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Study of the Ste. Genevieve formation at selected localities in Southern Illinois and Western Kentucky

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STUDY OF THE STE. GENEVIEVE FORMATION AT SELECTED LOCALITIES IN SOUTHERN ILLINOIS AND WESTERN KENTUCKY

BY

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A

THESIS

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ABSTRACT

The carbonate rocks of the Mississippian Ste. Genevieve Formation were studied megascopically in four quarries--Cave in Rock, Franklin, Three Rivers, and Fredonia Valley--within a small area of the Illinois-Kentucky fluorspar district and in a drill-core from the Cave in Rock Quarry. The rocks were studied microscopically in seventy-four thin sections prepared from samples from the quarries and the drill-core. The Ste. Genevieve Formation is typically an extremely oolitic, fragmentally fossiliferous limestone which is very light gray to white. The megascopic descriptions of the quarry exposures are presented as measured sections and columnar sections. A detailed log of the drill-core is in the Appendix.

The stratigraphic terminology used in this thesis is based on D. H. Swann's recently revised nomenclature of the upper Mississippian rocks in Illinois. The exposed sections of each quarry and the drill-core were correlated. This correlation illustrates the pinching out of the Aux Vases Sandstone in the south and the varying thicknesses of the strata.

The microscopic descriptions of the seventy-four thin sections are tabulated in a chart. They are classified according to R. L. Folk's (1959), carbonate rock classification. The implication of the observable features in the thin sections is that the Ste. Genevieve must have been laid down in a turbulent environment of strong currents or waves. The majority of the oolites were formed elsewhere and transported to the site of deposition. Minor oolitization did, however, occur at the site of deposition.

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Gratitude is also expressed to the various quarry owners who allowed the author to measure sections and collect samples in their quarries. Special thanks go to the Missouri Portland Cement Company of St. Louis, Missouri, which furnished the exploratory drill-core and its chemical analysis, and to Mr. W. Dean Weixelman of that company, who made certain information available.

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CHAPTER I

INTRODUCTION

A number of well-exposed sections of the Mississippian Ste. Genevieve Formation in the southeastern Illinois and western Kentucky fluorspar district have permitted detailed megascopic and microscopic study of this economically important limestone. Information is available from numerous quarries, which were picked because of their nearness to each other, because their proximity to Cave in Rock, Illinois (the core, which is from Cave in Rock, represents a complete section of the Ste. Genevieve Formation) enables possible correlation, and because of the thick exposures of the Ste. Genevieve Formation.

That part of the Mississippian System formerly recognized as the Fredonia Oolite Member was recently redefined by Swann (1963), and is now called, at least in the fluorspar district, the Ste. Genevieve Formation. It is typically a very light gray limestone, and is extremely oolitic.

A. Location

The Illinois-Kentucky fluorspar district is located in Pope and Hardin Counties of extreme southern Illinois and the adjacent Caldwell, Livingston, and Crittenden Counties of western Kentucky. Three quarries are located in western Kentucky, and the other quarry is located in southern Illinois. The drill-core is from southern Illinois. Table I lists the names of the quarries and their locations--the quadrangle, county, and state. Figure 1 is a location map of the quarries.

TABLE I

Quarry Locations

Quarry	Quadrangle	County	State
Cave in Rock	Cave in Rock	Hardin	Illinois
Franklin	Burna	Livingston	Kentucky
Three Rivers	Smithland	Livingston	Kentucky
Fredonia Valley	Fredonia	Caldwell	Kentucky

B. Geography

1. Topography

The quarries included in this report are in the Shawnee Hills section of the Interior Low Plateaus as described by Fenneman (1938). The margins of this section, which include the northwest portion of Kentucky, southern Illinois, and southeastern Indiana, are defined by the Bethel Sandstone (Dripping Springs) escarpment on the east and south, the Coastal Plain and the Ozark Highland on the west, and the Glacial Till Plain on the north (Flint [1928] and Fenneman [1938]).

This section is typified by gently rolling hills and ridges. The ridges are held up by underlying, hard, resistant sandstones; the valleys are underlaid by weaker, less resistant limestones and shales. Numerous sink holes dot the lowland areas indicating that solution work has been active in the underlying carbonate rocks. Some of the sinks are filled with water.

