annual Report of the Kentucky State Mine Inspector for 1911 lists 7,319 tons as the production for that year from the Road Fork mine of the Clearfield Lumber Co. This is undoubtedly the mine located 50 feet east of the Wrigley quadrangle and 1,100 feet south of Road Fork, which was served by a spur track from the Morehead and North Fork Railroad. The Annual Report for 1912 states that 6,277 tons was mined at the Road Fork mine. The Clearfield Lumber Co. is reported to have mined 7,759 tons in 1913, 7,306 tons in 1914, and 3,062 tons in 1915. Probably all of this coal came from the Road Fork mine. Production from 1916 to 1920 is unknown because the Kentucky Department of Mines issued no annual reports for these years. At least 13,596 tons (1911 and 1912) and probably a total of 31,723 tons (1911–15, inclusive) of coal was produced from the Road Fork mine of the Clearfield Lumber Co. It appears likely that the thickest part of the bed has been mined out. The Annual Report of the Kentucky Department of Mines for 1921 states that the Clearfield Lumber Co. was mining coal at Redwine, and the Road Fork mine probably was abandoned prior to that date. When the

Road Fork mine was visited by D. B. Reger in 1929 the entrances were caved (written communication, 1929) and the coal thickness could not be measured.

In scattered outcrops in the Wrigley quadrangle, the Fire Clay coal bed is a common banded, bright attrital coal, but to the east near Redwine, in the adjacent Sandy Hook quadrangle, the Fire Clay coal bed changes to a nonbanded coal, probably cannel coal. Formerly this thick pocket of coal was mined extensively and shipped to market by the now abandoned Morehead and North Fork Railroad. Measured sections follows:

Location 26:

Altitude at top of coal bed: 933 feet.	Feet	Inches
Coal (reported)	0	22

Location 27:

Altitude at top of coal bed: 920 feet.		
Sandy soil	2	0
Coal	--	8
Shale, with plant roots	--	6

Location 28:

Altitude at top of coal bed: 917 feet.		
Massive sandstone	--	--
Underclay	0	6
Shale, coaly	--	2
Coal	--	10
Underclay	--	3

Original inferred reserves are 1,110,000 short tons. Assuming 50 percent recovery, about 62,000 tons have been mined and lost in mining.

HAMLIN(?) COAL BED

A thin coal bed 5 to 15 feet below the Magoffin beds is questionably correlated with the Hamlin of the Hazard mining district. As shown in section 11, plate 5, and in the following sections, it nowhere contains more than 14 inches of coal and consequently no reserves were calculated. The coal was frequently split, as is shown in the section measured at location 27 (pl. 3):

Location 27:

Altitude at top of coal bed: 950 feet.	Feet	Inches
Sandstone	3	0
Shale	--	4
Coal	--	3–6
Sandstone	5	0
Coal	--	8
Underclay	1±	0
Concealed	22	6

Location 31:

Altitude at top of coal bed: 962 feet.	*Feet*	*Inches*
Sandstone	20	0
Shale, gray	--	3
Coal	--	7
Shale, silty, plant roots	5±	0

HADDIX COAL BED

A coal bed 5 to 25 feet above the Magoffin beds is correlated with the Haddix coal of the Hazard mining district. This coal is 3 inches thick at location 30 (pl. 3), and only coal blooms were found elsewhere. Generally the position of this coal is occupied by massive sandstone and no reserves in the bed are likely. The Haddix coal was measured only at location 30 as follows:

Location 30:

Altitude at top of coal bed: 982 feet.	*Feet*	*Inches*
Sandstone	30	0
Concealed	2	0
Shale	2	0
Coal	--	3

INDEX COAL BED

The Index coal bed, named by Adkison (1957, p. 12) from exposures near West Liberty, is recognized at only one outcrop in the Wrigley and Haldeman quadrangles, a short distance south of the divide on State Route 7 south of Wrigley. The coal is 8 inches thick underlain by 0.9 foot of underclay and overlain by 10.5 feet of shale. The bed is probably widespread on hilltops in the SW¼ of the Wrigley quadrangle, but it is not likely that there are any large reserves.

