THE SEDIMENTARY PETROLOGY OF THE LOGAN FORMATION IN LICKING COUNTY, OHIO

A Thesis

Presented in Partial Fulfillment of the Requirements for the Degree Master of Science

by

Robert Warren Pinker, B.S.

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Approved by

[signature]
Adviser
Department of Geology

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figures

Tables

Plates

INTRODUCTION

This report is on the petrography of the Logan Formation of Mississippian age in Licking County, Ohio. The Logan Formation of Licking County is a part of the Pretty Run facies (Holden, 1942). The Pretty Run facies extends from eastern Scioto County north to Wayne County (Figure 1). The four members of this facies, the Berne, Byer, Allensville, and Vinton, have the same lithologic character throughout the area, and therefore the Pretty Run facies in Licking County is representative of the Pretty Run facies in Ohio.

Although the stratigraphy and paleontology of the Logan Formation have been studied by many geologists, to the writer's knowledge these studies have not included the detailed petrography. Therefore, a study of the petrography of the Logan was undertaken in order that an interpretation of its sedimentary history, based on stratigraphy, lithology, and petrology could be made.

FIELD AND LABORATORY STUDY

The field work was done during June and July of 1969. It consisted of collecting sixty-eight hand-samples from six different locations. At each location the Logan was measured and described megascopicaly, and a sample was taken from each unit in the section.

A thin-section was prepared from each hand-sample and was examined with the aid of a polarizing microscope following methods outlined by Folk (1959). This examination included a 100-point count of the major constituents in the thin-section. The following data were recorded for each grain counted: the long and short axis, the roundness, and any special features such as inclusions, overgrowths, or replacement by other minerals.

The same data were recorded for each type of heavy mineral encountered in a thin-section. Because heavy minerals were not used for determining the rock name, they were not included in the 100-point count of the major constituents. Also, a 100-point count of grains versus pore space versus cement was made to give an indication of the porosity of the sample and of the percentage of each type of cement present.

The roundness of each grain counted was determined by comparison with Power's roundness chart. The sphericity of each grain was determined by dividing the short axis by the long axis, and the size of each grain was determined by averaging the long and the short axes.

The anlysis of the data obtained from each thin-section was accomplished with an IBM 360 Digital computer. The computer was used for calculation of roundness, sphericity, and grain size; for drawing a cumulative curve; and for calculating the following parameters from the cumulative curve: mean grain size, grain size modes, inclusive graphic standard deviation, skewness, and kurtosis. The computer was also used for determining average roundness, average sphericity, and average grain size for each mineral constituent in one thin section. The computer program is in Appendix II.

Graphs were then drawn from the data in order to determine variations in composition and grain size of the members (Figures 5 and 7). The graphs were then compared to determine areal variations in mineral composition and grain size within the Logan.

Finally, the samples were given five-fold names in the following manner.

> Grain size: prominent orthochemical cement, textural maturity, unusual transported constituents, main rock name.

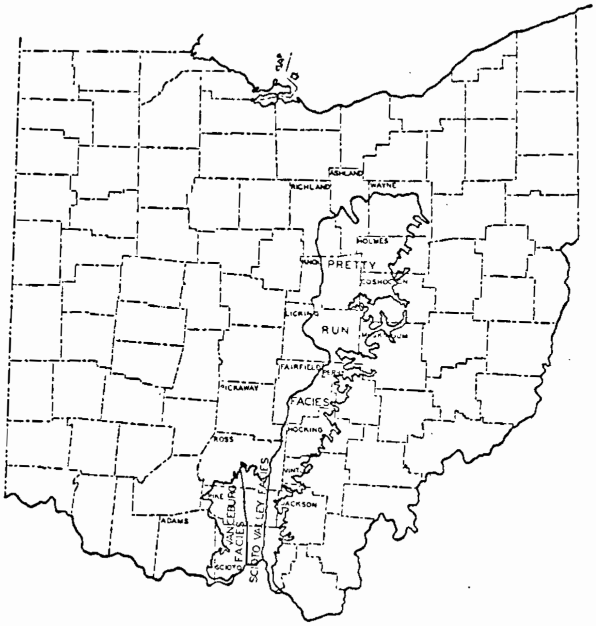

Figure 1. Map showing the location of the facies of the Logan

Figure 2. Map showing location of Licking County, Ohio.

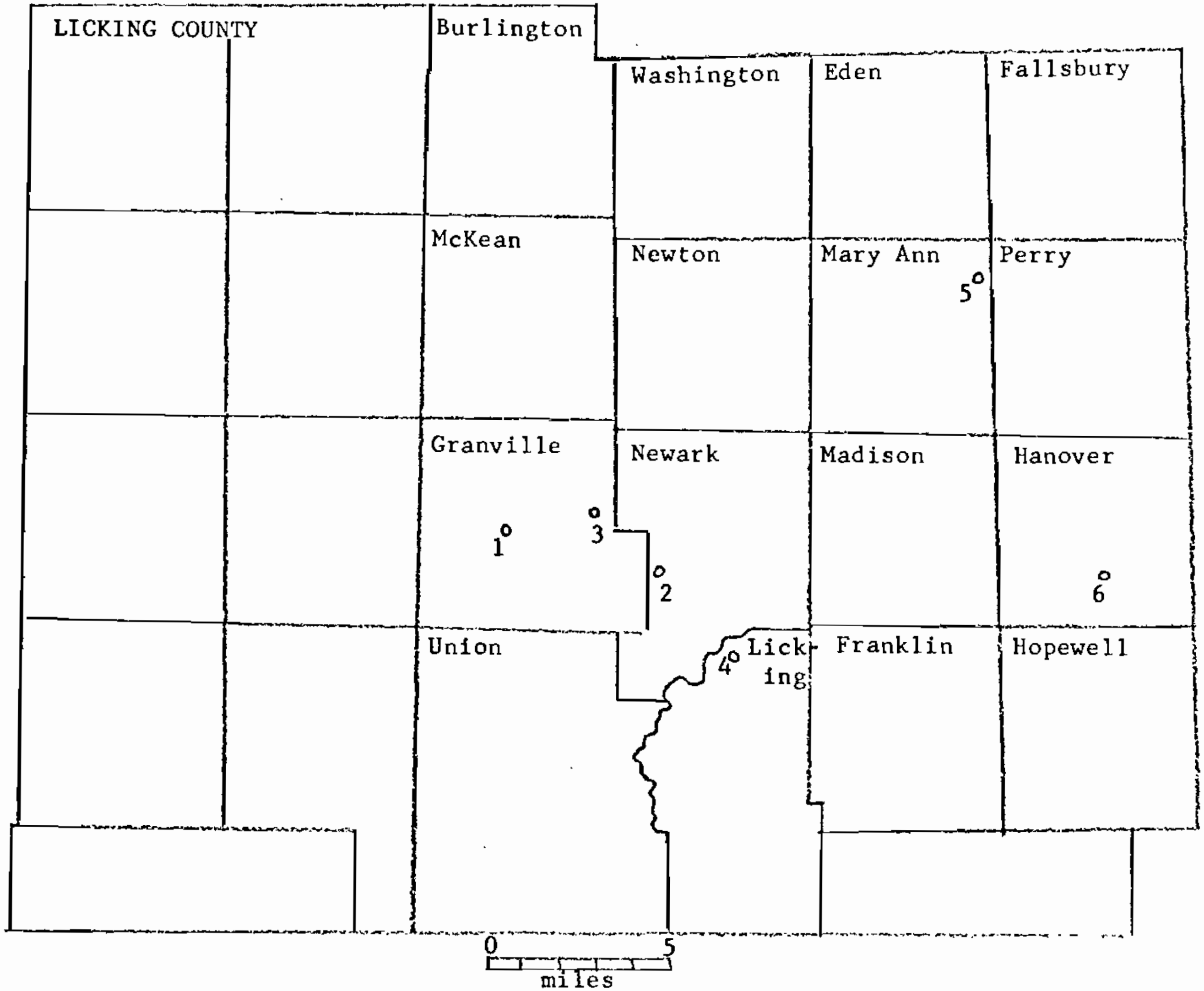

Figure 3. Area of study and location of measured sections.

The grain-size name was determined by the ratio of the percentage of gravel sand and mud. Textural maturity and main rock name were determined by using methods described by Folk (1959).

AREA OF STUDY

Licking County is located a short distance to the southeast of the center of Ohio. It is bounded on the north by Knox County, on the east by Muskingum and Coschocton Counties, on the south by Fairfield and Perry Counties, and on the west by Franklin and Delaware Counties (Figure 2). The city of Newark is located just southeast of the center of Licking County.

The sampled sections are located in Granville, Newark, Madison, Hanover, and Perry Townships. These townships encompass approximately 125 square miles (Figure 3). The locations and descriptions of the measured sections are given in Appendix I.

REGIONAL GEOLOGY

The Logan Formation crops out in a belt that trends north-northeast from Scioto County on the Ohio River, through Licking County, and into northeastern Ohio. Because of an eastward regional dip, the entire thickness of the Logan is exposed within Licking County. The Cuyahoga Formation of Mississippian age underlies the Logan to the west, and the Pottsville Series of Pennsylvanian age overlies it to the east. In some places outside of Licking County, the Maxville Limestone of Mississippian age lies between the Logan and the Pottsville (Figure 4).

PREVIOUS WORK

The only similar work involving petrology of the Logan Formation was done by Swick (1956), who described three different lithofacies

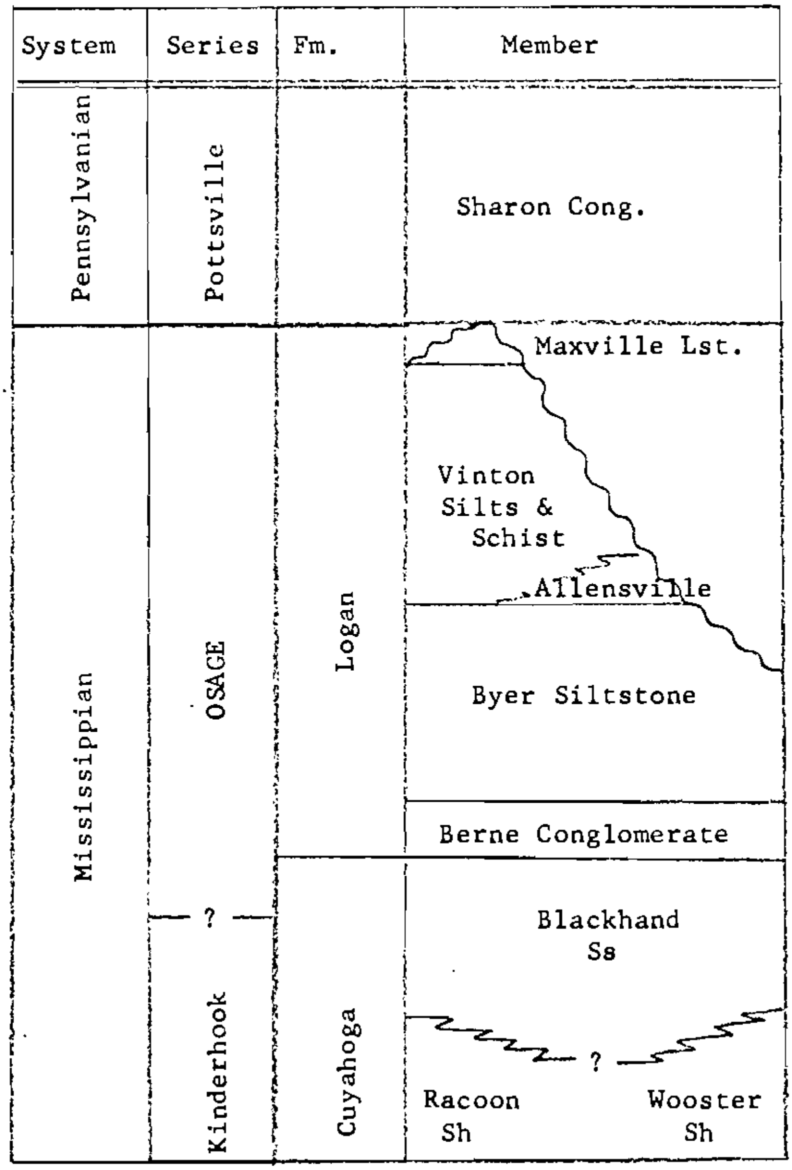

Figure 4. Stratigraphic chart of the units discussed in this report.

of the Berne Member of the Logan based on the percentage of pebbles present in a sample, the matrix composition, and the cementation of the conglomerates. For the sandstones and siltstones of the Berne, Swick estimated their composition as"...95 to 99 percent quartz, with traces of the following minerals listed in order of their abundance:

MUSCOVITE
ALTERED FELDSPAR
BIOTITE
ZIRCON
TOURMALINE
RUTILE
GARNET
GLAUCONITE(?)
SILLIMANITE(?)"

He further stated that "Quartz grains occasionally contain inclusions of biotite", and that some angular quartz grains "...were formed by percolating silica-rich ground waters."

ACKNOWLEDGMENTS

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LOGAN FORMATION

The name Logan was first used by Andrews (1870)for the 133.5 feet of fine-grained buff-colored sandstone beneath the Pennsylvanian rocks in Hocking County, Ohio. Hyde (1921) divided this unit into four members: the Berne, the Byer, the Allensville and the Vinton. These divisions of the Logan have also been applied to the Logan Formation in Licking County, and thus this 1921 classification is the one used in this report.

BERNE MEMBER

The Berne Member was defined by Hyde (1915) as the coarse, pebbly uppermost few feet of the Cuyahoga Formation. Later, he removed the Berne from the Cuyahoga and included it in the Logan Formation. The Berne consists of those beds between the Byer Member of the Logan and the Black Hand Member of the Cuyahoga. These beds had been previously named Conglomerate I by Herrick (1888).