Impressive bluffs, remnants of past erosion, parallel or nearly

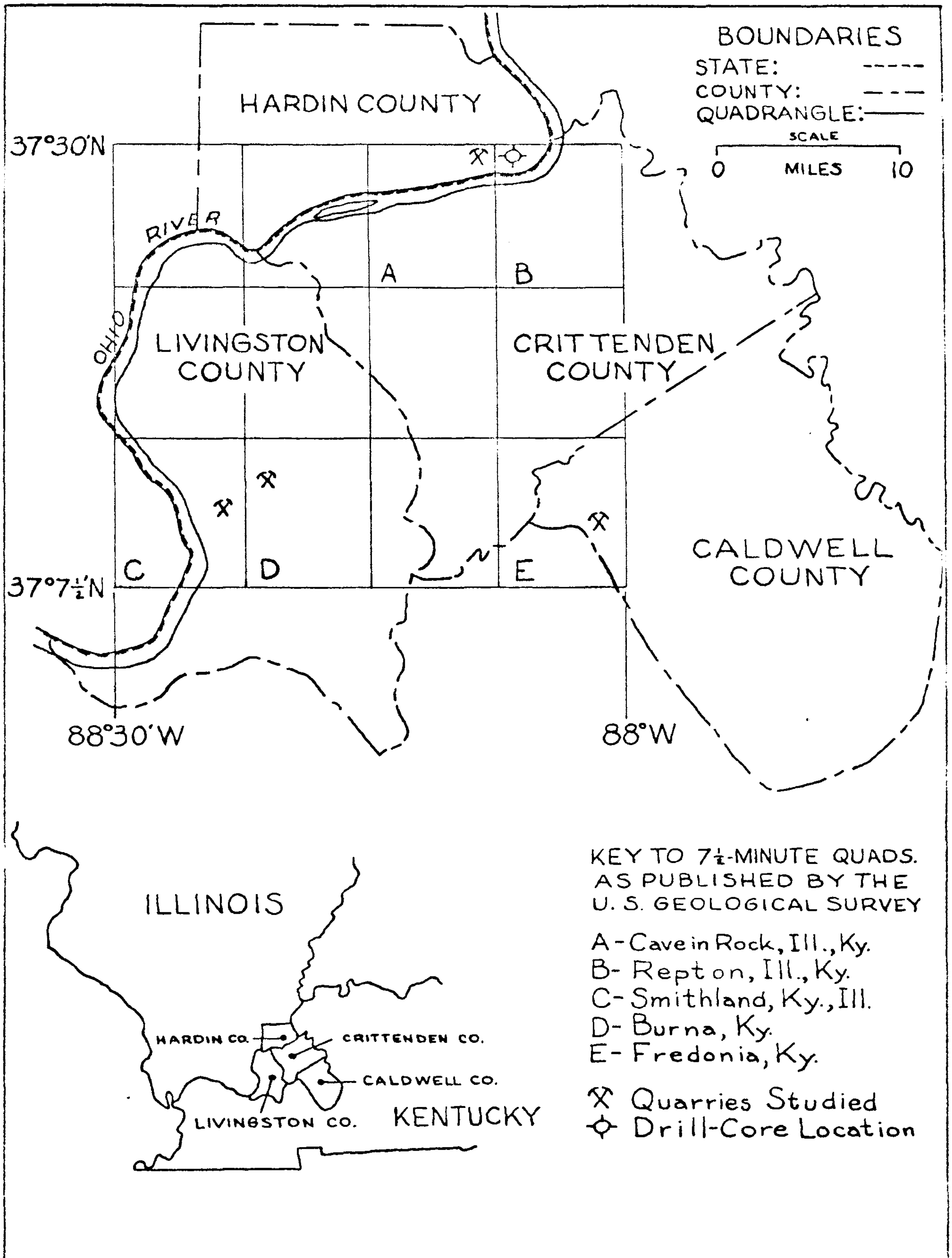

Fig. 1. Location Map

parallel the present courses of the two major local rivers--the Ohio and the Cumberland. The bluffs are mostly composed of limestone and shale with a sandstone caprock. All of the rock occurring as outcrops and quarry exposures in the immediate vicinity is Mississippian in age. Two quarries--the Cave in Rock Quarry and the Franklin Quarry--get their material from river bluffs.

The Ohio and Cumberland Rivers receive the drainage of the area from numerous small streams. These streams possess dendritic drainage patterns as a result of the relatively horizontal attitude of the rocks within the area.

2. Culture

Many small towns, mostly farming communities, exist within the immediate area. The most important of these are: Cave in Rock, Elizabethtown, and Rosiclare in Illinois; and Smithland, Burna, Salem, Marion, and Fredonia in Kentucky. Within the last few years, this area has seen a decrease in population. The nearest large city is Paducah, Kentucky, which is approximately 20 miles west of Smithland, Kentucky.

Cave in Rock, Illinois is linked to nearby Illinois towns by Illinois State Highways 1 (north) and 146 (west), and to Kentucky towns by a river ferry which joins Illinois State Highway 1 with Kentucky State Highway 91. The Kentucky portion of the thesis area is served by Kentucky State Highways 91 and 70, U. S. Highways 60 and 641, and several county highways.

The Illinois Central Railroad passes through Fredonia, Kentucky--the only town in the thesis area which possesses such transportation facilities.

Barge traffic exists on both the Ohio and Cumberland Rivers. The Cave in Rock Quarry uses this transportation media exclusively for shipment of rock down the Ohio River. When Franklin Quarry was operating, its products were transported on the Cumberland River.

