A STUDY OF THE WARRENSBURG SANDSTONE

A Thesis
Presented to
the Faculty of the Department of Geology
University of Missouri

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

by
Robert Lee Rayl
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The undersigned, appointed by the Dean of the Graduate Faculty, have examined a thesis entitled

A Study of the Warrensburg Sandstone

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and hereby certify that in their opinion it is worthy of acceptance.

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INTRODUCTION

The purpose of this research is to apply various statistical and qualitative analytical methods to a study of the Warrensburg channel sandstone. The area covered by this problem includes parts of Lafayette, Johnson, and Henry Counties, Missouri where the Warrensburg sandstone is exposed.

The collection of samples and field data was done during the summer of 1951 and the laboratory work was done during the fall and winter at the University of Missouri.
TOPOGRAPHY

Lafayette, Johnson, and Henry Counties, wherein the Warrensburg sandstone is exposed, are included in Branson's (1944) "Old Plains" topography. Branson describes this topography as having developed to old age since the time the tops of the hills were part of the general level. The major factors influencing the development of the topography were (1) Pennsylvanian shales on which the topography developed and (2) the uplift to the east which caused the streams coming in from the west to be slowed.

The northern edge of Lafayette County, where it is affected by the Missouri River, is part of Branson's (1944) "River Plains" topography. In Lafayette County the Missouri River is eroding its valley on the south side and the "River Plains" are not well developed.

Marbut (1898) called the upland, which extends from Lewis, Henry County, Missouri northward into Johnson and Lafayette Counties, the Warrensburg Upland. This upland forms a divide between the streams flowing northward to the Missouri River and those flowing southward into the Osage River.

The region underlain by the Warrensburg sandstone lies wholly within the drainage basin of the Missouri River. The streams have wide flat valleys and in the
northern part of the region the streams are aggrading. Davis Creek in Lafayette County has marshes developed along its course. To the south the streams have a steeper gradient due to greater relief and more resistant bedrock.
ECONOMIC RESOURCES

Sandstone

The Warrensburg sandstone was at one time an important source of building stone. The quarries at Warrensburg, Johnson County, supplied building stone for many large buildings in Nebraska, Iowa, and Missouri. Besides being used for construction purposes Buckley and Buehler (1904) report that the sandstone makes excellent grindstones. Branson (1944) states that some of the sandstone was cut and used for sidewalks.

An attempt was made to use the bituminous sandstone of the Warrensburg found at Higginsville, Lafayette County, for paving material. Dake (1914) reported that the experiment was a success but that the deposits were not developed.

At the present time the Warrensburg sandstone is not quarried for commercial purposes.

Soils

The soils are the most important natural resources of Lafayette, Johnson and Henry Counties. The rich, fertile soils of Lafayette County have made it one of the leading agricultural counties in the state.

The soils of Lafayette County are principally silt
loams. All of the soil types have been profoundly influenced by the inclusion of loess. Around Dover, Lafayette County, steep bluffs of loess have formed along streams and road cuts. The soil cover ranges up to sixty feet. The Waukesha silt loam occurs six miles east of Lexington, Lafayette County, along Tabo Creek. According to Krusekopf (personal communication) of the Missouri Soil Survey, the Waukesha has been influenced in color, texture, and composition by the underlying Warrensburg sandstone. DeYoung (1923) describes the Waukesha as a dark brown, mellow silt loam which occupies stream terraces above the normal overflow of the Tabo. This soil is under cultivation and is said to be one of the best soil types in agricultural value and productiveness.

In Johnson County the Boone fine sandy loam occurs along the trend of the Warrensburg and its color, texture, and composition are influenced by it (Krusekopf, personal communication).

No soil maps are available for Henry County, Missouri but the writer believes that because of the thin soil cover the Warrensburg would have a great effect on the soils overlying it.

Coals of economic value do not occur in the Warrensburg sandstone but coals of the adjacent formations are mined by both open pit and shaft methods. The coals
that are mined are discussed later under "General Stratigraphy."
GENERAL STRATIGRAPHY

Introduction

The Warrensburg sandstone crops out in a narrow north-south trending belt in the central parts of Lafayette, Johnson and Henry Counties. The rocks associated with the Warrensburg are Pennsylvanian in age, and the channel of the Warrensburg cuts parts of younger beds from the Nowata formation of the Marmaton Group to the lower formations of the Cherokee Group.

It shall be the purpose of this discussion to consider only those strata directly associated with the Warrensburg sandstone: i.e. the pre-Lenapah formations of Desmoinesian Series.

DESMOINESIAN SERIES

The term "Des Moines" was applied by Keyes (1892) to the marginal deposits of the Upper Carboniferous of Missouri and Iowa. The term was later restricted by Moore (1932) to include only the beds from the base of the Cherokee shale to the base of the Pleasanton shale.

The Desmoinesian Series is divided into the Cherokee and Marmaton Groups.

CHEROKEE GROUP

Haworth and Kirk (1894) used the term Cherokee as
a formational name for the shales exposed along the Ness River in Cherokee County, Kansas. The Cherokee is now defined as the lower group of the Desmoinesian Series and includes all strata between the top of the Mississippian and the base of the Marmaton Group. The group consists principally of shales, but limestone and coal beds are present and make good stratigraphic markers because of their persistency. A systematic study of the Cherokee in the three counties under discussion has not been attempted and information is of a general nature. From the generalized sections of Hinds and Greene (1915) the Loutre and Cheltenham formations appear to be absent in the area.

The Cherokee Group will be considered to be composed of the following formations in descending order:

6. Mulky formation
5. Lagonda formation
4. Bevier formation
3. Ardmore formation
2. Tebo formation
1. Graydon formation

Graydon Formation

The name Graydon Springs was applied by Winslow (1894) to sandstone and conglomerate filling sink holes
and depressions in Mississippian rocks. Shepard (1892) shortened the name to Graydon. The Graydon is one of the most widespread of the Pennsylvanian formations. In Lafayette, Johnson and Henry Counties the formation consists of only well-cemented sandstone beds with interbedded shale.

Tebo Formation

Marbut (1898) applied the name "Tebo" to a coal seam exposed along Tebo Creek in Henry County. McQueen (1943) gave the Tebo formational status and described the formation as being composed of a gray underclay with a sharp conchoidal fracture, a coal seam, and an overlying slaty shale. The shiny, pyritic coal averages about two feet in thickness and is mined in Henry and Johnson Counties. The overlying shale varies from two to fifteen feet.

Ardmore Formation

The term Ardmore was first used by Gordon in 1893. According to McQueen and Greene (1938) the Ardmore is highly variable in thickness but is fairly persistent. In Henry County the Ardmore is a blue-gray limestone which varies in thickness from six feet to a feather edge. In Johnson County it is a bluish-black, fossiliferous limestone, one foot thick which grades northward into the two
feet of nodular limestone common in Lafayette County.

**Bevier Formation**

Gordon (1893) applied the name Bevier to a coal mined near Bevier, Macon County, Missouri. The Bevier has been mined in Lafayette, Johnson and Henry Counties. It varies in thickness from a smut to almost four feet. Hinds and Greene (1915) reported that a thin shale parting or a layer of bone coal is present within the coal. This sub-bituminous coal is underlain by a carbonaceous shale or an underclay.

**Lagonda Formation**

The Lagonda was named by Gordon (1893). In Henry County the Lagonda consists of blue shale which Hinds and Greene (1915) reported to reach a thickness of thirty feet, while in Johnson County the Lagonda has a basal fossiliferous limestone bed overlain by a dark, slaty shale with thin bands of limestone. It varies in thickness from thirty to forty feet. The Squirrel sandstone member is present in gray shale in Lafayette County.