The Berne is composed of conglomerate, conglomeratic sandstone, and sandstone with some siltstone and shale units. The color ranges from orange-yellow to yellow, tan, and reddish-brown. The Berne is very poorly cemented and in most outcrops is friable. It consists of 90 to 99 percent quartz with varying amounts of feldspar, metaquartzite, chert, and accessory minerals.

Swick (1956) classified the Berne into three lithofacies which he named after the cities of Newark, St. Louisville, and Toboso. In general, the Toboso lithofacies is thin, poorly sorted, and conglomeratic. The St. Louisville lithofacies is moderately thick, moderately well-sorted, fossiliferous and conglomeratic. The Newark lithofacies is thick, well-sorted, fossiliferous, and sandy with small amounts of conglomerate.

At all of the sections measured during this study, the Berne lies above either the Black Hand Member or the interfingering Racoon Member of the Cuyahoga Formation. The contact at places is distinct and disconformable with a relief that ranges from several inches to two feet. However, only at location six was the disconformity traceable laterally for any distance. Usually, the contact is indistinct and gradational with the Cuyahoga. The contact between the Berne and the overlying Byer siltstone is gradational at all places. Beds of siltstone and fine sandstone are interbedded with beds of coarse sandstone, some of which contain pebbles.

The thickness of the Berne ranges from 3 feet at section 6 to 12.5 feet at section 2. This variation, according to Franklin (1961) is related to the distribution of the Berne with respect to the axis of the underlying Black Hand tongue. The Berne is thin over the axis of the tongue and thickens to the west-southwest of the axis.

Some beds within the Berne show well-developed tabular cross-bedding with dips ranging from 5 to 15 degrees and a general north-northwest trend(Hyde, 1915). Very few fossils are found in the Berne. Fagadau (1952, p. 29) identified only four species from the Berne: Rhipidomella missouriensis, Dictyoclostus winchelli, Syringothyris carteri, Platyceras haliotoides, and stated that "the Berne is fossiliferous only in its extreme western areas, as in central Licking County...". Many of the fossils are fragmented suggesting transport.

PETROLOGY

Texture

Seventeen samples of the Berne were examined and studied in thin-sections. The Berne is a terrigenous rock, composed of 70 to 88 percent terrigenous sediments and 12 to 30 percent orthochemical cements. The fabric of the Berne is homogeneous with pebbles distributed randomly through the sand. The packing of the Berne is loose. Before cementation the porosity of the Berne was between 17 and 34 percent. Now, after cementation, the porosity of the Berne samples ranges from less than 1 percent to 21 percent.

The average Berne sample is a pebbly medium-grained sandstone: ferruginous, siliceous, submature, quartzarenite. Samples range from almost pure quartzarenites to the border line between quartzarenites, subarkoses, and sublitharenites (Figure 8). They contain from 84 to 99 percent quartz. One to 6 percent feldspar, and 1 to 11 percent chert and rock fragments.

Textures in the Berne range from very fine-grained sandstone to sandy pebble-conglomerate. The largest particle encountered has a size of 8.7 mm. and the smallest 0.02 mm. The median grain size of the samples ranges from 0.073mm. to 8.94 mm., with most grains averaging between 0.25 mm. and 0.5 mm. (medium sand).

The Berne grains are poorly to moderately sorted and have a unimodal size distribution. Sand-size grains are uniformly mixed with 3 to 23 percent pebbles, 1 to 56 percent silt, and 1 to 7 percent clay-size particles. Depending upon the percent of clay, the Berne sediments are either texturally immature or submature. Interstices between larger grains are filled with smaller, more angular grains.

All classes of sphericity and roundness are represented in the Berne. The mean sphericity is 0.674 (intermediate), and the mean roundness is 0.36 (subrounded to rounded). This high roundness coupled with poor sorting indicates that the sediment is possibly multicycled sedimentary grains.

Descriptive Mineralogy

Quartz. The average Berne sample contains 94.6 percent quartz, which has an average diameter of 0.318 mm. (medium sand). The quartz grains have a unimodal size distribution and range in diameter from 0.02 mm. to 5.0 mm.

The average sphericity of the quartz grains is 0.679 (intermediate) with a primary mode in the very elongate type and a secondary mode in the very equant type. The average roundness is 3.78. The roundness distribution is unimodal and ranges from very angular to well rounded with a primary mode in the subrounded range.

Approximately 20 percent of the grains counted have overgrowths. Of these grains 75 to 80 percent have angular overgrowths. The remaining 20 to 25 percent have rounded overgrowths indicating some grain transport following overgrowth formation.

The Berne contains five of the six emperical types of quartz of Folk (1959, p. 74), and following is a description of each type (Table I).

Type 1 grains compose 56.8 percent of the quartz grains counted. These grains are either clear or contain vacuoles and/or mineral inclusions. Some vacuoles are filled with gas and some with liquid. They are randomly scattered and/or arranged in vacuole trains across the grains. The inclusions that could be identified are leucoxene, hematite, magnetite, muscovite, biotite, and tourmaline. These inclusions are randomly distributed through the grains. A few vacuoles occurred within the mineral inclusions. Almost every Type 1 grain contains some type of inclusions.

Type 3 grains compose 12.0 percent of the total quartz. These grains are either clear or contain vacuoles or mineral inclusions. The vacuoles are either arranged randomly or in vacuole trains across the grains. The mineral inclusions identified are muscovite, biotite, and leucoxene.

Type 4 grains compose less than one percent of the quartz. These contain vacuoles and mineral inclusions similar to Type 3 grains.

Type 5 grains compose 10.2 percent of the quartz. The grains contain inclusions of biotite, muscovite, and vermiculite and gas-filled vacuoles. Several grains show chert replacement along their composite borders.

Type 6 grains compose 15.3 percent of the quartz. These grains contain gas- and liquid-filled vacuoles and inclusions of muscovite and biotite. The composite sections of these grains exhibit straight to metaquartzite to crenulated boundaries with each other. Some grains exhibit a gneissic texture, i.e., a parallel optical orientation of composite sections. Some hematite staining was also observed on some grains, but this may be due to recent weathering. This type of grain shows good rounding, all grains having a roundness value of 3.0 (subrounded) or higher.

Chert. Twenty six grains of chert were observed during the point count. These compose 1.5 percent of the Berne. The chert grains are subrounded to well-rounded and have a unimodal size distribution from medium to very coarse sand. Most of the chert is unweathered, but some is deeply weathered and stained by hematite. A distinction was made between chert and metaquartzite in the following way: a grain was called chert if intragrain boundaries were not visible under 500 x magnification.

Feldspar. Orthoclase and microcline compose 2.4 percent of the Berne, with microcline being the more common. The microcline grains are subrounded to well rounded and exhibit a unimodal size distribution between fine and very coarse sand. Most are fresh and show very little alteration; a few exhibit slight vacuolization and hematite staining. In contrast, orthoclase grains are vacuolized and iron stained along cleavage surfaces; very few are unweathered.

Mica. Muscovite and biotite occur as subhedral fibrous particles scattered through the rock. They also occur as inclusions in many of the quartz grains. In some cases the mica particles are indented by quartz grains.

Rock Fragments. Sedimentary rock fragments and metamorphic rock fragments compose 1.5 percent of the total grains. The sedimentary rock fragments are well-rounded quartzite pebbles that are composed of smaller quartz grains cemented by silica. These occur in the larger the smallest being of very coarse sand-size. The metamorphic rock fragments are compositionally low-grade slate and phyllite particles in which the clays have been altered to sericite. These grains are subangular to subrounded, and exhibit a parallel internal optical orientation.

Heavy Minerals. The following heavy minerals in order of their abundance were observed in thin-sections of the Berne: zircon, tourmaline, and leucoxene. All of the heavy minerals seen have a roundness value of 4.0 (rounded) or higher. Tourmaline appears in two varieties, green and brown; all of the zircons are colorless. Heavy minerals compose less than one percent of the total grains and range in size from coarse silt to very coarse sand. Their distribution in the thin-sections is random.

Clay Minerals. There is a noted absence of clay minerals in the Berne. Only one sample contained a small amount (less than 1 percent) of illite in the limonitic matrix.

Orthochemical Minerals. There are three types of orthochemical cements in the Berne: limonite, hematite, and silica. Hematite and limonite are the dominant cements and silica is secondary, occurring as angular overgrowths on quartz grains. The ferruginous cements are probably authigenic; the silica is epigenetic, deposited by precolating ground water after lithification of the sediment. The evidence for this is a ferruginous staining under the silica overgrowths.

BYER MEMBER

Stratigraphy

The name Byer was taken from the town of Byer in Jackson County, Ohio, by Hyde (1912) and applied to the fine-grained sandstones lying between the coarser Berne and Allensville members of the Logan. Later work by Fagadau (1952) revealed this section of fine-grained sandstones to be part of the Cuyahoga Formation. Fagadau suggested that the name Byer be retained for the section of rocks between the Berne and the Allensville, but that a new type section be used.

The Byer unlike the Berne has a uniform lithology. It is a very fine-grained sandstone to coarse siltstone with irregular discontinuous shale beds. The color ranges from gray and greenish-gray to tan, light brown, and yellow. The lower part of the Byer is massive; the upper part is medium to thin bedded. All of the Byer is well cemented by limonite and silica. It consists of 91 to 99 percent quartz with 1 to 9 percent of feldspar, chert, and accessory minerals.

The thickness of the Byer ranges from 21 feet at section 5 to 38 feet at section 4. Hyde (1915) reported 80 feet of Byer at one locality in Granville township. Franklin (1961) reported 22 feet of Byer in Hanover township and 45 to 50 feet in central Licking County.

The Byer exhibits local small-scale tabular cross-bedding with dips ranging from 5 to 15 degrees and a north-northwest trend. In places, cross-strata dip in opposite directions within the same bed suggesting a rapid shifting of current direction or deposition by waves. Disrupted laminations also occur suggesting that the sediment was disturbed by burrowing organisms.

Fossils are common in the Byer but their distribution is sporadic. In some beds they are abundant; in others they are absent. Many fossils are fragmented, suggesting breakage by transport or high energy. Fagadau (1952) lists 37 different species of brachiopods, plecypods, and gastropods from the Byer. Some of the more shaly beds are marked by abundant worm,trails.

PETROLOGY

Texture

Nineteen samples of the Byer Member were collected and studied in thin section. The Byer is a terrigenous rock composed of 54 to 86 percent terriginous sediments, 7 to 32 percent matrix, and 1 to 29 percent orthochemical cement (Table III).

The fabric of the Byer is homogenous and exhibits tight packing. There is some interpenetration of quartz grains by ferruginous cement and some bending of mica flakes around quartz grains. The porosity of the Byer before cementation ranged from 1 to 29 percent, and now, after cementation, the porosity is less than 1 percent.

The average Byer sample is a very fine sandy coarse siltstone: ferruginous, siliceous, submature, quartzarenite. The Byer samples range from pure quartzarenites to borderline subarkoses and sublitharenites. They contain 91 to 100 percent quartz, 0 to 7 percent feldspar, and 0 to 6 percent rock fragments.

The mean grain size in the Byer samples is 0.049 mm. (coarse silt) and ranges from 0.032 mm. to 0.07 mm. (very fine sand). The size of the

smallest grain counted was 0.011 mm. (fine silt), and the size of the largest grain was 0.753 mm. (coarse sand). The grain size distribution is unimodal, and grains range in size from fine silt to coarse sand. The samples contain 6 to 15 percent sand, 49 to 94 percent silt, and less than 1 percent clay-size particles.

The roundness distribution in the Byer is unimodal, ranging from very angular to rounded. The mean roundness is 2.15 (subangular).

The sphericity distribution in the Byer is bimodal with a primary mode in the very elongate class and a secondary mode in the very equant class. The mean sphericity is 0.65 (subelongate), and all classes of sphericity are represented.

The Byer is well-cemented by hematite, linonite, and silica. The hematite and limonite occur as a clayey paste, and the silica occurs as overgrowths on quartz grains.

Descriptive Mineralogy

Quartz. The Byer contains from 91 to 100 percent quartz. The grain size distribution is unimodal, ranging from 0.02 mm. (medium silt) to 0.753 mm. (coarse sand). The average sphericity of the quartz is 0.653 (subelongate), and the distribution is bimodal with a primary mode in the very elongate class and a secondary mode in the very equant class. Sphericity values range from 0.56 to 0.79. The roundness distribution is unimodal and the roundness sorting is high. Approximately 80 percent of the grains are either angular or subangular.

The Byer contains four of the six empirical types of quartz of Folk (1959), and following is a detailed description of each type present.

Type 1 grains compose 68.1 percent of the quartz grains. Some grains are void of inclusions; others contain vacuoles only; still others contain vacuoles and mineral inclusions. The vacuoles are filled with gas and/or liquid and are either randomly scattered or in trains across the grains.

Most of the mineral inclusions are too small to identify. They occur as blebs or rods and are scattered randomly through a grain.

Those mineral inclusions that could be identified are biotite, muscovite, and tourmaline. There is a possibility that some of the rods are rutile, but no positive identification could be made. Almost every grain of this type contains some inclusions.

The grain size distribution is unimodal, with sizes ranging from medium silt to medium sand. The sphericity and roundness distributions are also unimodal, with all classes of sphericity and roundness represented. The mean grain size is 0.043 mm. (coarse silt); the mean sphericity is 0.653 (subelongate); and the mean roundness is 2.1 (subangular).

Type 3 grains compose 17.7 percent of the quartz grains. Of these grains 35 percent are void of inclusions; the remaining 65 percent contain vacuoles and/or microlites. Some vacuoles are filled with gas, others with liquid. They occur either randomly scattered through a grain or arranged in trains across a grain.

Most of the mineral inclusions are too small to identify. They occur as rods or blebs scattered randomly through the grains; occasionally the inclusions exhibit a parallel optical orientation. Muscovite was the only inclusion positively identified.

The grain size, sphericity and roundness distributions for this quartz type are the same as those for Type 1 quartz. The mean grain size is 0.052 mm. (coarse silt); the mean sphericity is 0.649 (subelongate); and the mean roundness is 2.0 (subangular).