C. Purpose of Investigation

Though the Ste. Genevieve Formation has been under study for many years, all of the geologic aspects have never yet been fully explained. In this thesis, the lithology and stratigraphy of four quarries within a small area of the Illinois-Kentucky fluorspar district are described; the lithologies of the quarries are compared, and the four are stratigraphically correlated.

The author was encouraged to make the study for these reasons:

1. In the Spring of 1963, the Missouri Portland Cement Company began opening a quarry at Cave in Rock, Illinois, which exposed a large amount of the Ste. Genevieve Formation for the first time. (One of the early descriptions of this section is included in this thesis),

2. The Missouri Portland Cement Company made a drill-core and a chemical analysis of the Cave in Rock area available to the author,

3. No one has attempted to apply the "history of events" of the Fredonia Oolite, proposed by D. L. Graf and J. E. Lamar (1950), to a stratigraphic sequence of thin sections or within a limited area.

Therefore, the objectives of this thesis are:

1. To study the carbonates of the Ste. Genevieve Formation,

2. To log, in detail, the drill-core from the Cave in Rock area in order to describe the stratigraphic units and to set up a complete stratigraphic section for comparative purposes,

3. To describe and correlate exposed sections of the four quarries in the thesis area.

4. To classify the thin sections of the Ste. Genevieve Formation according to R. L. Folk's classification of carbonate rocks (1959),

5. To test the applicability in a stratigraphic sequence of D. L. Graf and J. E. Lamar's series of historical events of the Fredonia Oolite with thin sections from a limited area.

D. Method of Investigation

In June, 1963, the author visited the thesis area with Dr. A. C. Spreng in order to become familiar with the Ste. Genevieve Formation and its subdivisions, to determine contacts, and to discuss problems. The author returned to the area in July to study the exposed quarry sections, collect samples for thin-sectioning, and to photograph the quarries.

Seventy-four thin sections were made from hand samples and the drill-core, thus preparing for study five stratigraphic suites of thin sections. The purpose of the study of the thin sections was twofold. The objective of the first study was to identify the constituents and to describe them by using R. L. Folk's classification (1959), and the second objective was to observe and test the historical events of formation as proposed by D. L. Graf and J. E. Lamar (1950).

E. Previous Work

The Ste. Genevieve Formation is important to three major industries--the "McClosky lime" of the oil fields in the Illinois basin is an important oil producer, fluorspar is mined from veins and bedded deposits which occur in the Fredonia Member in southern Illinois and western Kentucky, and bluffs in southern Illinois and western Kentucky composed of the Fredonia Member yield high-calcium limestone which is quarried for various rock products including agricultural lime and portland cement materials. The importance of the Ste. Genevieve Formation is obvious, and a great deal of literature has been devoted to it.

"Geology of Hardin County" by Stuart Weller et al. (1920), was one of the first publications to present a complete geological picture of southern Illinois, including the areal geology, lithology, stratigraphy, paleontology, and mining of the Mississippian strata. Though Marvin Weller et al. (1952), include stratigraphic, lithologic, and paleontologic information, their publication is mostly concerned with the mining and processing of fluorspar. The latest work published on the area, by J. W. Baxter et al. (1963), is concerned with the remapping of the fluorspar district to aid in the development of the fluorspar, zinc, and lead resources of southern Illinois.

J. M. Weller and A. H. Sutton (1940), discuss the regional setting of the Mississippian strata; small scale maps from Missouri to Indiana are included to illustrate the areal geology.

Recently Swann (1963), published a report on the stratigraphy of the Late Mississippian rocks. He redefined several units--including the Ste. Genevieve Formation in the fluorspar district--and described and correlated others which had not been conclusively correlated before. His publication has served as a guide for the stratigraphic nomenclature of this thesis. Two debatable contacts and unconformities are discussed by Tippie (1945), and Sutton (1951). Tippie believes that the unconformity between the Fredonia (old usage) and the Rosiclare is more prominent than that between the Ste. Genevieve (old usage) and the Renault. Sutton opposes this view.

The petrology of the Fredonia Oolite Member is set forth in great detail by D. L. Graf and J. E. Lamar (1950). They propound a series of historical events for the formation of the Fredonia Member; their study is neither in a limited area nor in a stratigraphic sequence. (This article is discussed in greater detail in a later chapter). N. H. Short (1962), in his study of the Ste. Genevieve at its type locality, describes the formation petrographically, and, using R. L. Folk's classification, assigns a name to the various lithologies.

CHAPTER II

GEOLOGY

A. General Geologic Setting and Structure

Surface exposures in the immediate vicinity of Cave in Rock, Illinois and adjacent parts of western Kentucky are wholly Mississippian in age and are generally confined to river bluffs and roadside cuts. The areal geology of the Illinois portion of the thesis area has been mapped in detail by S. Weller et al. (1920), J. M. Weller et al. (1952), and J. W. Baxter et al. (1963).