NICKELL COAL BED

The Nickell coal bed, named from the exposures in the southern part of the Cannel City quadrangle (Englund, 1955, p. 11), is probably represented by a coal in the highway cut at the crest of the ridge south of Wrigley on State Route 7. Here the coal is 15 inches thick, overlain by a thick, friable sandstone, and underlain by 1.9 feet of underclay and sandstone. In section 12, pl. 5, it is 8 inches thick, and it is probably present high on the ridges in most of the southeastern part of the Wrigley quadrangle. The reserves and the area underlain by the coal must be small, because the coal lies near the top of the ridges. No reserves were calculated.

SUMMARY

At least five of the major producing coals of eastern Kentucky, the Zachariah-Lily, Upper Elkhorn No. 1, Upper Elkhorn No. 2, Amburgy, and Fire Clay coals, are present in the Wrigley and Haldeman quadrangles. Over most of the area all the beds are too thin to constitute minable reserves under foreseeable economic conditions and energy needs. Because they are less than 14 inches thick they are not classified as coal reserves. The Grassy coal contains one pocket of nonbanded, probably cannel, coal near location 14 (pl. 3). This pocket is probably very local and could not support extensive mining, but the coal might have a good local market. Most of the thick reserves in the Fire Clay coal apparently have been mined or lost in mining at the Road Fork mine of the Clearfield Lumber Co., which probably operated from 1911 to 1916. Near the eastern margin of the quadrangle, the coal probably grades laterally to nonbanded (cannel) coal toward the Redwine district in the Sandy Hook quadrangle. It is unlikely that any large-scale mining is possible in the Wrigley and Haldeman quadrangles, and the doubtful continuity of the coal beds makes it unlikely that these very thin seams could be used for under ground gasification.

REFERENCES CITED

Adkison, W. L., 1957, Coal geology of the White Oak quadrangle, Magoffin and Morgan Counties, Kentucky: U.S. Geol. Survey Bull. 1047–A, 23 p.

American Society for Testing Materials, 1948, Manual of standards on refractory materials: Philadelphia, Pa., Am. Soc. Testing Materials.

——— 1954, Standards on coal and coke (with related information): Philadelphia, Pa., Am. Soc. Testing Materials, p. 111.

Averitt, Paul, and others, 1953, Coal resources of the United States—A progress report, October 1, 1953: U.S. Geol. Survey Circ. 293, 49 p.

Bates, T. F., and Comer, J. J., 1955, Electron microscopy of clay surfaces, *in* Clays and clay minerals, proceedings of the 3d Natl. Conf. on clays and clay minerals: Natl. Acad. Sci.—Natl. Research Council Pub. 395, p. 1–25.

Briggs, R. P., 1957, Coal geology of the Campton quadrangle, Wolfe, Lee, and Breathitt Counties, Kentucky: U.S. Geol. Survey Coal Inves. Map C–42.

Brindley, G. W., ed., 1951, X-ray identification and crystal structures of clay minerals: Mineralog. Soc. [Great Britain], 345 p.

Brindley, G. W., and Robinson, K., 1947, An X-ray study of some kaolinitic fireclays: British Ceramic Soc. Trans., v. 46, p. 49–62.

Browning, I. B., and Russell, P. G., 1919, Coals and structure of Magoffin County, Kentucky: Kentucky Geol. Survey, ser. 4, v. 5, pt. 2, 552 p.

Butts, Charles, 1922, The Mississippian series of eastern Kentucky: Kentucky Geol. Survey, ser. 6, v. 7, 188 p.

Campbell, M. R., 1893, Geology of the Big Stone Gap coal field of Virginia and Kentucky: U.S. Geol. Survey Bull. 111, 106 p.

628824 O—62——8

Crabb, D. H., 1930, Geologic map of the Morehead quadrangle, Rowan, Elliott, Morgan, Bath, Carter, and Menifee Counties, Kentucky: Kentucky Geol. Survey, ser. 6, scale 1:62,500.

Crandall, A. R., 1880, Preliminary report on the geology of Morgan, Johnson, Magoffin, and Floyd Counties: Kentucky Geol. Survey, ser. 2, v. 6, pt. 5, p. 315–338.

——— 1910, Coals of the Licking River region: Kentucky Geol. Survey Bull. 10, 90 p.

Crider, A. F., 1913, The fire clays and fire clay industries of the Olive Hill and Ashland districts of northeastern Kentucky: Kentucky Geol. Survey, ser. 4, v. 1, pt. 2, p. 592–711.