Type 5 grains compose 8.0 percent of the quartz grains. Of these grains, 50 percent did not contain inclusions. The remaining grains contain vacuoles and/or mineral inclusions. The vacuoles contain either liquid or gas and are randomly distributed. As in the other types, the mineral inclusions occur as rods of blebs of various sizes, randomly distributed, and in some cases exhibiting a parallel optical orientation. The mineral inclusions identified are muscovite and biotite.

The grain size distribution for this type is unimodal with grain sizes ranging from coarse silt to medium sand. The sphericity distribution is bimodal with a primary mode in the very elongate class and a secondary mode in the very equant class. Values range from 0.57 to 0.76. The roundness distribution is unimodal, with values ranging from angular to rounded. The mean grain size is 0.06 mm. (coarse silt); the mean sphericity is 0.65 (subelongate); and the mean roundness is 2.7 (subangular). This grain type tends to be larger and better rounded than Types 1 and 3.

Type 6 grains compose 2.7 percent of the quartz grains. Of these grains 41 percent are void of inclusions except for a few scattered vacuoles. The other 59 percent contain vacuoles and/or mineral inclusions. The vacuoles contain either gas or liquid and are randomly scattered through a grain. Most of the mineral inclusions are too small to identify.

The grain size, sphericity, and roundness distributions are similar to Type 5 quartz. Type 6 quartz grains are larger and have higher roundness values than Types 1, 3, and 5. Their mean sphericity is 0.66 (elongate); their mean grain size is 0.061 mm. (coarse silt); and their mean roundness is 2.6 (subangular).

Chert. Only four grains of chert were seen out of 1900 grains counted. These are well-rounded, of fine sand size, equant, and stained with iron oxide.

Feldspar. Of the 43 grains counted, 27 were microcline, 15 were orthoclase, and one grain was plagioclase. The feldspar grains are of very fine sand size, are subangular to rounded, and subelongate.

A few are slightly vacuolized, and some are altering to kaolinite. Microcline was identified by the characteristic plaid and spindle twins; orthoclase by its cleavage; and plagioclase by its albite twins.

Mica. Muscovite and biotite occur as fibrous particles distributed through the rocks. They also occur as inclusions in many of the quartz grains. In some cases the mica particles are indented by quartz grains and appear to be wound about them.

Metamorphic Rock Fragments. Twenty-four metamorphic rock fragments were counted, and compose 1.3 percent of the grains counted. Thirteen of these grains are muscovite schist, six are chlorite schist, and five are quartzose schist. The grains are of coarse silt size subangular to subrounded, and exhibit a parallel internal optical orientation.

Heavy Minerals. The following heavy minerals, in order of their abundance, were observed in thin-sections of the Byer: zircon, leucoxene, and tourmaline. These minerals are all of very fine sand size and rounded. Zircon was better rounded than tourmaline. Heavy minerals compose less than 1 percent of the total grains. They are randomly distributed and have no apparent preferred optical orientation.

Orthochemical Minerals. There are two orthochemical cements in the Byer: silica and ferruginous "clay" matrix. The silica is the primary cementing agent and occurs as angular overgrowths on approximately 90 percent of the quartz grains. The ferruginous clay occurs as a porefilling and is not an effective cement.

ALLENSVILLE MEMBER

Stratigraphy

The Allensville Member was named by Hyde (1912). The name was applied to coarser beds that lie above the Byer sandstone and below the Vinton siltstone.

The Allensville lithology is distinctive. It is bounded both top and bottom by coarse-grained sandstones. Between these lie the *Allorisma* Shale and Conglomerate II of Herrick (1888).

The Allensville consists of 94 to 99 percent quartz with 1 to 6 percent feldspar and other accessory minerals. The color ranges from yellow to reddish-yellow and reddish-brown. In some outcrops the Allensville is friable; in others it is well-cemented.

In measured sections 2 and 3 the Allensville-Byer contact is sharp and in some places has a slightly wavy relief. This possibly suggests a disconformity between the Byer and the Allensville (Franklin, 1961). At other localities the Allensville-Byer contact is gradational. The upper contact of the Allensville with the Vinton is also gradational.

Because of the gradational nature of the Allensville-Vinton contact, the thickness of the Allensville is difficult to determine. It ranges from 5 feet at section 4 to 15 feet at section 3. Franklin (1961) states that it may range from 0 feet to more than 28 feet within Licking County, and that the thickest sections are in northern Licking and southern Newark townships.

The distribution of fossils in the Allensville is variable. Some beds, especially those in the western part of the county, contain abundant fossils; other beds are barren. Some fossils are fragmented suggesting breaking during transport or by waves.

Fagadau (1952) lists 10 different species of brachiopods crinoids and pelecypods from the Allensville. The most important fossil is the pelecypod Allorisma winchelli, whose occurance is used as a stratigraphic horizon indicative of the Allensville. Worm trails and burrows are present in the finer beds of the Allensville.

PETROLOGY

Texture

Sixteen samples of the Allensville Member were collected and studied in thin-section. The Allensville is a terrigenous rock composed of 46 to 84 percent terrigenous sediments, 0 to 2 percent matrix, and 15 to 54 percent orthochemical cement (Table III).

The fabric of the Allensville is homogeneous within lithologies, and the grains are loosely packed. There is some interpenetration of quartz grains by limonitic matrix and some indentation of mica by quartz grains. The porosity of the Allensville before cementation was between 16 and 54 percent. Now after cementation, the porosity ranges from less than 1 percent to 16 percent.

The average Allensville sample is a bimodal, very fine to fine, and coarse sandstone: ferruginous, siliceous, calcareous, submature quartzarenite. The Allensville samples range from pure quartzarenites to borderline subarkoses and sublitharenites. They contain 94 to 100 percent quartz, 0 to 6 percent feldspar, and 0 to 6 percent lithic fragments.

The mean grain size in the Allensville samples is 0.262 mm. (medium sand) and ranges from 0.034 mm. (coarse silt) to 0.535 mm.

(coarse sand). The size of the smallest grain counted was 0.041 mm. and that of the largest 1.57 mm. The grain size distribution of nine of the samples is bimodal with a primary mode in the very fine to fine sand range, and a secondary mode in the coarse to very coarse sand range. The grains in each mode are moderately-well to very well-sorted, and the mean grain size of the bimodal samples is 0.115 mm. The other seven samples have a unimodal size distribution. These samples are very poorly to moderately well sorted, and have a mean grain size in the coarse sand range (1.23 mm.). The samples contain 16 to 100 percent sand and from 0 to 84 percent silt. No gravel or clay was encountered in the Allensville. The Allensville samples have textures comparable to a submature sand.

Descriptive Mineralogy

Quartz. The Allensville contains 94 to 100 percent quartz. The grain size distribution of the quartz is bimodal with a primary mode in the fine to very fine sand range, and a secondary mode in the coarse to very coarse sand range. Each mode is well-sorted within itself, but overall the quartz is poorly sorted.

The mean sphericity of the quartz is 3.1 (subrounded). The larger grains tend to be better rounded than the smaller grains. The coarse size mode has a mean roundness of 4.7 (rounded) and the finer size mode a mean roundness of 1.5 (angular). However, the roundness distribution is unimodal with all classes represented.

The mean sphericity is 0.68 (intermediate). The distribution is bimodal with a primary mode in the very equant class and secondary mode in the very elongate class. All classes of sphericity are represented, with values ranging from 0.62 to 0.74.

Some of the quartz grains are etched by carbonate and hematite. Other grains indent muscovite grains, and others are cemented by silica overgrowths. The overgrowths are angular and are epigenic, probably formed by precipitation from silica-rich ground water.

The Allensville contains four of the six emperical quartz Types of Folk (1959). Following is a detailed description of each Type present.

Type 1 grains compose 71.0 percent of the quartz grains counted. Some grains are void of inclusions; others contain vacuoles only; most contain vacuoles and mineral inclusions. The vacuoles are filled with gas or liquid and are either randomly scattered through the grain or arranged in vacuole trains across the grain. Most of the mineral inclusions are too minute to identify. They occur as blebs and rods of various dimensions scattered through the grains. Zircon, tourmaline, muscovite and biotite are the only identifiable mineral inclusions. Almost every Type 1 grain contains some inclusion.

Type 1 quartz grains have a bimodal sphericity distribution with a primary mode in the very equant class, a secondary mode in the very elongate class, and a unimodal distribution between them. The roundness distribution is unimodal and grains range from very angular to well-rounded. The larger the grain the higher the degree of roundness. The mean grain size is 0.192 mm. (fine sand). The mean sphericity is 0.68 (intermediate), and the mean roundness if 3.5 (subrounded).

Type 3 grains compose 12.51 percent of the quartz grains. All contain some type of inclusion, either vacuoles, microlites or both. When present, the vacuoles contain liquid or gas and are either scattered or arranged in trains in the grain.

The mineral inclusions that could be identified are muscovite and biotite. Other mineral inclusions occur as blebs or rods that are too small for identification. Most of the mineral inclusions are distributed randomly through the grains, although occasionally they have a similar optical orientation within the same grain.

The grain size, sphericity, and roundness distributions for Type 3 grains is the same as for Type 1 grains. The mean grain size is 0.243 mm. (medium sand); the mean sphericity is 0.685 (intermediate); and the mean roundness is 3.4 (subrounded).

Type 5 grains compose 6.31 percent of the quartz grains. This type of grain contains very few vacuoles, all of which are filled with liquid. The mineral inclusions are dominant in this type and occur as rods or blebs of various dimensions, usually too small to identify. Muscovite and biotite are the only inclusions possitively identified. In some grains the mineral inclusions have a similar optical orientation.

Type 5 quartz grains have a bimodal sphericity distribution with a primary mode in the very equant class and a secondary mode in the very elongate class. The roundness distribution is unimodal with all roundness classes represented. The larger grains tend to have higher roundness values. The mean grain size is 0.83 mm. (coarse sand); the mean sphericity is 0.692 (subequant); and the mean roundness is 3.5 (subrounded).

Type 6 grains compose 7.56 percent of the quartz grains. These grains contain inclusions of vacuoles and/or minerals. The vacuoles contain liquid or gas and are arranged in a random pattern through the grains. A few grains contain vacuole trains. The mineral inclusions occur as rods or blebs of various dimensions and are too small to identify.

The grain size distribution is bimodal with a primary mode in the coarse sand size and a secondary mode in the fine sand size. The sphericity distribution is also bimodal with primary and secondary modes in the very equant and very elongate classes respectively. The roundness distribution is unimodal with a high roundness sorting. The mean grain size is 1.12 mm. (coarse sand); the mean sphericity is 0.70 (subequant); and the mean roundness is 4.2 (rounded).

Chert. Of the 1600 Allensville grains counted, only 20 were chert. These were all rounded or well rounded, of coarse sand size, equant, and weathered or stained with hematite.

Feldspar. Twenty-two feldspar grains were counted. Three were microcline, three were plagioclase, and 16 were orthoclase. The microcline grains are of coarse sand size, equant, rounded to well-rounded, and contain vacuoles. The plagioclase grains are of fine sand size, subelongate, angular to subrounded, and contain many vacuoles. The orthoclase grains range in size from medium to very coarse sand. They all have equant sphericity, and their roundness values range from very angular to well-rounded. The larger feldspar grains have higher roundness values than the smaller grains. All of the orthoclase grains are vacuolized to some extent, and some are hematite-stained.

Heavy Minerals. The following heavy minerals, in order of their abundance, are present in the Allensville: leucoxene, tourmaline, zircon, hematite, rutile, muscovite, and biotite. Leucoxene and hematite have irregular shape; tourmaline, zircon, and rutile are subrounded to well-rounded; and muscovite and biotite are subhedral.

These minerals compose less than 1 percent of the Allensville, and are randomly distributed through the rocks.

Orthochemical Minerals. The Allensville contains three orthochemical cements: iron oxide, silica, and carbonate. Iron oxide occurs as a pore-filling clay and composes 90 to 99 percent of the cement in the samples. Silica occurs as epigenic overgrowths on 2 to 3 percent of the quartz grains. It is most likely a precipitate from silica-rich ground waters. Calcite is also epigenic and occurs as a replacement of iron oxide and in some cases entire quartz grains; in some samples it composes as much as 10 percent of the cement. The carbonate is most likely a precipitate from ground waters.

VINTON MEMBER

Stratigraphy

The Vinton Member was named (1912)and defined (1921) by Hyde. The name was applied to those beds that lie above the Allensville Member and beneath the Pottsville Series, or the Maxville Limestone where it is present. It is the youngest member of the Logan Formation.

The Vinton is composed of siltstone and shale with a few fine-grained sandstone lenses. The bedding ranges from thin to thick with the beds thicker towards the top of the formation. The Vinton is composed of 98 to 99 percent quartz and 1 to 2 percent feldspar and other minerals. The color of the Vinton is variable. Sandstones range from orange to blue, siltstone from tan to buff, and shales from buff to gray to bluish-gray.

In Licking County the Vinton lies conformably on the Allensville and disconformably below the Pottsville Series. At most outcrops, the basal Pottsville is a pebble conglomerate. This contrasts markedly with the Vinton siltstones and shales, so that the contact is easily recognizable when it is clearly exposed.

The Vinton contains cross-strata similar to the Byer. The cross-bedding is local, small-scale, tabular, and in most places is multi-directional. The finer beds of the Vinton exhibit worm trails, burrows, and some disrupted laminations.

The thickness of the Vinton varies throughout the county. This variation is a result of the relief on the pre-Pennsylvanian erosion surface. In some places the Vinton is absent, and the Pottsville lies on the Allensville. The thickness at Volgemeir's quarry in central

Licking County is 51 feet; in eastern Fairfield County the Vinton is 180 feet.