The Mississippian strata within the area dip slightly and are relatively undisturbed except by faulting. The beds dip from 3° to 5° to the northeast and strike approximately N. 70° W. The Fredonia Oolite Member of the Ste. Genevieve Formation has the largest areal distribution of all the strata present because of its thickness.

Numerous normal faults exist northeast of Cave in Rock, Illinois; some of the faults exhibit as much as 500' of displacement. The major trend is N. 50° to N. 60° E., but some small faults strike perpendicularly or nearly perpendicularly to this. These faults lie on the southeast end of a local structural high called Hick's Dome (centered in Sec. 30, T. 11 S., R. 8 E.). Here Devonian rocks are exposed at the center, and succeedingly younger rocks dip away in all directions. Descriptions of these faults are presented by S. Weller et al. (1920, pp. 55-75) and J. M. Weller et al. (1952, pp. 78-83).

The Cave in Rock area lies on the southern margin of the Illinois Basin. It is surrounded by structural highs--the Cincinnati Arch in the far northeast, the Nashville Dome in the southeast, and the Ozark Dome in the west.

B. Paleontology

Fossils are frequently found in the Ste. Genevieve Formation, but it is difficult to collect and identify well-preserved fossils except from weathered surfaces because the rock is resistant and the fossils are usually fragmental. In this thesis the identification of fossils is made at the generic level; but for stratigraphic reasons, emphasis is placed on *Platycrinites penicillus* or *P. huntsville*. The columnals (which are most distinctive) are the most commonly found part of this species. They are elliptically shaped, small (1/8 to 1/4" long), and they have a spiny border. In the past the top of the Levias Member of the Ste. Genevieve Formation and the beginning of the Renault Formation were marked by the disappearance of *Platycrinites penicillus*. Since the reorganization of the stratigraphic boundaries, the disappearance of this crinoid species marks the top of the Genevievian Stage, the Valmeyeran Series, and the Levias Member but not the Ste. Genevieve Formation. The Levias Member is now the basal Renault Member.

Thorough treatment of the fossils of the Ste. Genevieve Formation, including descriptions and photographs, is found in Stuart Weller et al. (1920, pp. 311-402) and J. M. Weller et al. (1952, pp. 84-97).

C. Stratigraphy

All of the stratigraphic units described in this thesis are part of the Valmeyeran and/or the Chesterian Series of the Mississippian System. This thesis is mainly concerned with the rock units of the Ste. Genevieve Formation--a part of the Genevievian Stage. None of the quarries discussed in this thesis has as complete a stratigraphic section as does the drill-core, which contains a section from the upper St. Louis