**Mulky Formation**

Broadhead (1872) applied the name "Mulky" to a coal bed exposed along Mulky Creek in Lafayette County. The
coal varies in thickness from as little as one inch in Henry County to as much as twenty-two inches in Lafayette County. Production of the coal has been carried out in the three counties under discussion where thickness and depth make it economically feasible.

MARMATON GROUP

Keyes (1937) named the Henrietta formation for escarpment exposures near Henrietta, Missouri. McQueen and Greene (1938) gave the Henrietta group status, and added the Altamont and Bandera formations which were formerly classed as Pleasanton. The Interstate Conference on Pennsylvanian Classification in 1948 abandoned the term "Henrietta" and adopted "Marmaton" in its place. The Marmaton now includes all of the post-Cherokee strata of the Desmoinesian Series: i.e., all of the strata from the base of the Fort Scott formation to the base of the Hepler sandstone.

The formations of the Marmaton that will be discussed here are:

6. Nowata formation
5. Altamont formation
4. Bandera formation
3. Pawnee formation
2. Labette formation
A. Lexington coal
1. Fort Scott formation
   C. Higginsville limestone member
   B. Little Osage member
   A. Blackjack Creek limestone member

Fort Scott Formation

Swallow (1866) named the Fort Scott from exposures near Fort Scott, Kansas. Three members, the Blackjack Creek limestone, the Little Osage member, and the Higginsville limestone have been assigned to the Fort Scott and these members persist in the area under discussion.

Blackjack Creek limestone member

The Blackjack Creek is a thin-bedded, blue or gray, fossiliferous limestone that weathers buff. It varies in thickness from two feet in Henry County to nine feet in Lafayette County.

Little Osage member

The Little Osage consists of shales in this area. The Summit coal is represented by a black, bituminous shale in Johnson and Lafayette Counties. The Houx limestone is represented by a calcareous shale in Lafayette County. The thickness of the Little Osage varies from a thin film to as much as twenty feet.
Higginsville limestone member

The Higginsville is a white to gray, thin-bedded, fossiliferous limestone. It varies in thickness from one foot to twelve feet.

Labette Formation

Haworth (1898) applied the name "Labette" to strata exposed at Labette, Kansas. The shales of the Labette vary in lithology from a basal clay to an upper slaty shale. The average thickness is about twenty feet. In the three counties the Lexington coal is important stratigraphically and economically.

Lexington Coal

The Lexington coal varies in thickness from one inch in Henry County to twenty inches in Lafayette County. It is the most important coal bed in Lafayette County because it occurs near the surface and is easily mined. Hinds (1912) describes the Lexington as hard and bright with little visible pyrite.

Pawnee Formation

Swallow (1866) originally used the term "Pawnee" but Moore (1936) amended Swallow's use of the term to include the strata between the Labette and the Bandera. The
four members of Pawnee are in ascending order: the Anna shale member, the Myrick Station limestone, the Mine Creek shale, and the Coal City limestone (Greene and Searight, 1949). Only the Myrick Station limestone has been reported in Henry and Johnson Counties (Hinds and Greene, 1915) but it is believed that all four members occur in Lafayette County. Hinds (1912) reports an ascending succession at Corder, Missouri of black slaty shale, blue to gray limestone, drab and blue shale, and bluish gray nodular limestone above the shales containing the Lexington coal.

Bandera Formation

The name "Bandera" was applied by Adams (1903) to exposures at Bandera, Bourbon County, Kansas. The lower unit of the Bandera is a shale with the Mulberry coal near its base. The shale is overlain by the Bandera Quarry sandstone member. The shale is usually well-bedded and varies in color from gray to maroon. According to Greene and Searight (1949) the Bandera Quarry sandstone is in part a channel fill similar to the Warrensburg. It grades from a silty shale to a massive sandstone.

Altamont Formation

The term "Altamont" as originally used by Adams
(1896) referred to a limestone bed in Labette County, Kansas. The Altamont has since been redefined to include three members: the Amoret limestone member, the Lake Neosho shale member, and the Worland limestone member (Cline and Greene, 1950). The Amoret is generally absent in the area where the Altamont crops out. Cline and Greene (1950, p. 37) found that the Lake Neosho shale rested on and appeared to be continuous with the Bandera shale. The overlying Worland consists of two limestone beds separated by a bed of calcareous shale.

**Nowata Formation**

Ohern (1910) defined the Nowata as the shale occurring between the Altamont and Lenapah limestones. The Warrensburg has been assigned by Greene and Searight (1949, p. 8) as the upper member of the Nowata. The Nowata varies from gray-green to red in color. It is thinly laminated and has a blocky fracture.
WARRENSBURG SANDSTONE

Introduction

Winslow (1892, pp. 45-54) applied the name "Warrensburg" to the sandstone cropping out around Warrensburg, Johnson County, Missouri. In his "Report on the Higginsville Sheet" Winslow (op. cit.) first postulated that the Warrensburg was a channel deposit. He gave the following reasons for considering the deposit a channel filling (p. 52):

1. The great thickness of the deposit.
2. Its long narrow shape.
3. The superposition of the sandstone upon the "Middle Coal Measure" rocks.
4. The inclusion of fragments of adjacent rocks.

Winslow mapped the northern end of the Warrensburg. Marbut (1898) recognized the Warrensburg in Henry County and assigned it to the Upper Des Moines Series. In his "Report on the Lexington Sheet" Marbut (1898) recognized the possibility that the Warrensburg and the Moberly might be directly related.

Age

The age of the Warrensburg has been a subject of controversy since it was first recognized. Recent workers, however, have given it a stratigraphic position in
the Upper Nowata formation of the Desmoinesian Series. Howe (1948) observed that a coarse, cross-bedded sandstone, resembling the Warrensburg, replaced the normal sequence in the Nowata scale. He stated that the sandstone was not seen higher in the section. Greene and Searight (1949) concurred with Howe and have extended the definition of the Warrensburg to include post-Altamont-pre-Lenapah sandstones as well as the channel sands of the Moberly and Warrensburg channels. They designated the Warrensburg as the upper member of the Nowata formation. Cline and Greene (1950) observed Bandera outcrops immediately adjacent to the Warrensburg and Cline (p. 17) tentatively suggested that the Warrensburg may be of Bandera age.

Location

The main channel of the Warrensburg is located in Lafayette, Johnson and Henry Counties. On the south bluffs of the Missouri River in Lafayette County the channel reaches a lateral extent of six miles. It converges to two miles at Higginsville and maintains this width southward in a sinuous pattern. It underlies Warrensburg, Cornelia, and Postoak in Johnson County. At Postoak it trends to the southeast to Lewis in Henry County. Although continuous exposures do not occur southwest of
Figure a. Color variation in the Warrensburg sandstone.

Figure b. Color variation in the Warrensburg sandstone.
Lewis, the deposit apparently trends in this direction. The Warrensburg is exposed in several places around Clinton in Henry County. In Artesian Park in Clinton ten feet of Warrensburg shale is exposed and a mile west, ten feet of typical Warrensburg sandstone occurs. Although the deposit was not traced further, it is believed that the general trend of the Warrensburg is toward the south or southwest from Clinton.

Shape and Thickness

The Warrensburg is a narrow, sinuous, elongate deposit that exceeds sixty miles in length and averages two miles in width. The highly variable thickness ranges from one foot to at least ninety feet. Well logs show that wells between Postoak and Warrensburg penetrated ninety feet of sandstone without reaching the bottom (Hinds and Greene, 1915, p. 95). A drill hole near Higginsville penetrated sixty-eight feet of surface material and one hundred twenty feet of sandstone (Hinds and Greene, 1915, p. 96). However, it is possible that the bottom of this well is in Cherokee sandstone. Near the edges of the channel the thickness decreases rapidly to as little as one foot.