Elrod, M. N., 1899, The geologic relations of some St. Louis group caves and sink holes: Indiana Acad. Sci. Proc. 1898, p. 258–267.

Englund, K. J., 1955, Geology and coal resources of the Cannel City quadrangle, Kentucky: U.S. Geol. Survey Bull. 1020–A, 21 p.

Floyd, R. J., and Kendall, T. A., 1955, Miscellaneous clay and shale analyses for 1952–1954: Kentucky Geol. Survey Rept. Inv., ser. IX, no. 9, p. 1–61.

Fuller, J. O., 1955, Source of Sharon conglomerate of northeastern Ohio: Geol. Soc. America Bull., v. 66, p. 159–176.

Galpin, S. L., 1912, Studies of flint clays and their associates: Am. Ceramic Soc. Trans., v. XIV, p. 301–346.

Goddard, E. N., and others, 1948, Rock color chart: Washington, D.C. Natl. Research Council; repub. 1951, Geol. Soc. America.

Greaves-Walker, A. F., 1907, The flint fire clay deposits of northeastern Kentucky: American Ceramic Soc. Trans., v. 9, p. 461–472.

Grim, R. E., and Rowland, R. A. 1944, Differential thermal analysis of clays and shales, a control and prospecting method: Illinois Geol. Survey Rept. Inv. no. 96, p. 1–23.

Hodge, J. M., 1908, Summary of report on the region drained by the three forks of the Kentucky River: Kentucky Geol. Survey Rept. of Progress for the years 1906 and 1907.

Huddle, J. W., and others, 1962, Coal reserves of eastern Kentucky: U.S. Geol. Survey Bull. 1120.

Keller, W. D., Wescott, J. F., and Bledsoe, A. O., 1954, The origin of Missouri fire clays, *in* Clays and clay minerals, proceedings of the 2d Natl. Conf. on clays and clay minerals: Natl. Acad. Sci.—Natl. Research Council Pub. 327, p. 7–46.

Kesler, T. L., 1956, Environment and origin of the Cretaceous kaolin deposits of Georgia and South Carolina: Econ. Geology, v. 51, no. 6, p. 541–554, 5 figs.

Kinter, E. B., and Diamond, Sidney, 1956, a new method for preparation and treatment of oriented aggregate specimens of soil clays for x-rays analysis: Soil Science, v. 81, no. 2, p. 111–120.

Klinefelter, T. A., and Hamlin, H. P., 1957, Syllabus of clay testing: U.S. Bur. Mines Bull. 565, 67. p.

Malott, C. A., 1919, The "American Bottom" region of eastern Greene County, Indiana—a type unit in southern Indiana physiography: Indiana Univ. Studies, v. 6, no. 40, p. 7–20.

McConnel, Duncan, Levinson, A. A., and de Pablo-Galan, L., 1956, Study of some chemically analyzed Ohio clays by X-ray diffraction and differential thermal analysis: Ohio Jour. Sci. 56, p. 275–284.

McFarlan, A. C., 1950, Geology of Kentucky: Lexington, Ky., Univ. of Kentucky, 531 p.

McFarlan, A. C., and Walker, F. H., 1956, Some old Chester problems—correlations along the eastern belt of outcrop: Kentucky Geol. Survey Bull. 20, 36 p.

McGrain, Preston, 1956, Recent investigations of silica sands of Kentucky, No. 2: Kentucky Geol. Survey Rept. Inv. ser. 9, no. 11, 32 p.

McMillan, N. J., 1956, Petrology of the Nodaway underclay (Pennsylvanian), Kansas: Kansas State Geol. Survey Bull. 119, pt. 6, p. 191–247.

Miller, A. M., 1910, Coals of the lower measures along the western border of the Eastern Coalfield: Kentucky Geol. Survey Bull. 12, 23 p.

——— 1919, Table of geological formations of Kentucky: Kentucky Dept. Geol. and Forestry, ser. 5, Bull. 2, p. 10, 147 (tables only).

Moore, R. C., and others, 1944, Correlation of Pennsylvanian formations of North America: Geol. Soc. America Bull., v. 55, no. 6, p. 657–706, illus., Chart no. 6, by the Pennsylvanian Subcommittee, Natl. Research Council Comm. on Stratigraphy

Morse, W. C., 1931, Pennsylvanian invertebrate fauna: Kentucky Geol. Survey, ser. 6, v. 36, p. 293–348.