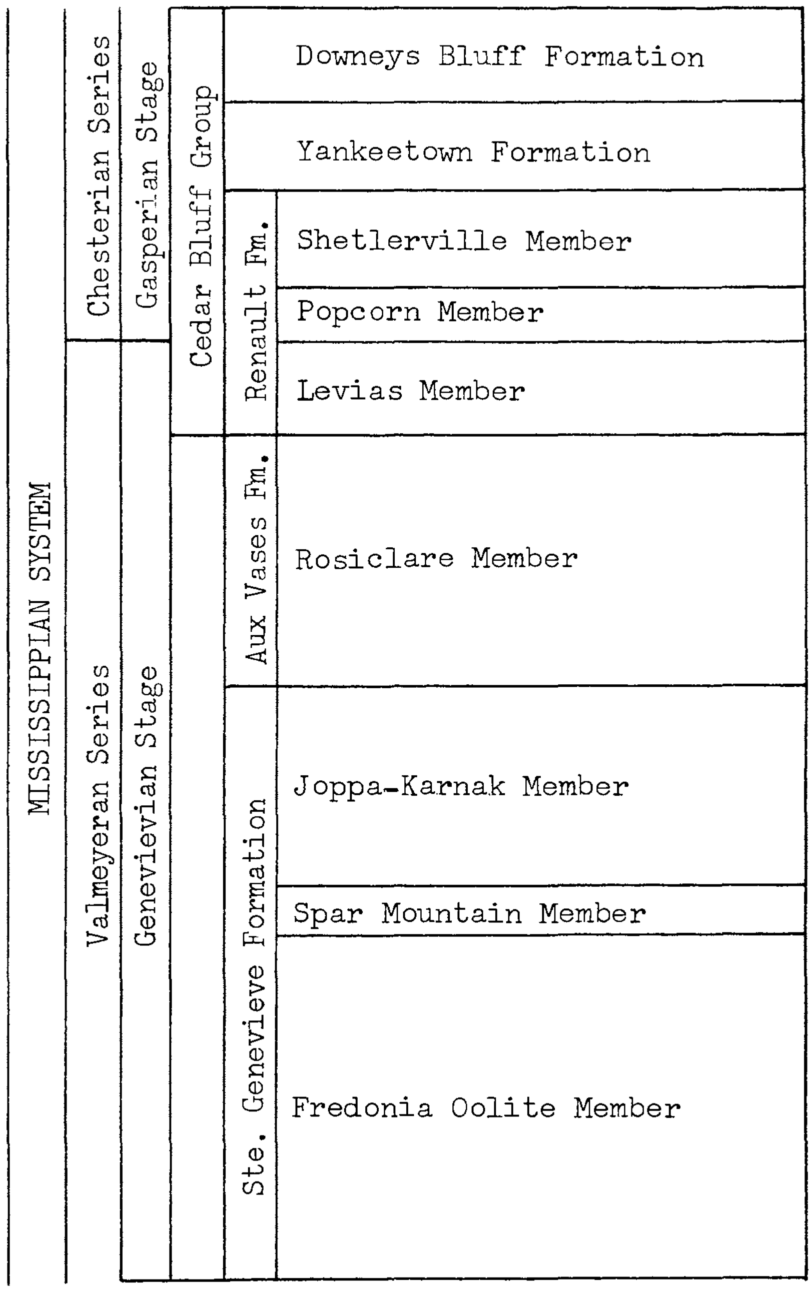

Fig. 2. Portion of the standard stratigraphic column of Illinois (Swann, 1963) showing associations of stratigraphic terms used in this thesis. (The figure does not depict the relative thicknesses of the units).

Formation to the top of the Downeys Bluff Limestone. Figure 2 presents all of the stratigraphic terminology used in this thesis. (The terminology in this writing is the same as that accepted by the Illinois State Geological Survey).

Mississippian System

For many years this system was considered to be a series or "subsystem" of the Carboniferous System. "Although the name Mississippian has been used for a subdivision of the Carboniferous since 1869, the Mississippian Period was first formally recognized by Chamberlin and Salisbury in 1906," (Weller, 1948, p. 97). The term Mississippian has been widely accepted since 1915, and has been used throughout the United States to designate rocks above the Devonian and below the Pennsylvanian. The Mississippian System derives its name from the Mississippi Valley where it is typically developed. Stuart Weller et al. (1920), divide the Mississippian into two parts--Lower and Upper. Their Lower Mississippian included three Groups: the Kinderhook, the Osage, and the Meramec, and it terminates at the top of the Ste. Genevieve Formation. J. M. Weller et al. (1948), raise the three groups of S. Weller et al. (1920), Lower Mississippian to series status. They (Weller et al., 1948), divide the Mississippian into four series; these are, in ascending order: the Kinderhookian, the Osagean, the Meramecian, and the Chesterian. Stuart Weller's 1920 classification is revived by J. M. Weller in 1952, but the terms Lower Mississippian and Upper Mississippian are replaced by Iowa Series and Chester Series respectively. Swann (1963), divides the Mississippian System into three parts following the little-used proposal of J. M. Weller and A. H. Sutton (in Moore, 1933, p. 262), to combine the Osagian and Meramecian Series into a single series called the Valmeyer. Swann calls this middle series the Valmeyeran. His lower and upper series retain the older names--Kinderhookian and Chesterian.

Valmeyeran Series

The Valmeyeran Series is the middle series of the Mississippian System; it lies above the Kinderhookian Series and beneath the Chesterian Series. It was named by J. M. Weller and A. H. Sutton in Moore (1933), for outcrops near Valmeyer, Monroe County, Illinois, but the name was used only by the Illinois State Geological Survey until recently. The series includes the Mississippian strata from the Fern Glen Formation at the base to the Levias Member of the Renault Formation at the top.

Genevievian Stage

Swann (1963), suggests that the term Genevievian Stage denote those rocks of the Valmeyeran Series which are above the St. Louis Limestone. This is the only stage in the Valmeyeran that is named. It includes the following stratigraphic units, from oldest to youngest: the Ste. Genevieve Formation, the Aux Vases Sandstone (redefined by Swann [1963]), and the Levias Member of the Renault Formation (redefined by Swann [1963]). The upper boundary is marked by the disappearance of *Platycrinites penicillus*. The name Genevievian was derived from the Ste. Genevieve Formation, which is the thickest unit of the stage.

Ste. Genevieve Formation

Shumard, in 1860, was the first to use the term Ste. Genevieve Limestone or Formation to describe the rock cropping out in the bluffs of the Mississippi River just south of Ste. Genevieve, Missouri. The term was rarely used for many years, and the rocks were included in the St. Louis Formation until Ulrich, working in Kentucky, described a limestone unit above the St. Louis Formation. He first called this unit the Princeton, but he later found that it was the same as the Ste. Genevieve of Shumard, and thereafter, he used the original name.