The cross-sectional shape of the Warrensburg may be seen by comparing a number of exposures. No one ex-
posure is large enough to show the concave shape. Along the south bluffs of the Missouri River at sample locality L 4 the base of the Warrensburg rests in a green shale about one hundred feet above the river. East of this exposure, at sample localities L 2 and L 3, the base of the Warrensburg is not exposed but the lowest part of the exposure is about thirty feet above the river. Similar exposures near Warrensburg in Johnson County also indicate a concave cross-sectional shape.

Bedding Structures

The unweathered part of the sandstone, such as that exposed in the quarries at Warrensburg, has beds from one foot to four feet thick. Leaf-like impressions of dark, carbonaceous material occur along the bedding planes and Buckley and Buehler (1904) state that the sandstone has a tendency to part along the planes of deposition of the carbonaceous material.

Cross-lamination is a distinctive characteristic of the sandstone of the Warrensburg. The beds dip from five to twenty degrees in a random direction. At one exposure, along Sand Creek in Henry County, six miles northeast of Lewis, the cross-laminae of one bed dips in one direction while those of the beds above and below dip in the opposite direction. Occasionally the cross-laminae are separated by a carbonaceous film.
Plate II

Figure a. Cross-lamination in the Warrensburg sandstone along Sand Creek, Henry County, Missouri.

Figure b. Ripple marks in the Warrensburg sandstone north of Fayetteville, Johnson County, Missouri.
Ripple marks are not commonly preserved in the Warrensburg. The sandstone is friable and poorly cemented on a weathered surface and irregularities such as ripple marks tend to be destroyed. One set of poorly preserved ripple marks were observed in an abandoned quarry west of Dover, Lafayette County, and another set was found eight miles north of Fayetteville, Johnson County, at sample locality F 13.

Occasional irregular nodules appear in the sandstone where silicification has produced a quartzitic sandstone. Buckley and Buehler (1904) reported that these "niggerheads" are a detriment to quarrying and are removed from the quarries by blasting.

Concretions are common in the Warrensburg but are generally confined to zones. In the zones rich in iron oxide these concretions are usually composed of hematite, limonite and/or goethite. Where stratification is evident these concretions appear to be displacive. In general, the concretions are hollow spheroidal bodies which vary in size from one to twelve inches along their main axis. The hollow interior of some concretions is filled with an iron rich clay.

Cement

The principal cementing agents of the Warrensburg sandstone are clay, iron oxide, calcium and magnesium
Figure a. Fourteen inch coal bed in the Warrensburg along Postoak Creek north of Warrensburg, Johnson County, Missouri.

Figure b. Local conglomeratic lens in the Warrensburg sandstone along Postoak Creek north of Warrensburg, Johnson County, Missouri.
Carbonates, silica, bitumens, and pyrite.

Clay as a cement is common in all sampled exposures. Illite is the principal mineral of the clay and was found in all samples tested. Pyrite in clay size is present throughout the sandstone.

Hematite and limonite are present in varying amounts in all exposures except the highly weathered zones. The zones from which the iron oxide has been removed are underlain by dark red, very compact zones. Galaxy (1951), from his work on the Moberly sandstone, believes that water moving through the sand tends to leach the iron oxide from the upper zones and deposit it in the lower. The iron oxide content of the samples that were tested varies from 5 to 17 per cent.

The percentage of carbonate cement in the Warrensburg is highly variable. Near Cornelia, Johnson County, Missouri, the sample from locality C 1 contained 22 per cent carbonate, whereas samples from nearby areas contained no carbonate. Buckley and Buehler (1904, p. 308) reported that the sandstone from the quarries north of Warrensburg contained 9.56 per cent calcium carbonate and 1.41 per cent magnesium carbonate. Calcite crystals are prominent in the sample from locality L 5, but the sample from locality L 4 contained no carbonate.

Silification has produced irregular nodules as
mentioned under bedding structures.

Bituminous cement is common in the Higginsville area. The color of the sandstone containing the bitumen is dark brown to black. The bitumen is lost through evaporation on weathered surfaces which according to Dake (1914) shows that the bituminous material contains little asphaltine. The bitumen content averages about 7.4 percent (op. cit. p. 187).

Shale

Shale and clay beds form an important and very interesting part of the Warrensburg. The shale appears as lenses in the sandstone and in places completely replaces the sandstone. Some of the shale beds may be flood plain deposits but in most cases their cross-sectional shape could not be determined. It is considered, however, that in general the shale is an integral part of the channel deposit. The percentage of shale increases toward the south. The minerals contained in the clay fraction of the shale will be discussed later under "Clay and Clay Minerals."

Conglomerate

The basal part of the Warrensburg, where it is exposed, is a conglomerate. The conglomerate varies from two to fifteen feet in thickness and is highly variable in
Plate IV

Figure a. Fossil wood replaced by hematitic clay in the Warrensburg sandstone.

Figure b. Fossil wood replaced by silica in the Warrensburg sandstone.
lithology. Marbut (1898, p. 168) reports fifteen feet of conglomerate along Sand Creek in Henry County that is composed of limestone, shale, coal, and sandstone pebbles with a matrix of sand cemented with clay and iron oxide. This exposure was not found by the writer.

Two and one-half feet of conglomerate consisting of weathered ironstone concretions is exposed above the water level of Postoak Creek north of Warrensburg at sample locality W 12. The maximum diameter of the concretions varies from ½ inch to nine inches. These solid ironstone concretions differ from the usual hollow hematitic-limonitic concretions of the Warrensburg. The exposure can be traced only twenty-five feet and appears to be a local lens in the sandstone.

Occasional cobbles and pebbles may be found higher in the sandstone.

**Carbonaceous Material**

Carbonaceous material is one of the outstanding characteristics of the Warrensburg. In places the sandstone has leaf or twig molds on parting planes and tiny scraps of woody material are often found incorporated in the rock. The shales sometimes have alternating light and dark layers giving it a varved appearance. When the shale is disaggregated and placed in water the dark material separates from the light and forms a carbonaceous
Figure a. Hematite, limonite and goethite concretion in the Warrensburg sandstone.

Figure b. Hematite, limonite and goethite concretions in the Warrensburg sandstone.
Figure a. Varve-like shale of the Warrensburg from sample locality L 1, one mile northeast of Dover, Lafayette County, Missouri.
Coal beds up to fourteen inches in thickness are occasionally found in the Warresburg. Such a deposit occurs in the creek bed of Postoak Creek north of Warreensburg, Johnson County, at sample locality W 12. The coal is about fourteen inches thick and has a lateral extent of about ten feet. It pinches out abruptly into sandstone. The hard, brittle, thin-bedded coal has a rectangular fracture and a bright luster. The coal probably formed in back eddies where plant material could accumulate and be preserved.

Large fragments of fossilized wood are often found in the sandstone and in the shale. The wood associated with the sandstone is usually replaced by a hematitic clay while that associated with the shale is usually replaced by silica.
PETROGRAPHIC STUDY

Sampling

The base used for sample collecting were the Missouri Highway Department County Maps. These maps are divided into ranges, townships and sections and the section lines provide an ideal grid pattern of one mile squares for sampling. An attempt was made to sample at each section corner but in some localities this was impossible because of the lack of exposures.

Samples were taken from relatively fresh surfaces, and where the thickness is over ten feet, samples were taken at five-foot vertical intervals. The average sample size was about 1000 grams.