Some fossils occur in the Vinton. They are most abundant in a fine-grained sandstone unit 2 to 12 feet thick which occurs 25 to 40 feet above the Allensville-Vinton contact. This unit is highly fossiliferous and is characterized by *Dictyoclostus agmensis*. The remaining portion of the Vinton is usually barren of fossils except for local siltstone beds. Fagadau (1952) lists 26 species from the Vinton.

PETROLOGY

Texture

Eight samples of the Vinton Member were collected and studied in thin-section. The Vinton is a terrigenous rock composed of from 61 to 85 percent terrigeneous sediments, and from 15 to 39 percent orthochemical cement.

The fabric of the Vinton is homogeneous and exhibits tight packing. As in the Byer, there is some interpenetration of quartz grains by ferruginous cement and some bending of mica strands around quartz grains. The porosity of the Vinton before cementation was 1 to 11 percent, and now, after cementation, the porosity is less than 1 percent.

The average Vinton sample is a coarse siltstone; ferruginous, siliceous, submature, quartzarenite. All of the Vinton samples are quartzarenites, composed of from 98 to 100 percent quartz.

The mean grain size in the Vinton samples is 0.04 mm (coarse silt) and ranges from 0.033 mm to 0.05 mm. The size of the smallest grain counted is 0.011 mm (fine silt) and that of the largest 0.073 mm. The grain size distributions of all the samples are unimodal with primary modes in the coarse silt size. The samples contain no gravel or clay, 15 to 20 percent sand, and 80 to 85 percent silt.

The roundness distribution of the Vinton samples is unimodal with a very high roundness sorting. Ninety percent of the grains are angular or subangular with the remaining 10 percent being either very angular or subrounded. Only two grains are rounded. The mean roundness is 1.97 (angular).

The sphericity distribution is bimodal with a primary mode in the very elongate class and a secondary mode in the very equant class. The mean sphericity is 0.664 (intermediate). All classes of sphericity are represented.

The cementation of the Vinton varies with lithology and type of cement. Those coarse units that are cemented by iron oxide are more friable and less well-cemented than those units cemented by silica or carbonate. The silica occurs as epigenic overgrowths, and the iron oxide occurs as a clay matrix. The carbonate includes both dolomite and calcite and probably formed as an epigenic precipitate, as did the iron oxide.

The Vinton samples are all texturally submature. The clay content is less than 5 percent, the sorting is very high, and the rounding is very poor.

Descriptive Mineralogy

Quartz. The samples of the Vinton studied contain 98 to 100 percent quartz. The grain size distribution of the quartz is unimodal with a primary mode in the coarse silt size. The quartz in all the samples is well to very well-sorted.

The mean roundness of the quartz is 1.97 (angular) with the larger grains better rounded than the smaller. The roundness distribution is unimodal, ranging from very angular to subrounded.

The mean sphericity is 0.667 (intermediate), and the distribution is bimodal with primary and secondary modes in the very elongate and very equant classes respectively. All classes of sphericity are represented, with values ranging from 0.58 to 0.79.

Many of the grains are etched around their edges by iron oxide and carbonate. Other grains indent micas, and others are joined by silica overgrowths, giving the grains a subedral appearance. These overgrowths are epigenic, formed by SiO_2 precipitation from silica-rich ground water.

The Vinton contains four of the six empirical quartz types of Folk, 1959. Following is a detailed description of each type. Type 1 composes 61.1 percent of the quartz grains counted. Of these grains 96.1 percent contain mineral or vacuole inclusions. The remaining 3.9 percent are void of inclusions. Some of the grains contain both vacuole and mineral inclusions. The vacuoles contain either gas or liquid and are randomly scattered throughout the grains. Most of the mineral inclusions are too small to identify. Those identified are biotite, muscovite, kaolinite, and rutile.

The grain size distribution is unimodal with a primary mode in the coarse silt size. The sizes are very well sorted and range from 0.019 mm to 0.068 mm. The sphericity distribution is bimodal with primary and secondary modes in the very elongate and very equant classes respectively and with sphericity values that range from 0.53 to 0.79. The roundness distribution is unimodal and ranges from 0.42 (very angular) to 3.1 (subrounded). The mean grain size is 0.39 mm (coarse silt); the mean sphericity is 0.66 (intermediate); and the mean roundness is 1.93 (angular).

Type 3 quartz grains compose 33.75 percent of the quartz grains. Of these 99 percent contain mineral and or vacuole inclusions. The vacuoles are filled with either gas or liquid and are randomly scattered throughout the grains. The mineral inclusions identified are biotite, zircon, and vermiculite. Most of the mineral inclusions are too small to identify. The inclusions occur as rods and blebs of various dimensions.

The grain size distribution is unimodal with a primary mode in the coarse silt size. The grains are well-sorted to very well-sorted and range from 0.015 mm. to 0.64 mm. The sphericity distribution is bimodal with primary and secondary modes in the very elongate and very equant classes respectively. The values range from 0.57 (very angular) to 0.77 (very elongate). The roundness distribution is unimodal and ranges from 0.54 (very angular) to 3.3 (subrounded); 92 percent are either angular or subangular. The mean grain size is 0.045 mm.(coarse silt); the mean sphericity is 0.67 (intermediate), and the mean roundness is 1.99 (angular).

Type 5 quartz grains compose 2.5 percent of the total quartz grains. All of those counted contain inclusions of minerals that I could not identify; biotite was identified in one grain. The microlites occur as rods or blebs or various dimensions randomly distributed. Occasionally, the microlites exhibit a subparallel optical orientation.

The grains have a unimodal size distribution, are very well sorted, and range in size from 0.017 mm. (medium silt) to 0.059 mm. (coarse silt). The sphericity distribution is bimodal, ranging from 0.5 to 0.79, with primary and secondary modes in the very elongate and very equant classes respectively. The roundness distribution is unimodal and ranges from 0.47 (very angular) to 3.0 (subrounded); 95 percent of the grains are either angular of subangular. The mean grain size is 0.042 mm. (coarse silt); the mean sphericity is 0.67

(intermediate); and the mean roundness is 1.97 (angular).

Type 6 quartz grains compose 2.0 percent of the total quartz grains. These grains all contain mineral inclusions which are too small to identify. As in type five grains, biotite was the only inclusion identified.

The grains have a unimodal size distribution, are well-sorted, and range from 0.11 mm. (fine silt) to 0.071 mm. (very fine sand). The sphericity distribution is bimodal, and the grains are either very elongate or very equant. There are no grains in the other sphericity classes. Values range from 0.52 to 0.79. The roundness distribution is unimodal with a primary mode in the subangular class. Values range from 0.92 (very angular) to 3.1 (subrounded). The mean grain size is 0.049 mm. (coarse silt); the mean sphericity is 0.66 (intermediate) and the mean roundness is 2.49 (subangular).

Feldspar. Four grains of feldspar were counted in the Vinton thin-sections. One is microcline and the other three are orthoclase. The microcline is 0.0823 mm. (very fine sand), angular, very elongate, and undergoing vacuolization and alteration to kaolinite. The orthoclase grains have a mean grain size of 0.024 mm. (medium silt), a mean roundness of 1.4 (angular), and a mean sphericity of 0.57 (very elongate). The orthoclase grains are fresh to slightly vacuolized.

Chert. Only one grain of chert was counted in the Vinton thin-sections. It is 0.29 mm. (medium silt) in diameter, rounded very elongate, and has a fresh appearance.

Heavy Minerals. The following heavy minerals in order of their abundance were identified from the Vinton: leucoxene, tourmaline, zircon, hematite, muscovite, and biotite. Leucoxene and hematite are irregular in shape and appear rounded; tourmaline and zircon are well rounded; and muscovite and biotite are subhedral. Tourmaline is green and brown; zircon is colorless. The heavy minerals compose less than 1 percent of the Vinton and are randomly distributed throughout the samples.

Orthochemical Minerals. The following orthochemical cements occur in the Vinton: iron-oxide, silica, and carbonate. Iron-oxide occurs as a pore-filling. It has most likely a detrital source as opposed to being authigenic, because there are hematite grains in the Vinton as well as iron-stained detrital minerals. Silica and calcite form less than 1 percent of the total cement, but are present. Their origin is epigenic as precipitates from ground waters. In unweathered samples the grains are well-cemented; in weathered samples they are poorly cemented.

Summary of Petrological Data

The Logan Formation is composed of four members which can be distinguished from each other in the field by grain size differences: the Berne and Allensville Members are coarser than the Byer and Vinton. This is the most obvious criterion which differentiates the members on a megascopic level. Additional thin-section study, however, reveals differences in mineralogy as well as grain size.

The Berne is the coarsest member of the Logan. It is composed of grains that range in diameter from silt to pebbles. The pebbles occur in greatest numbers at the erosional surface between the Black Hand and the Berne in the area of the central axis of the tongue-like body of the Black Hand. East and west of this axis the percentage of pebbles decreases as the distance increases, and correspondingly the percentage of sand and silt increases. The Berne has very poor to moderate sorting. The sands of the Berne closest to the axis of the Black Hand tongue have the poorest sorting (Sections 5 and 6). The samples are composed of rounded but poorly sorted grains and have textures comparable to submature sands.

The Black Hand and Berne have the same mineral composition. They differ only in the relative amounts of the minerals present. The Black Hand contains more feldspar than does the Berne, and the Berne contains higher percentages of feldspar, rock fragments and composite grains than do the younger members of the Logan (Figure 6).

The Berne is cemented mostly by iron oxide, that occurs as pore-filling and as detrital grains. The color of the Berne is the result of oxidation of the iron oxide cement.

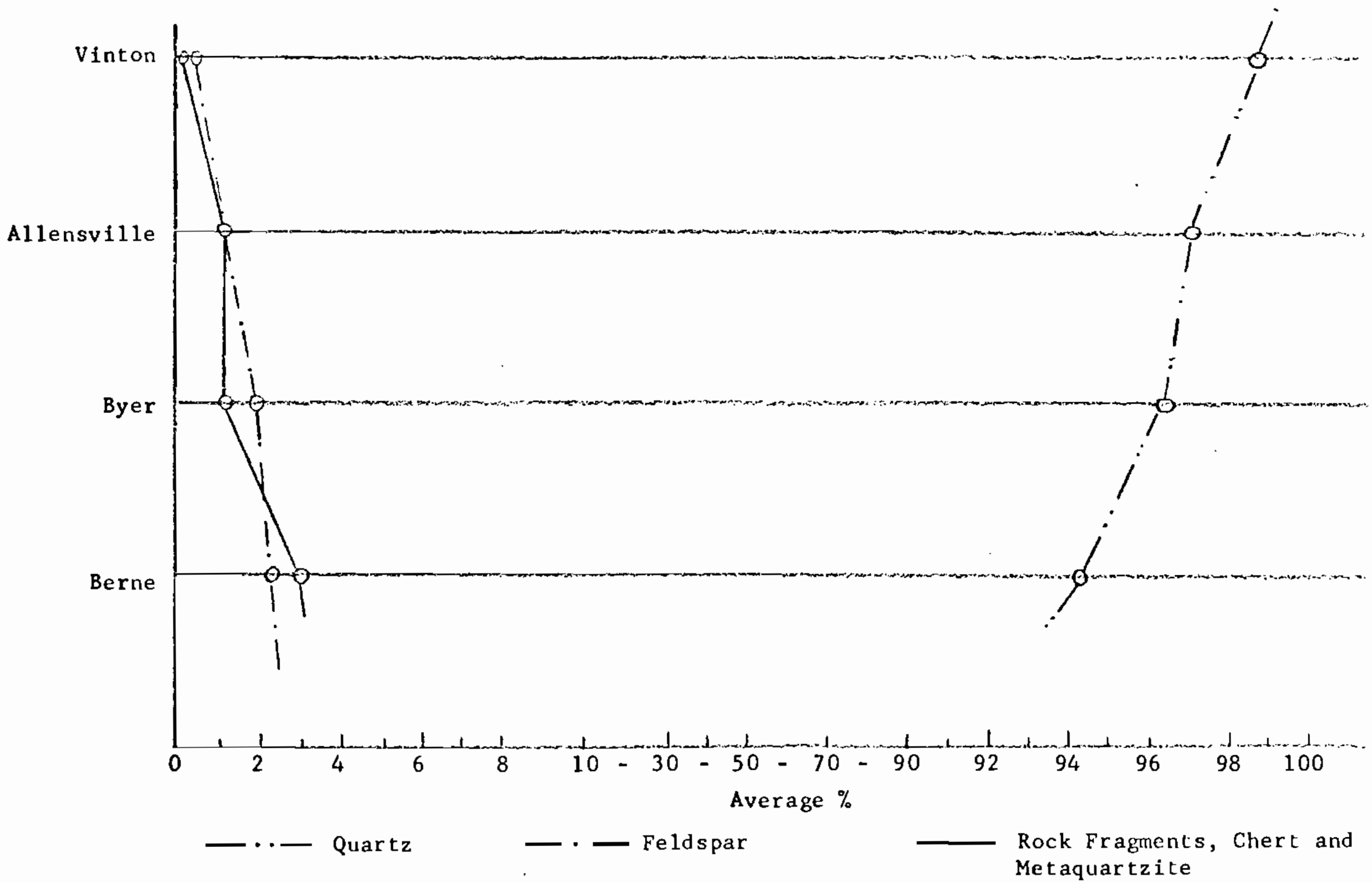

Figure 5. Variation of Major Mineral Constituents of the Logan Formation.