It is known today that the Ste. Genevieve outcrops throughout a large geographic area which extends from Iowa to Alabama. The formation is recognizable by its light gray to almost white color and its oolitic texture. Some chert exists in the lower part of the formation, and some sandstone in the upper part, but the rock is mostly carbonate.

The subdivisions of the Ste. Genevieve Formation have presented a major stratigraphic problem. Figure 3, from Swann (1963), compares thirteen versions of the terminology for the Mississippian rocks from the Ste. Genevieve Formation to the Bethel Sandstone in the fluorspar district which were developed during the last half century. Weller's (1952), version subdivides the Ste. Genevieve Formation into three members--the Fredonia Oolite, the Rosiclare Sandstone, and the Levias Limestone. That author further subdivides the Fredonia Oolite Member into three units: the Lower Fredonia, the Spar Mountain Sandstone, and the Upper Fredonia. For several years his classification was a standard reference for Illinois. The Missouri Portland Cement Company also used Weller's classification during exploratory drilling at Cave in Rock, but they eventually had to reclassify the Fredonia Oolite Member to meet local conditions.

Swann (1963), found through regional studies of both the surface and the subsurface that certain units through southern Illinois were

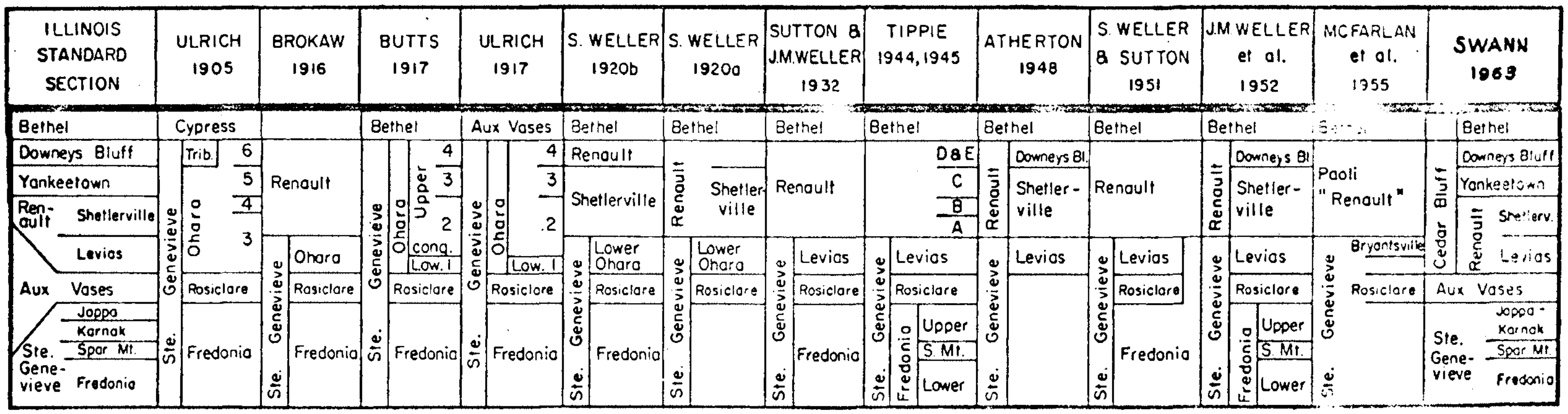

Fig. 3. Development of Ste. Genevieve and Lower Chester classification in the fluorspar district, Illinois and Kentucky. (Adapted from Swann, 1963, Classification of Genevievian and Chesterian [Late Mississippian] Rocks of Illinois, Figure 18, p. 49; by permission of D. H. Swann).

improperly correlated. He redefined the limits of the Ste. Genevieve Formation to include only that strata which previously was the Fredonia Member. The Fredonia Member, according to Swann, is overlain by the Spar Mountain Sandstone, and that writer uses two new terms--the Joppa and Karnak Members--to name the strata above the Spar Mountain. The Aux Vases Sandstone of Missouri is correlated by Swann with the Rosiclare Sandstone of southern Illinois. The term Rosiclare is now used as a local member name of the Aux Vases Sandstone Formation in southern Illinois. The Levias Limestone, formerly thought of as the upper member of the Ste. Genevieve Formation, is now considered a member of the Renault Formation because it contains Platycrinites penicillus, a characteristic crinoid of the upper Valmeyeran Series. The Illinois State Geological Survey has accepted Swann's classification, and it is now a part of their standard Mississippian section.

Swann's nomenclature is applied to the detailed log of the drill-core from Cave in Rock, Illinois (see Appendix). Figure 6, a generalized log of the core, shows both Swann's (1963), terminology and that applied by the Missouri Portland Cement Company during drilling at Cave in Rock. The thickness of the Ste. Genevieve Formation in the core is 178.6 feet.

Fredonia Oolite Member

The Fredonia Oolite Member is the basal member of the Ste. Genevieve Formation. It lies unconformably upon the St. Louis Formation, and, according to new nomenclature by Swann (1963), it is overlain by the Spar Mountain Sandstone Member. Formerly the Fredonia Member extended upwards to the Aux Vases (Rosiclare) Formation.