The localities sampled were recorded on the field map with a letter representing the geographic area and a number representing the location within that area. The letters used were:

"L" . . . . . Lexington area
"H" . . . . . Higginsville area
"F" . . . . . Fayetteville area
"W" . . . . . Warrensburg area
"C" . . . . . Cornelia area
"P" . . . . . Postoak area
"S" . . . . . South end
Disaggregation and Mechanical Analysis

The samples were first partially disaggregated by a motor-driven jaw-type crusner. The material was further disaggregated by rolling the grains in a wooden bowl with a wooden pestle. The softness of the wood and the rolling motion prevented breakage of the grains. Disaggregation was completed by rolling the material on a rubber mat with a wooden rolling pin. The completeness of the disaggregation was checked with a binocular type microscope.

When disaggregation was completed, the samples were reduced by the use of a sample splitter to about 100 grams and weighed on a torsion balance. The weighed sample was then placed on the top screen of a series of Tyler screens. The Wentworth scale was modified by the use of the .351 mm. and the .177 mm. screens. These additional screens provide greater accuracy in plotting cumulative curves.

<table>
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<th>Screen Sizes</th>
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<td>Wentworth Scale Diameter in mm.</td>
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<tr>
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</tr>
<tr>
<td>1/4</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1/8</td>
</tr>
<tr>
<td>1/16</td>
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The series of screens with the sample were placed on a Ro-Tap shaker and agitated for 15 minutes. The screens were then removed and the portion of the sample remaining on each screen was weighed and recorded. Percentages for each size fraction were calculated and used in plotting cumulative curves. The sand fraction was saved for heavy mineral study.
STATISTICAL STUDY

Systematic statistical methods were applied to the data received from the sieving in order that the relationship of the samples might be more easily compared.

First the millimeter sizes were converted to the phi scale. The phi scale was proposed by Krumbein (1934) to facilitate the application of statistical methods to sedimentary data. Krumbein applied a logarithmic transformation equation to the Wentworth scale so that values in phi units were obtained for the various sizes. The phi units increase with the decrease in grain size. The equation used is \( \phi = -\log E \), where "E" is the diameter of the grain in millimeters.

Cumulative curves were drawn and the medians and the first and third quartiles were obtained directly from them. From this information the values for quartile deviation, skewness, and sorting coefficient were derived. The cumulative curves were plotted with the cumulative weight along the ordinate and the phi units along the abscissa.

The quartile measures were first applied to sedimentary problems by Trask (1930) and Krumbein (1934, p. 229) later elaborated on the technique. The first quartile (Q₁) represents the coarsest 25 per cent of the sam-
ple. The median diameter ($Md$) is the diameter with 50 per cent of the grains larger and 50 per cent smaller. The third quartile ($Q_3$) is that which has 75 per cent of the grains coarser and 25 per cent finer.

The measure of size distribution is called quartile deviation. Krumbein and Pettijohn (1938, p. 234) define quartile deviation as one-half the difference between the third quartile and the first quartile. It may be expressed as $Qd \phi = 1/2 (Q_3 \phi - Q_1 \phi)$.

The extent of departure of the arithmetic mean of the quartiles from the median is called skewness (Krumbein and Pettijohn, 1938, p. 235). It is a measure of the symmetry of the grain sizes around the median. Skewness may be expressed by the formula $Sk \phi = \frac{1}{2} (Q_1 \phi / Q_2 \phi - 2Md)$.

Trask (1932, p. 71) developed the sorting coefficient ($So$) as a means of comparing the degree of sorting of a sediment. The sorting coefficient is expressed as $So = \sqrt{Q_3 / Q_1}$. Trask utilized the sorting coefficient in a study of 177 samples and concluded that samples with an $So$ value of 2.5 or less were well sorted, 2.5 to 4.0 normally sorted, and 4.0 or more, poorly sorted.
## CHART I

**STATISTICAL DATA ON SAMPLES FROM REPRESENTATIVE LOCALITIES**

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INTERPRETATION OF STATISTICAL DATA

The principal purposes for obtaining data on grain-size distribution were:

1. To determine the agent or agents of transportation and deposition.
2. To determine the direction of the source area.
3. To determine the relationship of the Warrensburg sandstone to the Moberly sandstone.

Galegor (1951) graphically illustrated the areal distribution of grain size by plotting the percentage by weight of the 2.0, 3.0 and 4.0 phi units and Q₁, Md and Q₃ in phi units along the ordinate and the distance in miles along the abscissa. This method as applied to the data obtained from the Warrensburg samples is shown on Plates XVIII and XLX.

The graphs drawn from the quartiles show a decrease in grain size to the south. The line is smooth with only minor variations. This would seem to indicate that the current carrying the material was moving from north to south.

The graphs using the percentage by weight of the phi units amplifies the minor variations of the previous graph. The coarseness of the samples from the Lexington area of Lafayette County is indicated by a high point on
the 2.0 \( \phi \) line. From there, the line drops abruptly in the Higginsville area of Lafayette County and the Fayetteville area of Johnson County and rises again at Warrensburg in Johnson County. The percentage of coarse material decreases from Warrensburg to Lewis and Clinton in Henry County.

The width of the channel in the Lexington area is about six miles or three times the normal width. One possible explanation for the width and the coarseness of the samples of this area would be a large tributary stream entering at this point from the north, northwest or west.

The coarseness of the samples from the Warrensburg area might also be attributed to a tributary stream.

Another explanation for the coarseness of certain samples would be weathering after deposition. There is a possibility that the finer material would be washed out of the sandstone subjected to water movement. However, the samples showing the highest percentage of fine material are in areas where the soil overburden is thin. The Lexington area has a soil overburden of about sixty feet.

The narrow elongate, concave shape of the Warrensburg seems to indicate that the depositional agent was confined within definite boundaries. The presence of cross-beds and some ripple marks indicates that the sediment was deposited in moving water. The gradual decrease
Plate XVIII

L - Lexington
H - Higginsville
F - Fayetteville
W - Warrensburg
C - Cornelia
P - Postoak
S - South end

Figure a.

2 \( \phi \) plotted with respect to areal distribution

Figure b.

3 \( \phi \) plotted with respect to areal distribution

Figure c.

4 \( \phi \) plotted with respect to areal distribution
Plate XIX

Figure a.

L - Lexington
H - Higginsville
F - Fayetteville
W - Warrensburg
C - Cornelia
P - Postoak
S - South end

$O_1$ plotted with respect to areal distribution

Figure b.

Midpoints plotted with respect to areal distribution

Figure c.

$O_3$ plotted with respect to areal distribution
in grain size from north to south is construed as evidence for a current moving from north to south. The absence of marine fauna in the Warrensburg and the abundance of fossil vegetation might be found in a nearshore marine or a non-marine environment.

Galegor (1951, p. 54) in his work on the Moberly sandstone concluded that a river would supply the following characteristics necessary for a deposit such as this:

1. a river would be restricted to a course by valley walls;
2. a river would have a current moving in a definite direction;
3. a river would have a near-by source of land plants;
4. a river would have the means of eroding, transporting, and depositing the sediment;
5. a river would have inherently the concave downward cross-section.

Galegor (1951, p. 70) concluded that the Moberly sandstone was deposited from a river moving from east to west. On the basis of information gained from statistical data it is considered that the Warrensburg sandstone was deposited from a current moving from north to south. The characteristics of the two sandstones are identical and it is considered that they are segments of the same
deposit.