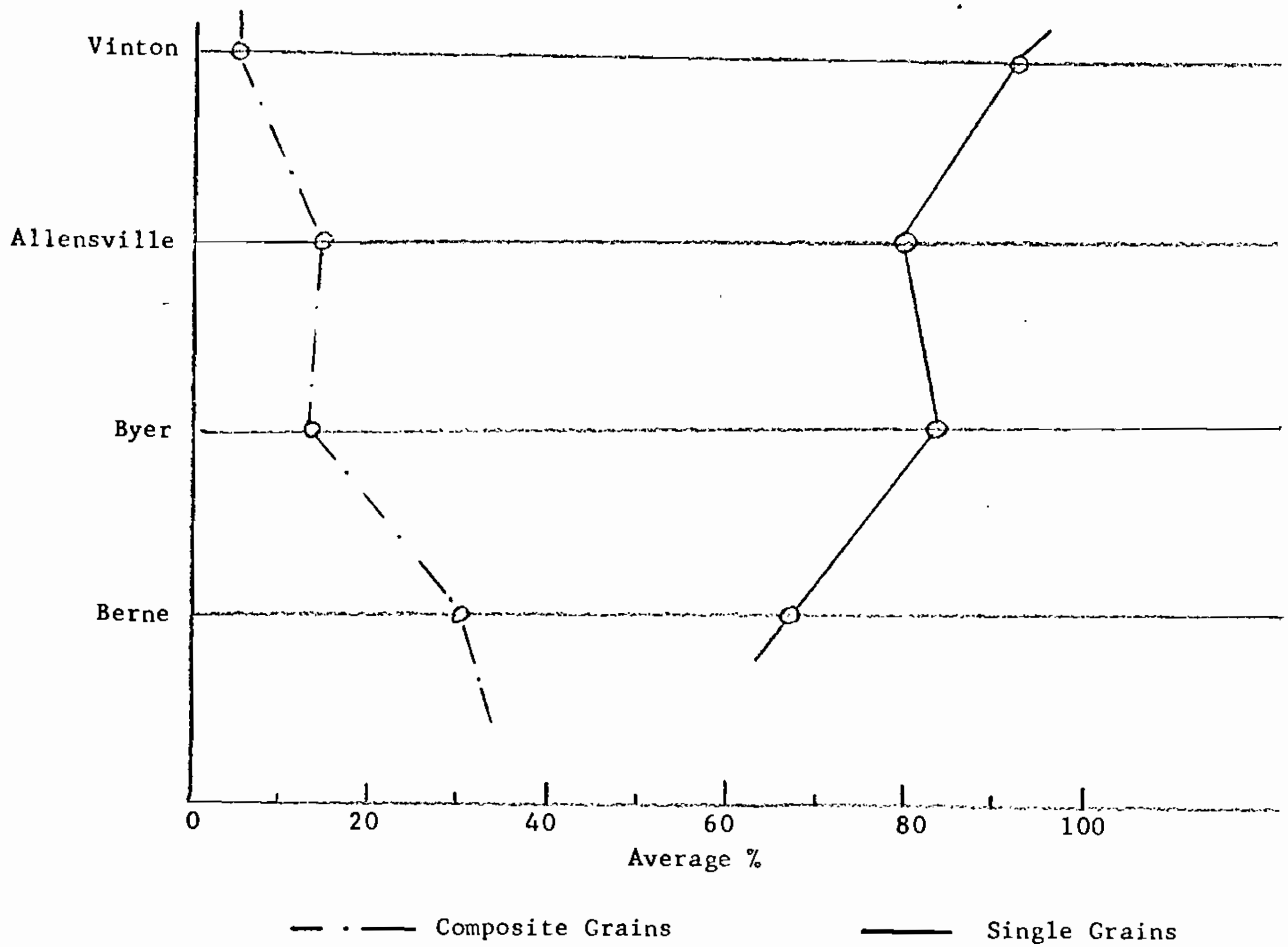

Figure 6. Variations in Simple and Composite Grains in the Logan Formation.

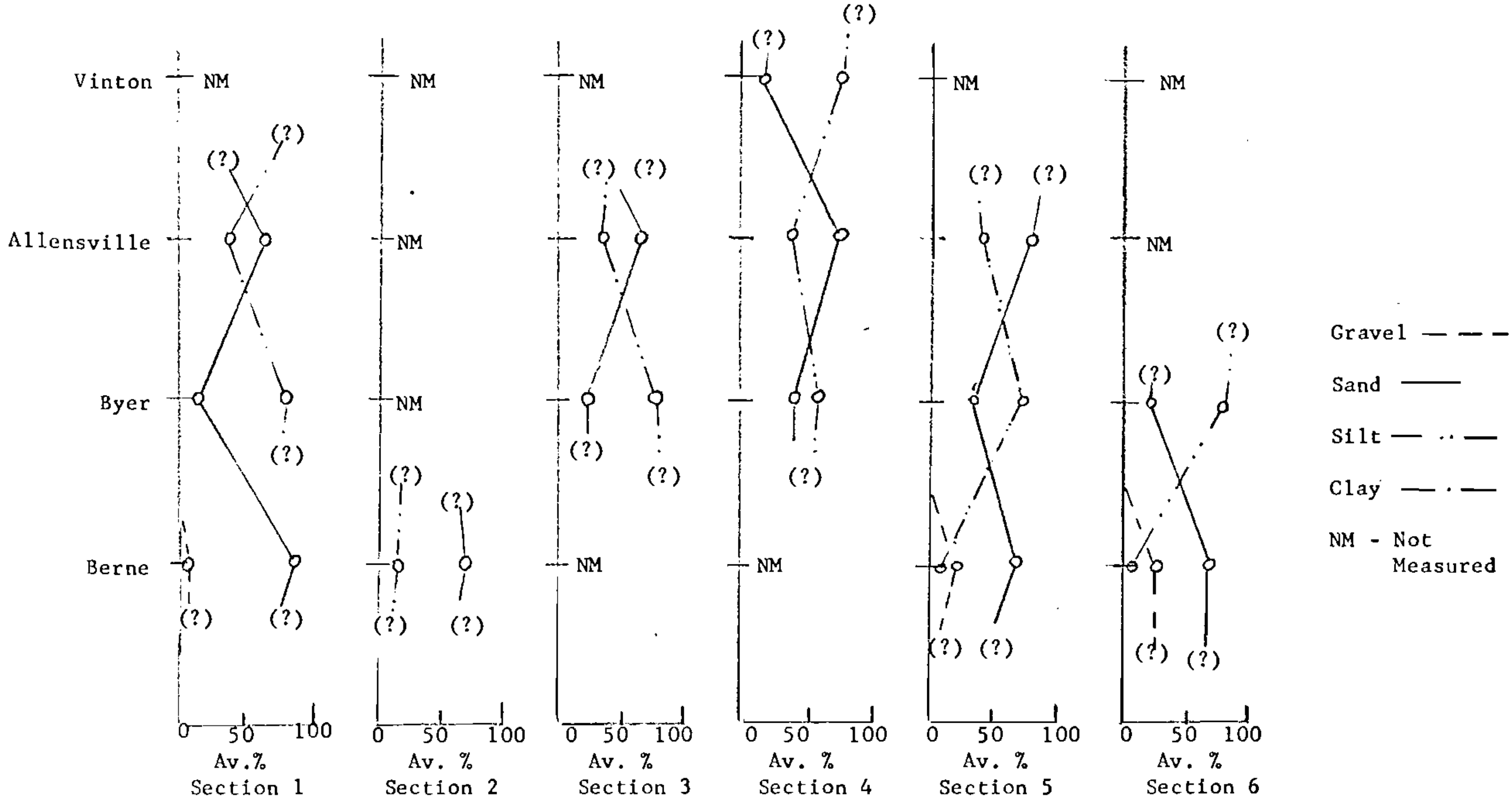

Figure 7. Graphs showing areal variations in the sizes of grains composing the Logan, based on Table 2 , page

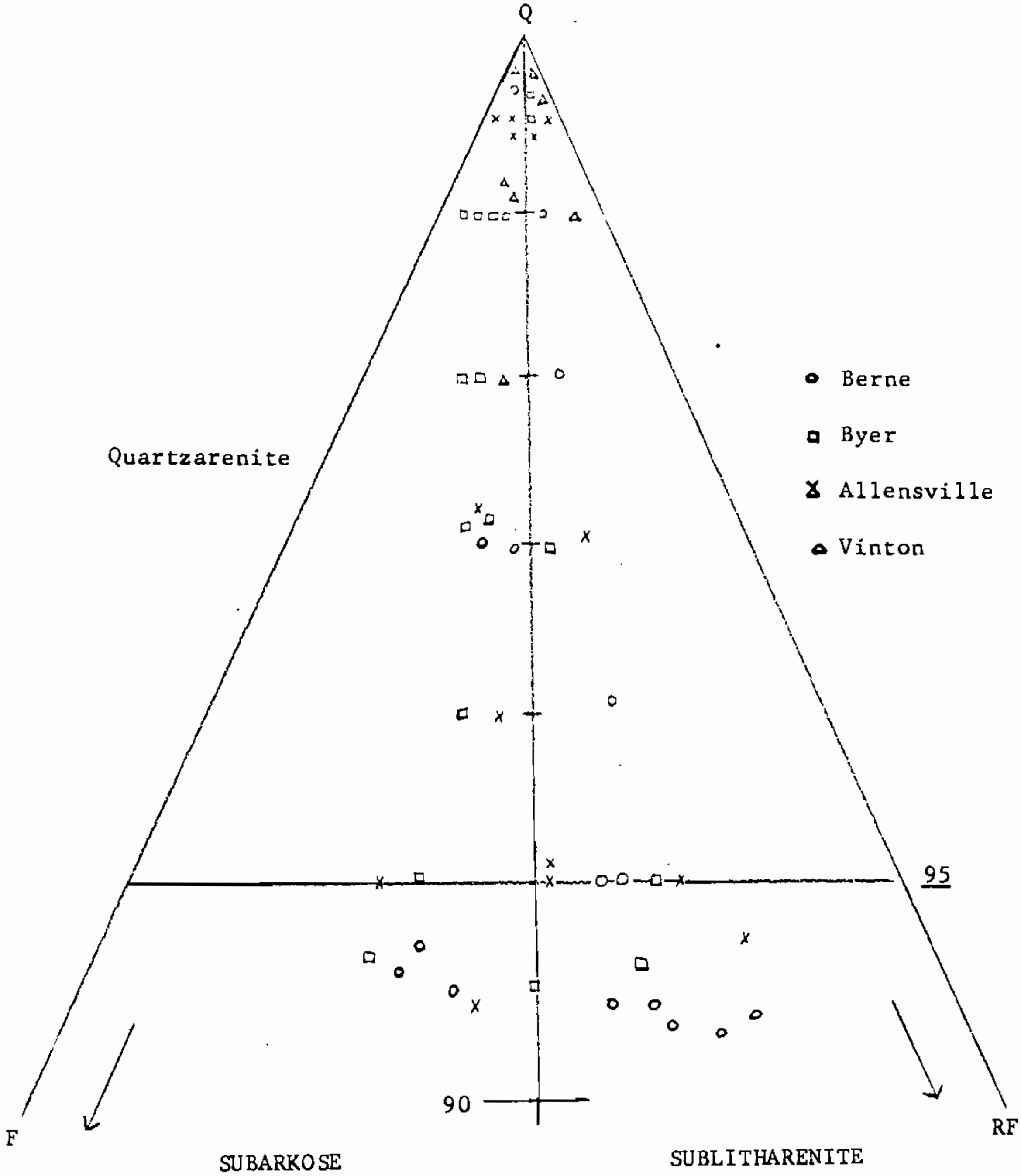

Figure 8. Distribution of Rock Types of the Logan Formation.

Member		Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
Vinton	G	X	X	X	0	X	X
	S	X	X	X	17	X	X
	S1	X	X	X	83	X	X
	C	X	X	X	0	X	X
Allensville	G	0	X	0	0	0	X
	S	60	X	61	72	59	X
	S1	40	X	39	28	41	X
	C	0	X	0	0	0	X
Byer	G	0	X	0	0	0	0
	S	22	X	18	46	40	21
	S1	78	X	82	54	60	79
	C	0	X	0	0	0	0
Berne	G	2	0.8	X	X	19	16
	S	98	89	X	X	77	78
	S1	0	10.2	X	X	4	6
	C	0	0	X	X	0	0

Table 2. Average percents of sizes of grains in the Logan by member and section. G=gravel; S=sand; S1=silt; C=clay.

The Byer is distinguished from the Berne and from the Allensville by grain size, sorting, and mineralogy (Figures 5 and 7). The Byer samples show little variation ranging from very fine sand to coarse silt. The Byer contains less feldspar, rock fragments, and composite grains that the Berne, and more of these than the Allensville and Vinton (Figure 6).

The thickness of the Byer varies according to that of the underlying Berne. Where the Berne is thinnest, the Byer is also thinnest.

The Byer sands are better sorted than the Berne. Sands in the Byer samples from sections 1 through 5 are moderate to moderately well-sorted. Those samples taken on or near the axis (section 6) have sand that is moderately well-sorted and bimodal. The textures of these sands are comparable to submature sands. As in the Berne, the closer the location of the sample to the axis of the Black Hand tongue, the poorer the sorting of the sand.

Marine fossils are abundant in the Byer. Some beds are composed of a fossil hash of broken fragments. Small-scale tabular cross-bedding and scattered burrows also occur.

Locally, the Allensville Member is very similar to the Berne. However, the Allensville contains fewer pebbles, the grains are more angular, most sands have a bimodal grain size distribution, and the areal distribution is more limited.

The grain size distribution of the Allensville samples is bimodal with primary and secondary modes in the coarse sand and very fine sand sizes. The coarse sand sizes are well-to very well-sorted and those of the fine sand size are moderately sorted. The grains in the larger mode are rounded to well-rounded, and those in the finer mode are angular to rounded. The sphericity for grains in both modes is similar. As in the Berne, the larger grains are better rounded than the smaller ones.

The mineral composition of the Allensville is similar to the other members. The percentages of feldspar, rock fragments and composite grains are less than the Byer and the Berne and greater than the Vinton (Figure 5 and 6).

The distribution of the Allensville is patchy, and in some areas the Vinton is in contact with the Byer. Also, the thickness of the Allensville decreases to the west. Eventually the Allensville disappears (Hyde 1915) and the Vinton rests on the Byer. In some areas the Allensville is represented only by a thin layer of sand grains. The Allensville is distinguished from the Vinton by its generally coarser grain size, poorer sorting, and mineralogy.