The Fredonia was named by E. O. Ulrich in 1905 for exposures in the vicinity of Fredonia, Caldwell County, Kentucky. It is typically light gray to white, extremely oolitic, and contains much fossil debris. Thick cross-bedded horizons are found locally. In the Cave in Rock area, a fine grained, light to medium gray dolomitic limestone occurs near the top of the Fredonia. While drilling in the Cave in Rock vicinity, the Missouri Portland Cement Company used Weller's (1952), terminology to log the cores, thus the Fredonia Oolite Member extended up to the Aux Vases (Rosiclare) Sandstone. Because two prominent dolomite beds were repeatedly found in the drill-cores, a local, five part classification of the Fredonia was developed. The nomenclature used for the five horizons was simply: Lower Fredonia, Lower Dolomite, Middle Fredonia, Upper Dolomite, and Upper Fredonia. Figure 6 shows that the Lower Dolomite would fall within the upper part of the Fredonia as it is now defined.

This author recorded 120.4 feet of Fredonia Oolite from the drill-core, using the new nomenclature developed by Swann (1963). This unit always occurs near the base of the exposed section in the various quarries, and thus a total thickness is not recorded. At the Cave in Rock Quarry, the Fredonia Oolite can be found in outcrop (as of July, 1963, it was not part of the quarry face). A total of 18.3 feet of Fredonia Oolite is exposed at Franklin Quarry and 35 feet at Three Rivers Quarry. The Fredonia Oolite (new usage) is not differentiated at Fredonia Valley Quarry.

Spar Mountain Member

This sandy, silty, shaly material forms a thin member of the Ste. Genevieve Formation which separates the lower Fredonia Member and the

Karnak Member. The Spar Mountain was named by Tippie in 1945 for a sandy exposure on Spar Mountain, occurring 55 to 60 feet below the Aux Vases (Rosiclare) Sandstone, in the SE$\frac{1}{4}$ NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 3, T. 12 S., R. 9 E., Saline Mines Quadrangle, Hardin County, Illinois.

In the past this unit was sometimes called the sub-Rosiclare Sandstone, and has been mistaken for the Rosiclare Sandstone.

The Spar Mountain Member was not detected in any of the quarries studied. In the core, however, a thin sandy unit 2.1 feet thick, which occurred 56 feet below the Aux Vases Sandstone, appears to be the Spar Mountain Member. The term sandstone can hardly be applied to this material because of the sparsity of sand grains. It is the only sandy calcareous material in this portion of the section, however, and since it is 56 feet below the Aux Vases, the author suspects that this lithology represents the Spar Mountain Member.

Joppa-Karnak Member

The lithology of the upper Ste. Genevieve Formation in south central and southwestern Illinois is such that its separation into two members--Joppa and Karnak--is feasible. In southeastern Illinois and western Kentucky, the lithology above the Spar Mountain Member and below the Aux Vases (Rosiclare) Member is more uniform, and a separation is impractical; thus in this location, it becomes the Joppa-Karnak Member. Both of these names were proposed by D. H. Swann in his (1963) report.

The Karnak is the lower of the two members; it is typically a limestone, and it resembles the Fredonia in that it is oolitic and cross-bedded. The type locality is four miles north of Karnak, Johnson County, Illinois.

The Joppa Member overlies the Karnak in south central Illinois, and it is assigned to beds that are shaly or sandy and that lie above relatively pure limestone. The member is named for exposures near Joppa, Johnson County, Illinois.

In the quarries and the core studied in this thesis, the Joppa-Karnak Member usually resembles the Fredonia Oolite Member. In the Cave in Rock area, however, a fine grained, dolomitic limestone occurs near the base of the member. In the drill-core 56.1 feet of this unit were recorded. A total of 48 feet of this joint member are exposed at Cave in Rock Quarry, 32.8 feet at Franklin Quarry, and 32.6 feet at Three Rivers Quarry. The Joppa-Karnak Member is not differentiated at Fredonia Valley Quarry.

Aux Vases Sandstone Formation

The Aux Vases Sandstone was originally named by Keyes in 1892 for exposures at the mouth of the Aux Vases River between St. Marys and Ste. Genevieve, Missouri. Swann (1963), has correlated this unit through subsurface studies with the Rosiclare Sandstone of the fluorspar district. The Rosiclare, formerly a member of the Ste. Genevieve Formation, is now the local name for the Aux Vases Sandstone in that area, and the Ste. Genevieve has been redefined.

Rosiclare Sandstone Member

The Rosiclare Sandstone Member is the local name for the sole member of the Aux Vases Sandstone Formation in the fluorspar district. Therefore, in this area, Aux Vases and the Rosiclare are synonomous terms. The member was named by Ulrich in 1905 for exposures in the Ohio River bluffs below Rosiclare, Hardin County, Illinois.