Galegor (p. 49) reported an average 2.15% for the first quartile of his westernmost samples. The average for the first quartile of the Lexington area was found to be 2.05%. It would be expected that the samples from the Lexington area would be finer than those of the Moberly if the Warrensburg represents the downstream segment. However, a large tributary stream entering the Warrensburg channel in the Lexington area would account for this discrepancy.

The average sorting coefficient of the Warrensburg is about 1.19 which is well within the 2.5 limit that Trask set for a well-sorted sandstone. The greatest variations from the average are in the Warrensburg and Lexington areas. Galegor (p. 49) reported an average of 1.37 for the Moberly. Krumbein and Sloss (1951, p. 75) state that the sorting coefficient "is an index of the range of conditions present in the transporting fluid (range of velocities, degrees of turbulence), and, to some extent, reflects the distance of transportation." The lower sorting coefficient of the Warrensburg is construed to mean that the sediment was transported farther than the material of the Moberly.

The average quartile deviation of the Warrensburg is .50% which is about the same as that of the Moberly.
Some of the samples from the Warrensburg and Lexington areas exceeded the average by .27 phi. Samples toward the south end around sample locality S 9 have a quartile deviation of about .70 phi. Although this evidence is not conclusive, heavy minerals from this locality seem to indicate the entrance of a tributary stream in this area.

All of the samples of the Warrensburg were skewed toward the finer sizes. A comparison with the data derived by Galegor (p. 49) shows that the Moberly is skewed less toward the fine than the Warrensburg. This is further evidence to support the conclusion that the Warrensburg is "downstream" from the Moberly.

From the evidence stated above it is concluded that the Warrensburg was transported and deposited by a river. It is realized that the evidence presented is permissive but not entirely restrictive to this conclusion. A stream of this type would be aggrading and as deposition continued the channel probably became braided. The braided channel would allow contemporaneous deposition of sandstone and shale. Lins (1950), in his work on the Tonganoxie sandstone of the Virgilian Series of Kansas, found that the Tonganoxie was deposited by a southwest-flowing stream. The evidence obtained from the statistical data of the Warrensburg and the outcrop pattern of the Warrensburg show that it, too, was deposited by a
south to southwest-flowing stream.
HEAVY MINERALS

Introduction

A study was made of the heavy minerals of the Warrensburg with the hope of obtaining information pertaining to the source and stratigraphic relationship of the sandstone. The primary objectives of the heavy mineral study are (1) percent of heavy minerals in sample, (2) identification and description of heavy minerals, (3) interpretation of information obtained.

Preparation of Sample

The sand fraction obtained from the mechanical analysis was used for the heavy mineral study. It was necessary to remove the iron oxide stain on the grains before determination of the heavy minerals. To accomplish this the sample was weighed and then treated with hot, dilute, hydrochloric acid until examination showed the grains to be free of stain. The acid was removed by washing with tap water and the sample was dried and weighed. The difference between the two weights gave an approximation of the amount of iron oxide in the sample. Effervescence before heating was noted in some samples indicating the presence of carbonate. The iron oxide content varies from 4 to 6 per cent.
Separation

The samples were split into two parts. One part was used for a gravity separation of the heavy minerals and the other was retained for x-ray study of the feldspar content.

A solution of tetrabromomethane (specific gravity 2.95) was diluted with acetone until a specimen of muscovite barely sank while quartz floated readily.

When the specific gravity had been adjusted the solution was placed in a separatory funnel and the sample was slowly added. The material in the funnel was stirred to break up aggregations and to insure thorough wetting of the grains. When all movement had ceased in the funnel the heavy mineral concentrate was caught on a filter paper, drained, and washed with acetone. The light minerals were also filtered and washed with the solvent to remove the heavy liquid. The tetrabromomethane was recovered by allowing the acetone to evaporate.

The heavy minerals of a sand are concentrated in the finer size fractions. This is due to the fact that for a certain size of quartz and feldspar there is a smaller size of heavy minerals which have the same settling rate. In order to obtain an accurate analysis of relative abundance of the heavy minerals, Rubey (1936) suggested that two size fractions be used. One fraction
would be used to represent the actual grain size and the other the relative grain size. However, the heavy minerals of the Warrensburg constitute less than one per cent of the sediment and it is believed that a size division with such a small amount of material would be impractical.

Results of Heavy Mineral Analyses

The heavy minerals were identified with a petrographic microscope and their abundance in the sample was determined with a binocular microscope. The minerals described below are arranged in the approximate order of their abundance.

Muscovite

Muscovite is not only the most abundant heavy mineral (about 1% of total constituents) of the Warrensburg, but it is also the most characteristic. Muscovite flakes are disseminated throughout the sandstone and appear to be concentrated along bedding planes. The cleavage faces vary from smooth to slightly crumpled and from transparent to cloudy. Many of the crystals contain small dark inclusions, some of which appear to be slightly magnetic. Some books of muscovite occur in the samples and in nearly all cases the edges of the books are ragged.

Aggregates

Three types of aggregates are found in the Warrens-
burg heavy minerals. Two types are abundant in all samples and the third occurs in scattered samples.

One of the aggregates is a gray, sericite-like, schistose aggregation of many minute crystals. It has a silky luster and a hardness of about 2 or 3. With immersion oils it shows high order interference colors and multiple extinction. Individual grains of the aggregate are too small to identify.

An aggregation of quartz with a fine-grained matrix is common to all samples. The quartz is clear and angular. None of the minerals of the matrix could be identified.

In some samples quartz is directly associated with the heavy minerals in an intergrowth relationship. The quartz either partially encloses the associated mineral or is attached to it. Tourmaline, zircon, magnetite, garnet, ilmenite, sphene, and staurolite were observed with this relationship to quartz.

Tourmaline

Brown tourmaline occurs in all samples of the Warrensburg and in some samples is accompanied by a bluish-green variety. The crystals show moderate birefringence and pleochroism. These properties resemble those ascribed to the dravite-schorlrite series by Winchell (1947, p. 303). The tourmaline occurs as angular grains and as prismatic crystals. Some inclusions are found in the brown variety.
Ilmenite or Leucoxene

Ilmenite, with its alteration product leucoxene, occurs throughout the Warrensburg. The ilmenite occurs as short, tabular, slightly magnetic crystals while the amorphous leucoxene occurs as white seams in the black ilmenite grains. Both minerals are opaque with transmitted light. The grains are sub-angular to sub-rounded.

Rutile

Small, rounded grains of reddish-orange to reddish-brown rutile are present in all samples except those from the Higginsville area. The rutile is opaque in transmitted light and has an adamantine luster in reflected light.

Zircon

Zircon is not abundant in any of the samples but is found in all. It occurs as tiny, colorless, elongated, crystals usually terminated with a bipyramid. It is nonpleochroic and has high birefringence.

Hematite and Limonite

All of the samples contain grains of hematite and limonite. These grains are earthy and relatively soft and are considered to be secondary. In the process of removing the iron oxide stain from the mineral grains some of the hematite and limonite was removed so that their true abundance as a heavy mineral could not be determined.
Magnetite

Two varieties of magnetite are present in the Warrensburg. One variety is a small, black, shiny grain that is highly magnetic. This type is common in samples from the Lexington area but decreases toward the south. It is not found in samples taken south of Warrensburg.

Some of the magnetite is a highly altered reddish-brown grain that is strongly magnetic. The grains are thin, and have a rough irregular surface. This type is present in all the samples.

Garnet

Garnet, like zircon, is not abundant in the Warrensburg but appears in most of the samples. The grains are usually well-rounded although an occasional dodecahedron is seen. The color varies from red to pink to almost colorless. One blood red variety occurs in the samples taken around Lewis in Henry County, but is not found in samples north of sample locality S 7.