The Vinton is the youngest member of the Logan Formation. It is composed of silt with varying amounts of fine sand and clay. The Vinton has a uniform distribution across the area with beds of siltstone alternating with beds of mudstone. Variations in the thickness of the Vinton are due to the relief on the pre-Pennsylvanian erosion surface above it.

The Vinton sands are unimodal and the grain size distributions are moderately-sorted to well-sorted. The average roundness of the Vinton grains is angular with grains ranging from very angular to subrounded. The sphericity values of the Vinton similar to those of the other members.

The mineralogy of the Vinton is similar to that of the other members. However, compared to the other members, the Vinton contains the smallest number of different minerals. Feldspar, chert and rock fragments compose less than 2 percent of the total grains. Quartz is dominant and composes from 38 to 100 percent of the grains.

Marine fossils are found in the Vinton. These are restricted to the mudstones and occur in greatest numbers in a zone approximately 25 to 40 feet above the base of the Vinton. Abundant worm trails, disrupted laminae, and burrows also occur in the finer rocks.

Cross-strata are more common in the siltstones of the Vinton than in the other members. The cross-beds dip from 5 to 15 degrees in a north-northwest trend.

Sedimentary Interpretation

The sedimentology of the Logan is closely related to that of the underlying Cuyahoga Formation. Therefore, a brief description and interpretation of the Cuyahoga, based on the work of others is discussed first.

Holden (1942) divided the Cuyahoga into seven facies from southern Ohio north: Henley, Hocking Valley, Granville, Toboso, Killbuck, River Styx, and Tinker's Creek facies (Figure 8). The Henley, Granville, Killbuck, and Tinker's Creek facies are shale facies separating the Hocking Valley, Toboso, and River Styx conglomerate and sandstone facies.

There have been two different interpretations of the sedimentation of the Cuyahoga Formation. Hyde (1915), Holden (1942) and Ver Steeg (1947) interpret the Cuyahoga as deltaic lobes extending from south-southeast into an open marine environment. These lobes were thought to be deposited by streams and reworked laterally by waves and longshore currents. The streams responsible for the lobes had short courses, moderate gradients, and high discharge rates. A decrease in grain size and pebble content and an absence of cross-strata to the north indicate deeper water and weaker currents in this direction. The intervening shale facies were deposited in quiet waters and are composed of clay, silt, and fine sand.

The other interpretation was set forth by Hicks (1878). That portion of the Cuyahoga represented by the River Styx, Toboso, and Hocking Valley coarse facies were thought by Hicks to be a series of bars, spits, or beaches which were deposited simultaneously or in sequence from east to west. Hicks argued that the structural features

Figure 9. Distribution of the facies of the Cuyahoga formation in Ohio. Conglomerate facies stippled and shale facies shaded. Mississippian Rocks crop out between the heavy black lines. Holden 1942 and Root 1958.

present in these facies can be accounted for by strong currents from the south rather than by stream action. The overall facies configuration, the abrupt lateral facies change to the east, and a gradual facies change to the west of the lobes also suggest a beach depositional environment. Arguments against this interpretation are a decrease in grain size to the north and the finger-like arrangement of the lobes. Later workers have favored an "Alluvial Fan Delta" hypothesis, but the question is still open to study.

Following is an interpretation of the source area, sediment transport, depositional environment, and diagensis of the Logan based on the previous petrographic analysis.

The source area of the Logan Formation was somewhere to the east-southeast of Licking County, (Hyde 1953). The mineralogy of the Logan indicates that the source was composed of primarily sedimentary and metamorphic rocks.

The following evidence points to a sedimentary source:

1) Sedimentary rock fragments composed of angular, fine grain size quartz cemented by silica

2) Abundant chert

3) Rounded overgrowths on well-rounded grains

4) High rounding of the heavy mineral suite

Approximately 95 percent of the sediment came from a sedimentary source rock.

A metamorphic source accounted for approximately 5 percent of the sediment. Mineral evidence of this source is abundant mica, low-grade metamorphic rock fragments, and metaquartzite. The highly vacuolized quartz grains in the Logan are most likely from quartz veins which may occur in either a metamorphic or sedimentary terrain.

An igneous or metamorphic source is suggested for the Logan by feldspar and quartz grains. However, the feldspar grains are weathered and small in size, and the quartz grains have rounded overgrowths. This suggests that the grains may have originated from an igneous source, but that they were probably contributed to the Logan sediments as recycled grains from a sedimentary source that contained igneous rocks fragments, rather than directly from an igneous source. Also, many of the feldspar and chert grains are stained by hematite suggesting exposure to weathering.

The coarse character of the sediment in the Berne and the Allensville indicates that either there was a high gradient and sufficient water to transport coarse material a long distance or that the source was near to the depositional site. The regional geography of the area during Mississippian time as presently understood does not offer a near source. More likely the source was several hundred miles away with moderate relief and sufficient water and gradient to allow coarse-grain transport. If the source is distant, as is most likely, then large amounts of water would be necessary for sediment transport. Thus a humid climate was most likely. A humid climate is also indicated by the weathering on the feldspar grains. Undulosity in some grains may be the result of either metamorphism of the source area or contribution of recycled metamorphosed grains from a sedimentary rock.

The four members of the Logan Formation have the same source area as indicated by mineralogical similarity. Therefore, differences in sorting, roundness, and grain size are a function of transport and depositional environment rather than the result of a changing source area.

The Logan Formation in Licking County represents the migration of a marine environment across distributary channels of a subaerial deltaic environment. The migration was caused by tectonic fluctuations, changes in the amount of sediment deposited, and shifting distributaries. Each member of the Logan represents a different stage of this migration.

The Berne is the combined result of deltaic distributaries and lateral reworking of the Cuyahoga sediments by marine currents and waves. The most likely explanation for the Berne is that the sediment supply decreased due to either a lowering of the source area or a decrease in rainfall in the source area, allowing available energies to rework and sort the existing sediments. During this reworking, a slight uplift or decrease in the rate of subsidence may have occurred which allowed some erosion of the Cuyahoga lobes. Evidence of this "uplift" can be seen in the Berne as local channels which were cut into the Toboso lobe. Coarse sediment was left behind on these channel areas as a lag deposit and the finer material was carried out to either side of the channels and across areas of muds (areas of Killbuck and Granville facies).

These channels have previously been described as a disconformity between the Black Hand Member of the Cuyahoga and the Berne Member of the Logan (Hyde 1953). My field studies, however, indicate that the "disconformity" is actually the result of local reworking rather than widespread erosion. The channels are local and meandering and contain sediments which have the poorest sorting in the Logan.

The sedimentology of the Byer indicates that it was deposited in a shoreface area below effective wave base. The abundance of fossils indicates that sediment was deposited at a constant slow rate, a condition conducive to the survival of faunal communities. The absence of clay sizes and the high degree of sorting of the Byer indicates that the sediment was winnowed for some time by submarine currents and waves. Thin beds of poorly sorted fossils fragments indicate that at times storms disrupted sedimentation and destroyed faunal communities.

The Allensville Member represents a slight seaward migration of the seas during which time coarser material was mixed with finer Byer-like sediments. The coarse material may be the result of an uplift in the source area or increase rainfall in the source area, enabling a re-working of the Cuyahoga type sediment from the east. However, an uplift in the source area would result in a unimodal size distribution, an increase in the percentages of various minerals, and composite grains. The thin-section analyses shows the opposite to be the case, i.e., a decrease in percentages of minerals other than quartz and a decrease in composite grains.

Most likely, there was a slight uplift in the source area which contributed coarser Cuyahoga type sediment to the basin. This then was probably reworked into beaches where the sediment was rounded and well-sorted. Then as the shoreline shifted or storms occurred, these supermature beach sediments were swept out by marine currents into deeper areas and mixed with well-sorted Byer-like silt. The sporadic and localized nature of these currents is indicated by interbedded fine silt and coarse bimodal sandstones. The bimodal combination of supermature coarse sand grains with no gradation between coarse and fine sizes indicates a mixing of two environments. The Allensville is the product of the mixing of beach and shoreface environments.

The Vinton represents a renewed subsidence of the depositional area coupled with a lowering of the source area and decreased rainfall. These factors produced less sediment and finer grain sizes. Abrupt lateral and vertical lithologic changes indicate the sporadic nature of the currents which were depositing, reworking and sorting the Vinton sediments.

The Vinton deposition differs from the Byer in that the rate of sedimentation for the Vinton was sporadic and rapid and that of the Byer was fairly uniform and slow. This difference is indicated by the higher fossil content of the Byer and the more abundant cross-beds and burrows of the Vinton.

Much of the upper part of the Vinton has been eroded. The presence of the Maxville Limestone which rests disconformably on the Vinton in some areas, suggests that seas transgressed the entire area before later uplift, erosion, and deposition of the Pottsville Series.

Diagenetic effects which can be seen in the Logan Formation include replacement of quartz by carbonate and iron oxide minerals and precipitation of silica around quartz grains. The color of the Logan is due to the recent oxidation of what iron was present in the rocks at the time of their deposition.

In summary, the Logan is the result of tectonic changes which caused the migration of the seas across the deltaic environment of the Cuyahoga sediments. The Berne Member represents the reworking of the coarse lobes, concentration of the coarse sediments and the laternal spreading of the finer sediments. The Byer Member represents the deposition of a shoreface sediment over the coarse Berne. A temporary decrease in the rate of subsidence is the reason for the deposition of the Allensville. During this time the seas were probably shallower and storms more frequent which allowed for the mixing of beach and shoreface environments. The Vinton represents the renewed migration of the seas caused by increased subsidence. The Maxville was probably deposited in Licking County disconformably above the Vinton, but was later removed by pre-Pennsylvanian erosion.

TABLE I

Sample	Five-Fold Name
b 12	Fine to course sandstone: ferruginous, submature, sublitharenite
b 13	Fine to very coarse sandstone: gerruginous, submature, sublitharenite
b 14	Slightly granular, fine to very coarse sandstone: ferruginous, submature, sublitharenite
b 21	Pebbly, fine to very coarse sandstone: ferruginous, submature, sublitharenite
b 22	Silty, very fine to coarse sandstone: ferruginous, immature, quartzarenite
b 23	Very fine to coarse sandstone: ferruginous, submature, sublitharenite
b 24	Very fine to coarse sandstone: ferruginous, submature, quartzarenite
b 25	Slightly silty, very fine to coarse sandstone: ferruginous, silicious, submature, subarkose
b 26	Silty, very fine to coarse sandstone: ferruginous, silicious, immature, sublitharenite
b 51	Silty, granular, sandstone: ferruginous, submature, sublitharenite
b 52	Silty, very fine to medium sandstone: ferruginous, submature, sublitharenite
b 53	Silty, very fine to coarse sandstone: ferruginous, submature, quartzarenite
b 81L	Pebbly, granular, sandstone: ferruginous, submature, quartzarenite
b 81u	Pebbly, granular, sandstone: ferruginous, submature, quartzarenite
b 82	Very fine to coarse sandy siltstone: ferruginous, immature, quartzarenite
6 83	Very fine to coarse, silty, sandstone: ferruginous, submature, subarkose
b 84	Granular, fine to very coarse sandstone: ferruginous, submature, quartzarenite
B 11	Very fine slightly sandy siltstone: ferruginous, submature, quartzarenite
B 12	" " " " " " "

B 13	Very	fine	slightly	sandy	siltstone:	ferruginous,	submature,	quartzarenite
B 31	"	"	"	"	"	"	"	"
B 32	"	"	X	"	"	"	"	"
B 33	"	"	X	"	"	"	"	sublitharenite
B 34	"	"	"	"	"	"	"	"
B 35	"	"	X	"	"	"	"	"
B 36	"	"	"	"	"	"	"	"
B 37	"	"	"	"	"	"	"	quartzarenite
B 38	"	"	"	"	"	"	"	"
B 39	"	"	"	"	"	"	immature	"
B 310	"	"	"	"	"	"	"	"

B 41 Very coarse siltstone: ferruginous, submature, subarkose

B 42 Very fine sandy siltstone: ferruginous, submature, quartzarenite

B 43 Very fine sandy siltstone: ferruginous, submature, quartzarenite

B 81 Bimodal very fine sandstone, very coarse siltstone: ferruginous, submature, quartzarenite

B 82 Sandy siltstone: ferruginous, submature, quartzarenite

B 83 Sandy siltstone: ferruginous, submature, quartzarenite.

A 11 Bimodal silty sandstone, coarse sandstone: ferruginous, immature, quartzarenite

A 12 Bimodal very coarse sandstone, coarse sandstone: ferruginous, immature, quartzarenite

A 31 Slightly silty, very coarse sandstone: ferruginous, immature, quartzarenite

A 32 Bimodal coarse sandstone, very fine sandstone: ferruginous, immature, quartzarenite

A 33 Vimodal very coarse sandstone, silty sandstone: ferruginous, immature, quartzarenite

A 41 Slightly silty very fine to very coarse sandstone: ferruginous, immature, quartzarenite

A 42 Bimodal very coarse sandstone, silty very fine sandstone,
ferruginous, immature, sublitharenite

A 43 Slightly silty, very fine to coarse sandstone: ferruginous,
immature, quartzarenite

A 44 Bimodal very coarse sandstone, silty very fine sandstone:
ferruginous, immature, subarkose

A 45 Bimodal very coarse sandstone, fine sandy siltstone: ferruginous
immature, quartzarenite

A 46 Bimodal very coarse sandstone, sandy medium siltstone: ferruginous,
immature, quartzarenite

A 51 Slightly silty very fine to very coarse sandstone: ferruginous,
submature, quartzarenite

A 52 Sandy medium siltstone: ferruginous, submature, quartzarenite

A 53 Bimodal very coarse sandstone, medium siltstone: ferruginous,
submature, quartzarenite

A 54 Slightly silty very fine to very coarse sandstone: ferruginous,
submature, quartzarenite.