Patterson, S. H., and Hosterman, J. W., 1960, Geology of the clay deposits in the Olive Hill district, Kentucky, *in* Clays and clay minerals, proceedings of the 7th Nat'l. Conf. on clays and clay minerals: London, Pergamon Press, Mon. no. 5, p. 179–194.

Perry, E. S., Hudnall, J. S., Miller, R., and Lane, R. C., 1930, Structural map of Carter County, Kentucky: Kentucky Geol. Survey, ser. 6 (map, scale approximately 1: 62,500).

Phalen, W. C., 1906, Clay resources of northeastern Kentucky: U.S. Geol. Survey Bull. 285, p. 411–416.

Potter, P. E., and Siever, Raymond, 1956, Cross-bedding, pt. 1 *of* Sources of basal Pennsylvanian sediments in the Eastern Interior basin: Jour. Geology, v. 64, no. 3, p. 225–244.

Ries, Heinrich, 1922, The clay deposits of Kentucky: Kentucky Geol. Survey, ser. 6, v. 8, p. 1–241.

Robinson, L. C., and Hudnall, J. S., 1925, Map of the areal and structural geology of Morgan County, Kentucky: Kentucky Geol. Survey, ser. 6 (map, approximately 1: 62,500).

Robinson, L. C., Hudnall, J. S., and Richardson, H. T., 1928, Reconnaissance structural map of Elliott County, Kentucky: Kentucky Geol. Survey, ser. 6 (map, approximately 1: 62,500).

Schultz, L. G., 1958, Petrology of underclays: Geol. Soc. America Bull., v. 69, no. 4, p. 363–402, 14 figs.

——— 1960, Quantitative X-ray determinations of some aluminous clay minerals in rocks, *in* Clays and clay minerals, proceedings of the 7th Natl. Conf. on clays and clay minerals: London, Pergamon Press, Mon. no. 5, p. 216–224.

Shapiro, Leonard, and Brannock, W. W., 1953, A field method for the determination of titanium: Econ. Geology, v. 48, p. 282–287.

——— 1956, Rapid analysis of silicate rocks: U.S. Geol. Survey Bull. 1036–C, p. 19–56.

Siever, Raymond, and Potter, P. E., 1956, Sedimentary petrology, [Pt.] 2 *of* Sources of basal Pennsylvanian sediments in the Eastern Interior basin: Jour. Geology, v. 64, no. 4, p. 317–335.

Stockdale, P. B., 1939, Lower Mississippian rocks of the east-central interior: Geol. Soc. America Special Paper 22, 248 p.

Stokley, J. A., and McFarlan, A. C., 1952, Industrial limestones of Kentucky, No. 2: Kentucky Geol. Survey, ser. 9, Rept. Inv. 4, 99 p.

Stokley, J. A., and Walker, F. H., 1953, Industrial limestones of Kentucky, No. 3: Kentucky Geol. Survey, ser. 9, Rept. Inv. 8, 62 p.

Twenhofel, W. H., 1950, Principles of sedimentation: New York, McGraw-Hill Book Co., 673 p.

Waagé, K. M., 1950, Refractory clays of the Maryland coal measures: Maryland Dept. Geology, Mines and Water Resources Bull. 9, p. 1–182.

Wanless, H. R., 1939, Pennsylvanian correlations in the Eastern Interior and Appalachian coal fields: Geol. Soc. America Special Paper 17, 130 p.

——— 1946, Pennsylvanian geology of a part of the southern Appalachian coal field: Geol. Soc. America Mem. 13, 162 p.

Weller, J. M., and others, 1948, Correlation of the Mississippian formations of North America: Geol. Soc. America Bull., v. 59, p. 91–106.

Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Jour. Geology, v. 30, p. 382.

Wilmarth, M. G., 1938, Lexicon of Geologic Name of the United States (including Alaska): U.S. Geol. Survey Bull. 896, 2396 p.

Wilson, C. W., Jr., and Stearns, R.G., 1957, Paleogeography during deposition of Pennsylvanian sand bodies in Tennessee [abs.]: Geol. Soc. America Bull., v. 68, p. 1812.

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