Kyanite

The kyanite occurs as colorless, elongate, tabular grains. They may be distinguished from books of muscovite by the good 010 cleavage and the 85° angle the 001 cleavage makes with the 010. Kyanite is abundant in a few samples and appears all along the trend of the Warrensburg.
Staurolite

Staurolite is found in all sample localities. It has a reddish-brown color and is sub-rounded with only an occasional trace of a crystal face. Inclusions are seen in many of the grains. It is distinctly pleochroic in brown.

Miscellaneous

Sphene, monazite, pyrite, and biotite are found in only a few samples. Sphene occurs in all sample localities but only one or two grains are found in a sample. Monazite was found in the sample from locality S 7 but was found in no other sample. Only one grain of pyrite and one of biotite were found. Both were from samples from the Lexington area. Differential thermal analyses of the clay fractions of the Warrensburg show pyrite to be present in clay size in all localities. For this reason it is considered that pyrite is probably more abundant in the untreated sample and that some of it is destroyed by the hydrochloric acid when the iron oxide stain is removed.

Interpretation of Heavy Mineral Data

The muscovite of the Warrensburg sandstone is one of the most striking characteristics in the hand specimen and in the heavy mineral concentration. Keller and Ting (1950) found that although mica is abundant in Pennsylvan-
ian rocks, too little is known about the cause of its abundance to base an interpretation on it.

The muscovite of the Warrensburg varies from smooth, transparent flakes to cloudy crumpled flakes. Some of the crumpling may be due to the disaggregation process but probably most of it is due to contact with sand grains during transportation and compaction. Dake (1921) believes that mica may be ground to a powder during transportation and may be completely removed from a sediment. X-ray diffraction patterns show that muscovite is present in the less than two micron clay fraction and it is considered that this size was achieved by disaggregation during transportation. However, it is entirely conceivable that the tiny crystals were formed from illite. B. B. Cox (personal communication) believes that not only may illite be formed through the breakdown of muscovite, but muscovite may be crystallized from illite. Dana (1947) reports that muscovite is frequently of a secondary origin and that it may be derived from the alteration of topaz, kyanite, or feldspar.

The muscovite flakes of the Warrensburg often contain tiny inclusions and some iron oxide stains along the cleavage. The inclusions are dark in color and their identity could not definitely be determined. Some of the inclusions which appeared to be slightly magnetic were
tentatively identified as magnetite. Other inclusions may be garnet or tourmaline.

Muscovite is an original constituent of the more crystalline rocks that are rich in potash and alumina. Granites and syenites and their pegmatitic equivalents usually contain muscovite. Metamorphic counterparts of these rocks as well as mica schists and phyllites are also rich in mica. It is considered that at least the larger grains of muscovite are detrital and that they were originally derived from an acid igneous or a metamorphic source.

The sericite-like aggregate may be related to the muscovite or it may be entirely independent. The tiny crystals composing the aggregate appear to be platy and have a pearly luster. It is entirely possible that these aggregates are associated with phyllites which represent low rank metamorphism. When sericite is abundant, metamorphism of the feldspar in felsites is usually indicated (Pirsson, 1947).

Tourmaline occurs in the Warrensburg as elongate prismatic crystals or as angular fragments. The crystals show little rounding which may be attributed to the high resistance coefficient to abrasion for tourmaline. Krynine (1946) believes that it is one of the most wear resistant of the common minerals and cites the work of F. W. Freise who found the resistance coefficient to abrasion
for tourmaline to be 850 to 950 as compared to 245 for quartz. The tourmaline of the Warrensburg may fall into either of two provenances ascribed for tourmaline by Krynine (p. 68): granitic tourmaline or tourmaline from a pegmatized injected metamorphic terrain. Some evidence, such as the small percentage of heavy minerals, points toward the conclusion that the Warrensburg was formed from a reworked sediment. However, Krynine (p. 76) states that the tourmaline of a second-cycle sediment is usually represented by several different types. This contrasts with the one major and one minor type of tourmaline of the Warrensburg.

For the most part the heavy mineral suites of the Warrensburg and Moberly are almost identical although some differences may be noted. Galegor (p. 61) reported pyrite as sixth in abundance in the Moberly while it was found in only one sample of the Warrensburg. However, pyrite is abundant in the clay fraction of Warrensburg and was not apparent in the one sample of Moberly clay that was tested. This difference may be due to a difference in the distance of transportation or to post-depositional chemical weathering. Pyrite is probably the source of some of the iron oxide coating of the mineral grains.

Galegor (p. 63) also found garnet to be almost completely lacking in the Moberly. The garnet of the War-
rensburg is not abundant but it appears in nearly all samples. Two types of garnet are persistent throughout the entire length of the sandstone exposures and another type is found only in samples from localities S 8 to S 17. This indicates the possibility of a tributary stream entering the channel around sample locality S 8 about three miles east of Shawnee Mound, Henry County, Missouri.

One of the most significant differences between the heavy minerals of the Warrensburg and the Moberly is the magnetite. Only a negligible amount of magnetite was reported from the Moberly but the Warrensburg contains two fairly persistent varieties. One variety is a small, black, shiny, grain which is present only north of Warrensburg, Johnson County. The other variety is persistent throughout the Warrensburg. It is a highly altered, reddish brown to black, strongly magnetic grain.

A large, tributary stream entering the Warrensburg channel around Lexington could account for the minor differences in the heavy minerals suites of the two sandstones.
The feldspar-quartz ratio of the Warrensburg sand is an interesting and somewhat controversial point. The scope of the problem did not permit a thorough study but some data were obtained to supplement the heavy mineral study and the mechanical analysis data.

Dana Russell (1937) found that in a stream such as the Mississippi River there is a little reduction in the size of the feldspar grains less than .25 millimeter in diameter. Material of this size is usually carried in suspension and the water acts as a cushion around the grains, thus reducing the effect of abrasion. However, in an aggrading stream such as the Warrensburg probably was, the material would be transported principally by saltation or rolling. This would effect a reduction in size due to abrasion accompanied by an increase in chemical alteration due to greater surface area of the particles. Orthoclase, with its more pronounced cleavage, would be reduced in size more readily than the sodium-calcium feldspars but would undergo less chemical alteration. From these facts the following hypotheses were derived:

(1) The percentage of feldspar in the sand fraction will decrease as the distance from the source increases.
(2) The potassium feldspar will be reduced in size but will undergo less chemical alteration than the sodium-calcium feldspars. X-ray diffractions were run on some representative samples and on some artificial mixtures with the purpose of determining the percentage of feldspar in the samples. It was found that only the unweathered feldspar retains its x-ray identity. On the basis of a comparison of the intensities of the feldspar reflection of the Warrensburg samples with the reflections of the artificial mixtures, it is estimated that the Warrensburg contains about 10% "fresh" feldspar in the sand fraction. The major reflections for feldspar are the 3.26 and 3.20 angstrom reflections. The intensities of these reflections for the Warrensburg samples are less than the intensities of these reflections for the artificial mixture containing 20% feldspar. Since feldspar and quartz constitute about 95% of the sand fraction, it is believed that the maximum percentage of feldspar could be found by determining the percentage of quartz in the sample. Quartz is more resistant to chemical alteration and will retain its x-ray identity.