A 55 Medium to coarse sandstone: ferruginous, submature, quartzarenite

V 42	Very	coarse	siltstone:	ferruginous,	submature,	quartzarenite
V 44	"	"	"	"	"	"
V 45	"	"	"	"	"	"
V 46	"	"	"	"	"	"
V 47	"	"	"	"	"	"
V 48	"	"	"	"	"	"
V 49	"	"	"	"	"	"
V 410	"	"	"	"	"	"

TABLE III

Slide	Pore Space	Grains	Cement	Cement type
C 81	29%	69%	1%	limonite
C 82	32	67	2	limonite
C 83	31	69	1	limonite
C 84	18	82	1	limonite
b 12	6	66	28	limonite & hematite-80-20
b 13	10	75	15	limonite,hematite,SiO_2-70,25,5
b 14	16	71	13	hematite-limonite, 60, 40
b 21	12	66	22	limonite,hematite, 80, 20
b 22	3	81	16	limonite,hematite, 80, 20
b 23	3	78	19	limonite, SiO_2
b 24	2	70	28	limonite illite containing SiO_2 silt
b 25	21	71	8	limonite,hematite, 85, 15
b 26	0	83	17	limonite,hematite, SiO_2, 70,25,5
b 51	8	78	14	limonite, 1% hematite
b 52	3	65	32	limonite Mont, with SiO_2silt
b 53	1	75	24	limonite-clay (Mont)
b 81L	18	82	--	
b 81u	19	73	8	limonite
b 82	2	45	53	limonite & SiO_2 silt
b 83	5	72	24	limonite & qtz. silt
b 84	14	66	21	limonite,hematite
B 11	1	70	29	limonite
B 12	21(Matrix)	75	2	limonite
B 13		79	1	limonite
B 31	17	70	13	limonite, SiO_2
B 32	32(Matrix)		54	limonite, SiO_2
B 33	16	65	19	hematite, SiO_2
B 34	18	77	5	hematite, SiO_2, clayey matrix
B 35	7	86	7	hematite, SiO_2, clay matrix
B 36	15	66	19	limonite, SiO_2, clay matrix
B 37	12	70	18	limonite, SiO_2, clay matrix
B 38	14	67	19	limonite, SiO_2, clay matrix
B 39	21	66	13	limonite, SiO_2, clay matrix
B 310	13	75	13	limonite, SiO_2, clay matrix
B 41	9	77	14	hematite, SiO_2, clay matrix
B 42	23	72	5	limonite, SiO_2, clay matrix
B 43	13	63	24	limonite, SiO_2, Carbonate clay matrix
B 81	12	70	18	hematite SiO_2, clay matrix
B 82	19	72	9	limonite, clay matrix
B 83	30	62	8	limonite, SiO_2, clay matrix
A 11	0	54	46	Fe_2O_2 - 36 $CaCo_2$-10
A 12	0	46	54	Fe_2O_3 - 52 $CaCo_3$ - 2

TABLE III (continued)

A 31	2	61	37	36 Fe_2O_3, 1 SiO_2
A 32	0	71	29	$Fe_2O_3$29
A 33	0	58	43	Fe_2O_3OH
A 41	0	61	39	$Fe2O_3$
A 42	0	73	27	Fe_2O_3
A 43	2	65	33	Fe_2O_3
A 44	0	56	44	Fe_2O_3
A 45	0	51	49	Fe_2O_3
A 46	0	77	23	Fe_2O_3
A 51	2	68	30	Fe_2O_3
A 52	0	68	32	Fe_2O_3
A 53	0	82	18	Fe_2O_3
A 54	0	81	19	Fe_2O_3
A 55	1	84	15	$Fe_2O_3$13, $SiO_2$2
V 42	0	65	35	Fe_2O_3
V 44	0	61	39	Fe_2O_3
V 45	0	76	24	Fe_2O_3
V 46	0	67	33	Fe_2O_3
V 47	0	71	29	Fe_2O_3
V 48	0	85	15	Fe_2O_3
V 49	0	76	24	Fe_2O_3
V 410	0	76	24	Fe_2O_3

Amounts of pore space, grains, cement and cement types in each slide given in percent. b = Berne; B = Byer; A = Allensville; V = Vinton

Member	Section	Sample
B	3	10

Plate 1. Section 2 showing Racoon Member of the Cuyahoga Formation and the Berne, Byer and Allensville Members of the Logan Formation.

Plate 2. Cross-bedding in the Byer Member at Section 3.

Plate 3. Allensville-Byer contact.

Plate 4. Volgomier's Quarry, Vinton and Allensville Members.

Plate 5. Volgomier's Quarry, Vinton-Allensville Contact.

Plate 6. Allensville at Volgomier's Quarry

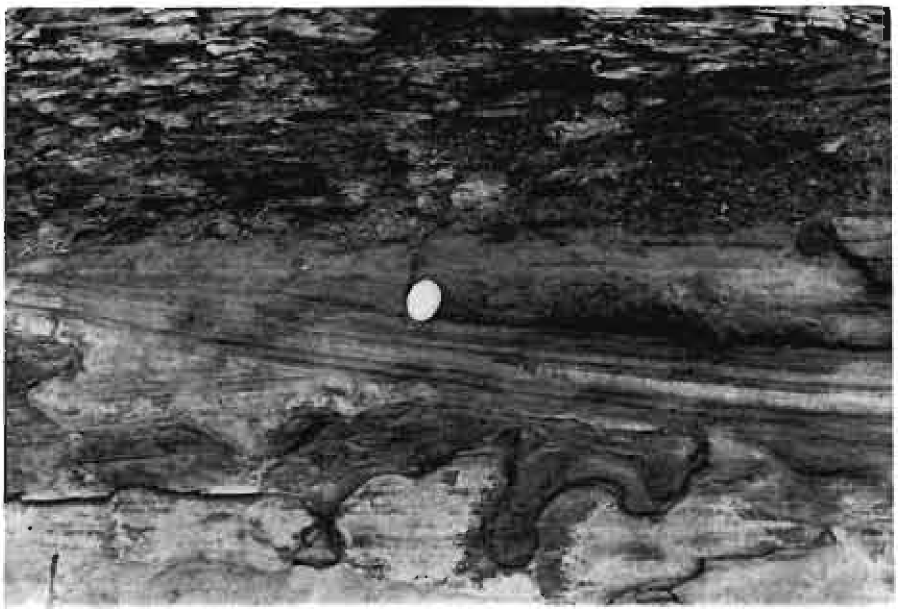

Plate 7. Cross-bedding in a siltstone unit of the Vinton at Volgomier's Quarry.

Plate 8. Concretionary Structure in the Vinton at Volgomier's Quarry.

Plate 9. Cuyahoga and Logan Formations at Mary Ann Furnace, (Section 5).

Plate 10. Channel in the Black Hand Member in which Berne was deposited.

Plate 11. Black Hand, Berne, and Byer Members in the Pennsylvania Railroad cut at Section 6.

Plate 12. Channeling in the Black Hand.

Plate 13. Pennsylvanian-Vinton contact showing erosional nature of the contact.

Plate 14. Burrowing and worm trails in the Vinton Member of the Logan.

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APPENDIX I

STRATIGRAPHIC SECTION 1

Section measured in N. E. ¼ of S. W. ¼, Granville Township, Granville quadrangle, at corner of Burg and Thresher streets about one-half block west of Denison University. Section starts at base of cliff and is measured upward to top of cliff. Elevation of base of section estimated at 1067 feet.

	Feet	Inches
MISSISSIPPIAN SYSTEM		
LOGAN FORMATION		
Allensville Member		
9. Covered: top of section.		
8. Sandstone: yellow; fine- to medium-grained; evenly bedded; weathers to 1-inch thick plates; fossiliferous...est.	3	0
7. Covered Interval....................est.	2	0
6. Sandstone: orange; medium- to fine-grained; massive....................	0	8
5. Sandstone: tan, orange-tan, and yellow; medium- to fine-grained; poorly sorted; weathers into slabs ½ to 3 inches thick; fossiliferous..........................	4	2
4. Sandstone: gray and tan, weathering tan; medium- to fine-grained; irregularly bedded. Alternation of thinner-bedded, weak, slope-forming beds with stronger, thicker ledge-forming beds as in units 4 and 5 of stratigraphic Section 3.............	7	5
3. Sandstone: orange; coarse-grained; poorly cemented with ferruginous cement..	0	2
Byer Member		
2. Sandstone: tan; fine-grained with grains up to 1/5 millimeters; massive with thin beds of fossils up to 2 inches thick, mostly crinoid stem plates; some brachiopods...........................	7	4
1. Base of Section.		
Total thickness	24	9

STRATIGRAPHIC SECTION 2

Section measured at Dugway raodside park on Ohio Route 16 where Raccoon Creek impinges against cliff in Newark Township, Newark quadrangle, in what would be the S. E. ¼ of N. W. ¼ of S. W. ¼ if the township were square. Base of section estimated at 850 feet from topographic map but probably actually lower. Section begins at lowermost exposed shale and siltstone in creek bed and is measured upward and northward to top of hill north of cliff.

	Feet	Inches
MISSISSIPPIAN SYSTEM LOGAN FORMATION Byer Member		
12. Top of Section: at top of highway right-of-way marker.		
11. Siltstone: tan; poorly exposed..........	16	6
10. Sandstone: orange-tan; many grains in excess of one millimeter; pebbles up to 1/3 inch; fossiliferous; poorly cemented..........................	1	9
9. Sandstone: tan; grains about ½ millimeter........................	2	6
8. Siltstone: gray; irregularly bedded; some sandstone......................	2	4
7. Sandstone: tan; fine to coarse; some grains up to two millimeters........	4	6
6. Conglomerate: pebbles in sandy matrix; most ¼ to ½ inch in diameter but occasionally one up to one inch long (quartz); ferruginous; sand and silt concretions up to two inches in diameter...............................	0	8-10
CUYAHOGA FORMATION Cuyahoga Undifferentiated		
5. Shales, Siltstones and Sandstones: interbedded; lowest sandstone forms ledge above unit 4; others from ledges within unit; lowest sandstone has grains up to 1/8 millimeters; white mica; cross-bedded. Unit is mostly near top. Ledge beneath unit 6 at one place is yellowish tan, has quartz		

	sand grains up to ½ millimeter in diameter and could be called Black Hand Member. Thirty feet to west, unit immediately beneath unit 6 is silty shale. At this point a 10-inch ledge of Black Hand type (fine-grained) is 6 feet below the Berne...........	56	8
4.	Shale and Siltstone: gray shale and tan siltstone interbedded; contains white mica and black flecks........	7	7
3.	Covered Interval: up stream bank across highway, and about 50 yards to west to lowermost outcrop on cliff on north side of park..................	11	11
2.	Shale: gray interbedded with occasional gray siltstone up to 3 inches in thickness...........................	12	0
1.	Base of Section: lowermost exposure in stream bed.		
	Total thickness	116	5

STRATIGRAPHIC SECTION 3

Section measured in abandoned quarry on south side of a hill about 0.7 mile west of B. M. 1082 in N. E. ¼ of S. W. ¼, Granville Township, Granville quadrangle. Section begins at base of cliff and continues to top of the cliff. Elevation of base of the section estimated at about 1061 feet.

	Feet	Inches
MISSISSIPPIAN SYSTEM		
LOGAN FORMATION		
Vinton Member		
18. Covered: top of section............	2	0
17. Sandstone: tan; fine-grained with some ironstone cement bands; poorly exposed..........................	3	0
Allensville Member		
16. Sandstone: like unit 15 except that it appears to have been cracked and then had the cracks filled with a coarser sandstone. Much better cemented; forms overhanging ledge.................	2	4
15. Sandstone: orange; medium- to fine-grained; poorly sorted; forms slope.............................	2	4
14. Sandstone: like unit 13..........	0	8
13a. Sandstone: greenish tan; fine-grained.........................	0	5
13. Sandstone: orange-tan; medium-grained; poorly sorted; limonitic crinoid stem plates and brachiopods; hematitic streaks.................	1	0
12. Sandstone: like unit 5.........(est)	6	0
11. Sandstone: like unit 5...........	0	4
10. Sandstone: like unit 4...........	0	4
9. Sandstone: like unit 5...........	1	0
8. Sandstone: like unit 4...........	0	5
7. Sandstone: like unit 5..........	1	9

6. <u>Sandstone</u>: like unit 4............	1	1
5. <u>Sandstone</u>: coarser than unit 4 but similar; forms ledge; pelecypod near top.................	1	5½
4. <u>Sandstone</u>: gray and tan; fine-grained; silty; irregularly bedded; with limonite fossils, mostly near base; gray mud burrow-like fillings. Weathers to slope.........................	1	3
3. <u>Sandstone</u>: brown and yellow; ferruginous; coarse-grained; poorly cemented. Contact at base sharp and gently wavy. Contact at top irregular and wavy.........................	0	2-4
<u>Byer Member</u>		
2. <u>Sandstone</u>: tan; massive; fine-grained with a few grains up to 1/10 millimeter in length. Some mica flakes. Several lens- or channel-like limonitic fossil zones which pinch out laterally. Thickest is 6 inches from bottom. Contains abundant crinoid stem plates..............	11	10
1. <u>Base of section</u>..................	-	-
Total thickness	37	4½

STRATIGRAPHIC SECTION 4

Section measured by Jesse E. Hyde in Vogelmeier's Quarry about 1.5 miles south of Newark city square, southeastern Newark Township, Newark quadrangle (Modified after Hyde, 1953, p. 68).