A preliminary study of the feldspar content of the Warrensburg with unstained samples revealed a maximum of 20% feldspar. However, Markward (1952, p. 41), using staining techniques, reported the feldspar content to vary
## CHART II

**X-RAY DATA OF SAND FRACTION OF REPRESENTATIVE SAMPLES**

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"I" in the table above is a relative value for the intensity of the reflections. Values range from 10 (the strongest) to 0.
from 33.1 to 42.3%. In comparing the feldspar of the Warrensburg to that of the Moberly, Markward found that (1) the maximum total feldspar percentage is higher in the Moberly sand than in the Warrensburg sand, and (2) the potassium feldspar percentage reaches a greater maximum in the Warrensburg than in the Moberly. From these facts, it might be reasonable to conclude that the feldspar of the Warrensburg is farther from its source than the feldspar of the Moberly.
CLAY AND CLAY MINERALS

The importance of clays as indicators of depositional environment and source area led to a preliminary study of the clays of the Warrensburg. The principal objectives were: (1) to determine the relationship of the clay fraction to the sand fraction, (2) to determine if the clays of the Warrensburg are similar throughout the deposit, and (3) to determine the relationship of the clays of the Warrensburg to the clays of the Moberly. Unfortunately only one sample of Moberly clay was available and no valid conclusions could be drawn concerning the relationship of the clays of the two deposits.

Representative samples were selected from the shales and siltstones of sample localities L 1, H 5, F 9, C 1, C 9, and S 6 and from the clay fraction of the sandstone from locality W 6.

The two techniques used for the clay study were differential thermal analysis and x-ray diffraction. It was found that at least two methods of analysis were desirable because of the limitations of each technique. Thermal reactions of some minerals are so similar that positive identification is difficult. Other minerals, such as feldspar, have no thermal reactions within the temperature range used. X-ray diffraction, particularly
of clay mixtures, is also sometimes unsatisfactory. A relatively small amount of quartz will yield a diffraction pattern so intense that it may mask a larger amount of clay. By using both methods determination may be made with reasonable certainty.

The samples were disaggregated by the same method used for mechanical analysis samples and carbonate compounds were removed by acidifying in dilute hydrochloric acid. The acid was removed by washing with distilled water until a pH of about 6.5 was attained.

Only the less-than-two microns fraction of the clay was used for analysis. The sample was placed in a .005 N solution of sodium oxalate and vigorously agitated to break up aggregates and to insure dispersal. When the material had settled for four hours, five centimeters was siphoned from the beaker and allowed to dry at about 100 degrees centigrade. The settling time (1.25 centimeters per hour) for the less-than-two microns fraction with sodium oxalate as a dispersing agent was computed from Stoke's law.

**Differential Thermal Analysis**

The differential thermal analysis is a dynamic method of heating a substance causing it to undergo chemical or physical changes. The changes may be the loss of water, decomposition, oxidation, crystallization, and/or
change in crystal lattice.

The differential thermal unit used was constructed from specifications by Berkelhammer (1945). The sample is heated in an oxidizing atmosphere from room temperature to 1000 degrees C. by an electrical resistance type furnace. The heating rate is about 10 degrees C. per minute. The thermal reactions are recorded by a chromel-alumel thermocouple and a mirror-galvanometer. A beam of light reflected by the mirror to photostat paper records a continuous thermal curve.

During the heating of the sample two thermal influences are evident, the heat of the thermal reaction and the differential heat inflow from the sample block to the sample. When the temperature difference between sample and the inert alumina is zero, a straight line is recorded on the thermal graph. When the sample is absorbing heat at a greater rate than the inert (endothermic reaction) there will be a downward deflection of the thermal curve. The opposite thermal reaction (exothermic) results in an upward deflection. The intensities of thermal reactions and the temperatures at which they occur are different for each clay mineral and provide a means of identification.

All of the samples were run with 250 ohms resistance in the galvanometer circuit.
Limonite (Grim and Bowland 1945)

Kaolinite (Grim, Bradley and Brown 1951)

Illite (Grim, Bradley and Brown 1951)

Muscovite (Grim, Bradley and Brown 1951)

Glaucite (Grim, Bradley and Brown 1951)
<table>
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<th>Material</th>
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<td>S 6 Clay</td>
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<td>Moberly Clay</td>
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<tr>
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**Plate XXII**
X-ray Diffraction

X-ray diffraction as a technique for determining clay minerals and their associates is excellent for confirming data obtained from thermal analysis. With this technique it is possible to determine minerals associated with the clay which have no thermal reactions within the temperature range used for thermal analysis.

The x-ray unit used, the North American Phillips Company X-ray Spectrometer, produced copper radiation collimated through 1 degree slits and filtered through a nickel filter. The samples were scanned from 70 degrees to 5 degrees 2 Theta. The 2 Theta values were converted to Angstrom units by use of the U.S.G.S. Circular 29 (Switzer, et. al., 1948).

Mineral Determination from Thermal and X-ray Data

The determination of the mineral constituents of the clays of the Warrensburg was accomplished by comparing the thermal curves and x-ray data with standards presented in the literature. It was found that the Angstrom values obtained from the spectrograms varied as much as .04Å from the true value. This variation was attributed to the lag of the recording unit behind the radiation unit and to the difficulty in obtaining precise measurements of the 2 Theta values.
Plate XXIV

F9 Clay
< 2 microns
Saturated with Glycol

C1 Clay
< 2 microns
Saturated with Glycol
Plate XXV

C9 Clay
< 2 microns

S6 Clay
< 2 microns

Moberly Clay
< 2 microns

INTENSITY
### CHART III

**X-RAY DATA OF CLAY FRACTION OF REPRESENTATIVE SAMPLES**

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# CHAPTER IV

## X-RAY DATA OF CLAY FRACTION OF REPRESENTATIVE SAMPLES

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**Illite and Muscovite**

Illite is present in all of the samples tested in an amount large enough to give characteristic thermal peaks. Muscovite is present but in an amount too small to give a deflection of the thermal curve.

Plate XX shows the thermal curves for illite and muscovite. According to Grim and Rowland (1944) the illite clay minerals have endothermic reactions between about 50 and 250 degrees C., 500 and 600 degrees C., and 850 and 925 degrees C. Exothermic reactions occur between 925 and 980 degrees C. The thermal reactions are slight and the final endothermic and exothermic reactions may not be noticeable.

All of the Warrensburg samples and the Moberly clay have endothermic reactions at 150 degrees and 200 to 225 degrees. These two reactions are interpreted as the loss of absorbed water in the illite. The endothermic reactions occurring between 500 and 600 degrees are probably in part due to the hydroxyl loss of the illite, but the exact temperature at which this reaction occurs cannot be ascertained because of similar reactions of other minerals. The exothermic-endothermic crystallization reactions between 850 and 980 degrees is not perceivable.

The presence of both illite and muscovite are confirmed by the x-ray spectrograms of the clays (Plates
XXIII, XXIV and XXV). With the exception of the strong 5.04 to 5.07 Å reflections of the muscovite, the major reflections of illite and muscovite have the same Angstrom values. The major reflections of the illite and muscovite are 10.16 to 10.40 Å, 4.46 to 4.53 Å, 2.56 to 2.59 Å and 1.50 to 1.52 Å. Muscovite does not occur in clay size in sample W 6.

**Kaolinite**

The thermal curve of kaolinite (Plate XX) shows an intense endothermic reaction between 550 and 650 degrees C., and a sharp exothermic reaction between 960 and 990 degrees C. A slight exothermic effect is sometimes apparent between 650 and 950 degrees C.

The usually intense endothermic reaction of kaolinite is not strong enough in the Warrensburg clays to distinguish it from similar reactions of other minerals. The exothermic is slight but persistent in all curves. This reaction is caused by the crystallization of the amorphous alumina produced by the decomposition of the kaolin lattice in the endothermic reaction. On the basis of the intensities of the reactions, the amount of kaolinite in the samples is estimated to be from 10 to 20%.

X-ray spectograms of the clays show an unmistakable 7.14 to 7.38 Å reflection for the kaolinite.
As a further check sample C 1 was heated to 600 degrees C. for eight hours and again subjected to x-radiation. Since the crystal lattice of kaolinite is destroyed at 600 degrees C. (Kerr, et al, 1949), the 7.14 to 7.38 Å reflection was missing in the fired clay.

**Feldspar**

Feldspar has no thermal reactions under 1000 degrees C. but its presence is indicated by the numerous x-ray reflections on the spectrograms. The principal reflection of the feldspar is the 3.19 to 3.24 Å. The intensities of the reflections are slight but well defined.

**Chlorite**

The presence of chlorite is not detectable from the thermal curves but x-ray spectrograms show at least four of the clays to contain some chlorite. The principal reflection of the chlorite, the 14.7 to 14.9 Å reflection, is distinct in the spectrograms of samples L 1, H 5 and F 9. Sample C 1, when fired to 600 degrees C., shows a distinct 14.73 Å reflection that was not evident before heating. According to Brindley and Robinson (1951) this reflection, the 001, becomes more intense when chlorite is heated. Montmorillonite also has a 14 to 15 Å reflection that is difficult to distinguish from chlorite. However, when samples F 9 and C 1 were solvated with ethylene gly-
The 18 Å reflection of solvated montmorillonite was not evident and montmorillonite was considered to be absent. Further examination will probably show the presence of chlorite in smaller amounts in the other samples.

Quartz

At about 575 degrees C, alpha quartz is inverted to beta quartz and a slight endothermic reaction results (Plate XXII). This reaction could not be distinguished on the thermal curves of the Warrensburg clays because of the masking effect of the reactions of other minerals. However, x-radiation of quartz produces an unmistakable pattern of strong, sharp lines. MacEwan (1951) states that the 3.35 Å reflection can be seen when only one per cent quartz is present. The 3.36 Å reflection of the Warrensburg clays is intense and persistent. The sample S 6 from the south end of the Warrensburg has a more intense 3.36 Å reflection than the samples to the north.

Pyrite

Pyrite is present in varying amounts in all of the Warrensburg clays but is not detectable in the one sample of Moberly clay that was tested. Pyrite has a sharp exothermic reaction at about 450 degrees C and an endothermic reaction between 550 and 650 degrees C. A difference in grain size may result in two endothermic reactions between
550 and 650 degrees C. (Plate XXII). The thermal curves of the Warrensburg clays show moderate to intense exothermic reactions at about 450 degrees C. but the endothermic reaction cannot be distinguished from similar reactions of other minerals.

The x-ray reflections of the pyrite are masked by quartz and other minerals.

**Hematite and Limonite**

Hematite does not have a thermal reaction within the temperature range used for thermal analyses but its presence is indicated by the 1.69 to 1.71 A° reflections on the x-ray spectrograms. It is present in detectable amounts in samples L 1, H 5, W 6, and C 9. Hematite probably occurs in the other samples but in an amount too small to be detected.

Limonite (Plate XX) has an endothermic reaction at about 310 degrees C. This reaction occurs in samples H 5 and W 6.

**Montmorillonite**

Montmorillonite appears to be absent in the Warrensburg clays. Samples C 1 and F 9, which are considered typical, were saturated with ethylene glycol and allowed to stand for twenty-four hours. Any montmorillonite present would give rise to an intense 18 A° reflection on the
x-ray spectrograms due to interlamellar absorption of the glycol. This reflection is not present on the spectrograms and montmorillonite is considered to be absent.

Conclusions from Clay Analyses

The clays of the Warrensburg are an interesting and complex mixture of several minerals. The clays seem to be typical of a river deposit in that there is a definite relationship between the sand-size and clay-size particles. Abrasion during transportation tends to reduce sand-size material to clay.

Illite, which constitutes at least 50% of the clay, is a normal associate of a muscovite-rich sediment. Cox, as mentioned under "Heavy Minerals," believes that illite forms directly from muscovite. However, since muscovite comprises only one percent of the sediment it is considered that part of the illite may have formed from the feldspar. Kerr et al. (1949) considers illite to be most abundant as a secondary mineral in sediments. This would appear to be the case of the illite of the Warrensburg. The good porosity of the sand would allow adequate circulation for the solutions leaching the muscovite and feldspar.

The presence of kaolinite provides some insight on the source area of the Warrensburg. In general, it is not feasible to suggest that illite and kaolinite form under the same conditions and it is suggested that the kaolinite
represents the kaolinitic clays and scales of the Lower Pennsylvanian. Kaolinite is stable and is capable of being transported without being altered.

The quartz and feldspar of the clays was probably abraded from larger particles during transportation. There appears to be an increase in the amount of clay-size quartz toward the south which would seem indicative of longer transportation. The percentage of feldspar is probably greater than is indicated by the spectrograms because of the loss of x-ray identity through weathering.

The chlorite of the Warrensburg constitutes only about 5% of the clays. It is present in detectable amounts in samples from the northern end of the deposit but decreases in abundance to the south. The significance of this decrease is not known but it is suggested that the chlorite was altered or partially removed during transportation. It is concluded, therefore, that the clays toward the south have been transported further.

It is believed that future and more detailed study of the clays of the Warrensburg will show that the percentage of quartz, feldspar and illite increase toward the south end of the deposit. Conversely, the percentage of pyrite and chlorite will be shown to decrease to the south. These relative increases and decreases would be typical of a south flowing stream.
SUMMARY

1. On the basis of recent work by Howe (1948) and Greene and Seabright (1949) the Warrensburg sandstone has been designated as the upper member of the Nowata formation.

2. The relationship of exposures at Clinton, Henry County, Missouri to exposures at Lewis, Henry County, Missouri indicate that the trend of the south end of the Warrensburg is to the southwest.

3. The comparison of the basal Warrensburg at several exposures along the south bluffs of the Missouri River in Lafayette County demonstrates the concave cross-sectional shape of the Warrensburg.

4. Ripple marks and cross-laminations indicate that the Warrensburg was deposited by moving water. Plant remains and coal beds indicate a nearby source of vegetation. The adjacency of sandstone, shale, conglomerate and coal at the same stratigraphic level indicates that the depositional agent had highly variable currents. These depositional conditions are suggestive of a river deposit.

5. Plant remains are the only fossils found in the Warrensburg. Future work with the spores from the Warrensburg coals will probably show the true age of the deposit.
6. In general, the grain size of the sandstone decreases from north to south. This indicates that the current of the depositional agent was moving from north to south.

7. The increase in grain size in the Lexington and Warrensburg areas could be caused by tributary streams entering at these points.

8. The sorting coefficient and the quartile deviation of the Warrensburg and Moberly are very similar. The average quartile and median of the Warrensburg is smaller than that of the Moberly.

9. The similarity of the major heavy minerals of the Warrensburg and the Moberly indicates that the source areas were very similar and suggests that the two sandstones are segments of the same deposit.

10. The presence of some important heavy minerals in the Warrensburg that are not found in the Moberly is indicative of tributary contamination in the Lexington area.

11. The smaller total feldspar percentage and the greater maximum potassium feldspar percentage in the Warrensburg indicates that the Warrensburg is farther from its source than the Moberly.

12. In general, the clay fraction of the Warrensburg is genetically related to the sand fraction.
13. The kaolinite of the Warrensburg clays may represent
the erosion of the kaolinitic clays and shales of the
Lower Pennsylvania.
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Shepard, E. M. (1898), "Geology of Greene County," Missouri Geol. Surv., Vol. XII.


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