MISSISSIPPIAN SYSTEM LOGAN FORMATION Allensville Member	Feet	Inches
5. Sandstones: buff or yellow; moderately fine-grained; irregularly bedded; with numerous beds of coarse, reddish, iron-stained sandstone, some of them very coarse and with the grains well assorted. Most of the coarse material in the upper half; some shale in lower part. Bed fossiliferous..........................	14	0
4. Shale: bluish gray; argillaceous; little grit; some fossils...............	3	9
3. Sandstone: coarse; quartz grains well sized and rounded; rather hard and with much less iron than in the upper beds. Fossils sometimes present. Lower surface very sharp and very even; upper surface broken by large ripples which cause the bed to vary in thickness from half an inch to six inches. Rarely it is wanting entirely. This is the bed which Prosser calls Conglomerate II of Herrick........	0	6
2. Shale: bluish; hard; gritty; numerous fossils and Spirophyton markings; the "Fucoid" layers of Hicks. *Allorisma winchelli* zone........................	5	0
1. Sandstone: reddish; very coarse; loose; grains uniformly sized and all about one millimeter in diameter and rounded or subangular; lower surface slightly irregular...................	1	4
Total Thickness	24	7

STRATIGRAPHIC SECTION 5

Section measured in N. E. ¼ of S. E. ¼ of Mary Ann Township, Newark quadrangle about 0.2 mile north of Road Junction 837 (Mary Ann Furnace) on County Road 210. Section begins at bed of Rocky Fork and is measured upward and eastward to top of cliff. Base of section estimated as 802 feet in elevation.

	Feet	Inches
16. Covered............................	-	-
MISSISSIPPIAN SYSTEM		
LOGAN FORMATION		
Allensville Member		
15. Shale and siltstone........... (est.)	6	0
14. Sandstone: yellow, brown, and white; coarse-grained; limonitic and hematitic	2	3
Byer Member		
13. Siltstone: tan, bedded........(est.)	5	0
12. Siltstone: massive.............(est.)	10	0
11. Siltstone: tan and gray interbedded irregularly with gray shale; ironstone in joints and in irregular beds; 3 feet from base is a concretion zone with ironstone shells; westhers into irregular blocks 3 to 4 inches thick; about 7 feet from base is a zone of occasional subspherical concretions with ironstone shells...............	10	0

Joints

Strike	Dip
N. 65° E.	80° N.
N. 88° E.	Vertical
S. 79° E.	Vertical

	Feet	Inches
Berne Member		
10. Sandstone: tan and yellow; fine-grained with occasional pebbles up to ½ inch long; sand and pebbles mostly quartz; cross-bedded and unevenly bedded; punky; occasional crinoid stem plate........	4	2
9. Sandstone: tan to yellow; fine-grained	1	8

8.	Disconformity (?): wavy surface......	-	-
7.	Sandstone: yellow; fine-grained with occasional pebble....................	0	8
6.	Conglomerate: tan and yellow; quartz pebbles in quartz sandstone matrix; most pebbles about ¼ inch in diameter but some up to 1½ x 1 x ½ inches; grades into unit above at once place; at another place it truncates the unit below and is truncated by the unit above; cross-bedded; iron concretions....................	0	6
	CUYAHOGA FORMATION Black Hand Member		
5.	Sandstone: light brown with yellow streaks; weathers than; fine-grained; mostly quartz grains, sub-rounded to angular with larger grains 3/4 millimeter in diameter; cross-bedded.......................	2	8
4.	Sandstone: yellowish than to orange yellow; weathers light tan to light brown; fine-grained with occasional pebble or group of few pebbles; massive to thin-bedded; upper part weathers to plates; some beds cemented with iron minerals..........................	21	9

Joints in Units 4 and 5

Strike	Dip
S. 85° E.	85° S.
S. 30° E.	85° W.
N. 58° E.	85° N.
N. 60° E.	85° N.

3.	Road...............................	-	-
2.	Covered interval...................	17	1
1.	Sandstone in bed of stream..........	-	-
	Total Thickness	81	9

STRATIGRAPHIC SECTION 6

Section measured by Richard N. Crombie on the north wall of the Baltimore and Ohio Railroad cut about 590 feet west of the railroad bridge across the Licking River in the eastern end of Black Hand Narrows, southeastern Hanover Township, Frazeysburg quadrangle, (Crombie, 1952, Section 31,p.146).

	Feet	Inches
QUATERNARY SYSTEM		
PLESITOCENE SERIES		
5. Glacial drift: with igneous erratics	7	0
MISSISSIPPIAN SYSTEM		
LOGAN FORMATION		
Byer Member		
4. Siltstone: light brown, weathers grayish black; some very fine quartz grains; evenly bedded with beds up to 5 inches in thickness........................	20	2
Berne Member		
3. Conglomerate: dark brown; limonitic; tough; well cemented with limonitic and siliceous cement; pebbles up to 2½ inches in length but with an average diameter from ¼ to ½ inch. A pebbly sandstone 1 inch in thickness is at the top of the unit................	1	2
CUYAHOGA FORMATION		
Black Hand Member		
2. Sandstone and conglomerate: whitish-gray to yellow-orange; medium to fine white sand of clear quartz grains. This sugary white sand of angular to subrounded grains has limonitic stained yellow spots. The sand is friable and massive with well rounded white quartzite pebbles up to 1 inch in diameter. The conglomerate is in long thin bands or lenses from 18 to 20 feet in length and from 1 to 2 inches in thickness. This unit is more conglomerate than unit No. 1...............	11	5¼
At 8 feet, 1 inch a bedding plane striking N. 70° W. and dipping 4° N.E.		

1. Sandstone and conglomerate: yellow-orange weathers blackish; massive; fracture angular and blocky; semi-friable with limonitic layers up to 1 inch in thickness. The medium-grained sandstone, composed of approximately 99 percent quartz with some black and gray, has a yellow coloration which seems due to limonitic staining of the quartz grains. The conglomerate, of well rounded, mostly white quartzite pebbles, is scattered both vertically and horizontally throughout the unit........	12	8
At 10 feet, 4 inches occurs a layer of limonite up to 1/6 inch in thickness and a light clay-shale band which pinches out to the east and west along the outcrop.		
Total Thickness	52	5¼

APPENDIX II

```
      DIMENSION ROUND (100), OBJECT (100),WIDTH (100), LENGTH (100), SO
     1RT (25), TOT (27), GR (100), SP (100), STORE (100), STORY (100), S
     2TORO(100), ISUM(50), NTOT(27,25)
      INTEGER*NTOT
      READ (5,700) (SORT(KK),KK=1,25)
  700 FORMAT (11F7.4/2F7.4,12F4.0)
      WRITE (6,701) (SORT (KK), KK-1,251)
  701 FORMAT((13(2X,F7.5))/(6(2X,F4.3)),(6(2X,F4.2)))
      DO 34 II=1,100
      ROUND (II)=0.0
      OBJECT (II)-0.0
      WIDTH (II)=0.0
      TENGTH (II)-0.0
      GR (II)-0.0
      SP (II)=0.0
   34 CONTINUE
   47 IR=0
      LU=0
   48 READ(5,800) NN
  800 FORMAT (69X,I3)
      IF(NN.EQ.101) GO TO 91
      LB=LU+1
      LU=LB+NN-1
      DO 31 JI=1,27
   31 TOT(JI)=0
      READ(5,100)(ROUND(MM),OBJECT(MM),WIDTH(MM),TENGTH(MM),MM=LB,LU)
```

```
100 FORMAT((6(2F2.0,2F4.1)))
    DO 10 I=LB,LU
    IF(OBJECT(I).NE.1.0)  GO TO 75
    Z=0.145
    GO TO 20
 75 IF(OBJECT(I).NE.2.0) GO TO 76
    Z=0.05
    GO TO 20
 76 IF(OBJECT(I).NE.3.0) GO TO 77
    Z=0.02
    GO TO 20
 77 Z=0.01
 20 U=WIDTH(I)*Z
    V=TENGTH(I)*Z
    IF(TENGTH(I).EQ.0.0)GO TO 92
    GR(I)=(U+V)/2.0
    SP(I)=U/V
 50 DO11 J=1,13
    IF(GR(I).LT.SORT(J) GO TO 21
    IF(J.NE.13) GO TO 11
 23 TOT(J+1)=TOT(J+1)+1
    GO TO 51
 21 TOT(J)=TOT(J)+1
    GO TO 51
 11 CONTINUE
 51 DO12 J=14,19
```

```
      IF(SP(1).LT.SORT(J) GO TO 24
      IF(J.NE.19) GO TO 12
      TOT(J+2)=TOT(J+2)+1
      GO TO 52
   24 TOT(J+1)=TOT(J+1)+1
      GO TO 52
   12 CONTINUE
   52 DO 13J=20, 25
      IF(ROUND(I).NE.SORT(J)GO TO 13
      TOT(J+2)=TOT(J+2)+1
      GO TO 10
   13 CONTINUE
   10 CONTINUE
      IR=IR+1
      DO1 LL=1,27
      NTOT(LL,IR)=TOT(LL)
    1 CONTINUE
      DO 69 MI=LB, LU
      STORE(MI)=GR(MI)
      STORY(MI)=SP(MI)
   69 STORO(MI)=ROUND(MI)
      IF(LU.EQ.100) GO TO 53
      GO TO 48
   53 DO 14 L=1,99
      M=L+1
      DO 15 N=M,100
      IF(STORE(L).LT.STORE(N))GO TO 15
      TEMP=STORE(L)
```

```
      STORE(L)=STORE(N)
      STORE(N)=TEMP
   15 CONTINUE
   14 CONTINUE
      AMEAN=(STORE(16)+STORE(50)+STORE(84))/3.0
      GSD=(STORE(16)-STORE(84))/4.0+(STORE(5)-STORE(95))/6.6
      ASYM=(STORE(16)+STORE(84)-2.0*STORE(50))/(2.0*(STORE(84)=STORE(16)
     1))+(STORE(5)+STORE(95)-2.0*STORE(50))/(2.0*(STORE(95)-STORE(5)))
      PEAKED=(STORE(95)-STORE(5))/(2.44*(STORE(75)-STORE(25)))
      DO 18 KKK=1,27
   18 TOT(KKK)=0
      DO 16 IM=1,100
      DO 17 IN=1,13
      IF(STORE(IM).LT.SORT(IN)) GO TO 61
      IF(IN.NE.13) GO TO 17
      TOT (IN+1)=TOT(IN+1)+1
      GOTO 54
   61 TOT(IN)=TOT(IN)+1
      GOTO 54
   17 CONTINUE
   54 DO 19 IN = 14,19
      IF(STORY(IM).LT.SORT(IN)) GO TO 62
      IF(IN.NE.19) GO TO 19
      TOT (IN+2)=TOT(IN+2)+1
      GO TO 55
   62 TOT (IN+1)=TOT(IN+1)+1
      GO TO 55
   19 CONTINUE
```

```
 55 DO 32 IN=20,25
    IF(STORO(IM).NE.SORT(IN) GO TO 32
    TOT(IN+2)=TOT(IN+2)+1
    GO TO 16
 32 CONTINUE
 16 CONTINUE
    WRITE(6,202)
202 FORMAT(3X,'0.0030',1X,'0.0078',1X,'0.0156',1X,'0.0312',1X,'0.0625'
   1,1X,'0.1250',1X,'0.2500',1X,'0.5000',1X,'1.0000',1X,'2.0000',1X,'4
   2.0000',1X,'8.0000',1X,'16.000',1X,' 16.00)
    WRITE(6,205) IR
205 FORMAT(1X,13)
    WRITE(6,203)((NTOT(LL,LM),LL=1,14),LM=1,IR)
203 FORMAT(1417)
    WRITE(6,210)
210 FORMAT(/17X,'VE',3X,'E',2X,'SEL',1X,'INT',1X,'SEQ',1X,'EQ',2X,'VEQ
   2',34X,'VA',3X,'A;,2X,'SA,2X,'SR',3X,'R',2X,'WR')
    DO569 LM=1,IR
569 WRITE(6,211)(NTOT(LL,LM),LL=15,27)
211 FORMAT(17X,7(13,1X),34X,6(13,1X))
    WRITE(6,202)
    WRITE(6,203)(TOT(JK),JK=1,14)
    WRITE(6,210)
    WRITE(6,211)(TOT(JK),JK=15,27)
    WRITE (6,204) STORE(1),STORE(50),STORE(100),AMEAN,GSD,ASYM,PEAKED
204 FORMAT (1'MINIMUM',1X,E13.5,1X,'MEDIAN',1X,E13.6,1X,'MAXIMUM',1X,E1
```

```
  13.6,1X,'MEAN',1X,E12.6,1X,'SORTING',1X,E13.6 / 'SKEWNESS',1X,E13.
  26,1X,'KURTOSIS',E13.6)
   GO TO 47
92 CALL PDUMP
91 STOP
   END
```

Definition of Variables

Round: Roundness value

Object: Power of objective lens

Width: Width of grain in number of squares from objective grid

Tength: Length of grain in number of squares from objective grid

Sort: Array for sorting grains

TOT,NTOT: Arrays for totaling grains of various similar characteristics

GR: Grain size

SP: Sphericity

Store,Story,Storo: Arrays for storing grain size, sphericity and roundness values

NN: Counter for number of grains per slide. When NN equals 101, computations for one slide begins.

Z: Value for size of one square on the objective grid

AMEAN: Graphic Mean

GSD: Inclusive Graphic Standard Deviation

ASYM: Inclusive Graphic Skewness

PEAKED: Graphic Kurtosis

APPENDIX III

Formulas Used in Sediment Statistics Computation[1]

GRAPHIC MEAN

$$M_z = (016 + 050 + 0\ 84)/3$$

INCLUSIVE GRAPHIC STANDARD DEVIATION

$$O_I = \frac{084 - 016}{4.0} + \frac{095 - 05}{6.6}$$

INCLUSIVE GRAPHIC SKEWNESS

$$SK_I = \frac{016 + 084 - 2(050)}{2(084 - 016)} + \frac{05 + 095 - 2(050)}{2(095 - 05)}$$

GRAPHIC KURTOSIS

$$K_G = \frac{095 - 05}{2.44\ (075 - 025)}$$

1. Robert Folk, Petrology of the Sedimentary Rocks (Austin, Texas, 1959), Page 29.

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