Tippie (1945) reported that a thin layer of Rosiclare Sandstone existed on the east end of Franklin Quarry. Sutton (1951) believed that this was a misidentification, and he was of the opinion that no Rosiclare Sandstone was present in the quarry. The author of this thesis studied the west end of the quarry (Table IV), and found nothing recognizable as Rosiclare.

Six feet of greenish shale with intercalated limestone and four feet of brownish sandstone representing the Rosiclare Member are near the top of the exposed section in the Cave in Rock Quarry. The Rosiclare was not found in the other quarries. The core from Cave in Rock, Illinois contains 24.8 feet of Rosiclare.

Cedar Bluff Group

This new unit proposed by Swann (1963) groups three dominantly limestone formations together. They are, in ascending order: the Renault Formation (including the Levias and Shetlerville Members), the Yankeetown Formation, and the Downeys Bluff Formation.

Renault Formation

The limits of this formation have been recently changed (Swann, 1963); they now include the youngest beds of the Genevievian and the oldest beds of the Gasperian. In older writings the Renault was considered wholly Chesterian in age; its lower part is now believed to be Valmeyeran. The Renault Formation (recent usage) is divided into three parts--the Levias Member, the Popcorn Sandstone Bed, and the Shetlerville Member.

The Renault Formation (named by S. Weller in 1913 for Renault Township, Monroe County, Illinois) overlies the Aux Vases Formation, and is overlain by the Yankeetown Formation.

In the drill-core where a continuous section was logged, this formation was 32.1 feet thick. The formation is not found in the face of any quarry studied except that of Franklin Quarry. Here, 39.3 feet are exposed. In the other quarries the Renault Formation may be seen cropping out above the quarry face.

The common lithologies of the Renault Formation are limestone, shale, and associated sandstones. The lower third of the core is an oolitic, medium bedded limestone; the middle third is a calcareous shaly material; and the upper third is limestone.

Chesterian Series

The Chesterian Series (named by Worthen in 1860 for the town of Chester, Randolph County, Illinois) is the uppermost series of the Mississippian System. It overlies the Valmeyeran and is overlain by the Pennsylvanian System. The lithology of the Chesterian Series is dominated by clastic materials.

In the fluorspar district the Chesterian Series begins at the top of the Levias Member (Renault Formation). The first member is a thin sandstone bed named the Popcorn. In this thesis the Chesterian rocks were only studied in order to complete the log of the core. Several quarries had Chesterian rocks cropping out above the quarry face, but these were not pertinent to this study.

Gasperian Stage

The Gasperian Stage is the oldest of the three Chesterian Stages. The name, proposed by Swann (1963) is derived from the Gasper Limestone. The type section of this unit is found in the Gasper River bluffs in

Warren County, Kentucky; it overlies Platycrinites penicillus bearing beds and underlies the Big Cliffy Sandstone. All of the Chesterian units discussed in this thesis belong to this stage.

Popcorn Sandstone Bed

This bed is assigned to the Renault Formation and separates the Levias Member (Valmeyeran Stage) and the Shetlerville Member (Gasperian Stage). The term Popcorn Sandstone Bed (named for an exposure near Popcorn Spring in Lawrence County, Indiana) was proposed by Swann (1963) to indicate the lower few inches or few feet of the Shetlerville Member, which is sandy, shaly, or impure limestone material.

This unit is identifiable in the core; it is 0.3 feet thick and quite sandy.

Shetlerville Member

The upper and thickest unit of the Renault Formation--the Shetlerville (named by Stuart Weller in 1920 for exposures near Shetlerville, Hardin County, Illinois)--is the first major Chesterian unit. It overlies the Levias Member and underlies the Yankeetown Formation. The lower few inches or few feet are described as the Popcorn Sandstone Bed (see above).

In the core, where 15.0 feet of Shetlerville were logged, the member possesses a limestone lithology with some thin shale beds.

Yankeetown Formation

The Yankeetown Formation in the Cave in Rock area is predominantly a green shale with several red phases. This formation was first described and named by Stuart Weller in 1913. He named the unit for exposures near Yankeetown School in Monroe County, Illinois. Weller (1952), included this unit in the Shetlerville Member, but because of its lithology, it is now considered a separate unit. The Shetlerville Member underlies the Yankeetown, and the Downeys Bluff Formation overlies it. The core contains 31.6 feet of this formation. It is easily recognizable in the upper face of Franklin Quarry because of its red color.

Downeys Bluff Formation

The Downeys Bluff Formation (named by Atherton in 1948 for exposures at Downeys Bluff on the Ohio River below Rosiclare, Hardin County, Illinois) is the top unit of the Cedar Bluff Group. In the core, where 33.4 feet of this formation were logged, the Downeys Bluff is mainly composed of limestone. This formation underlies the Bethel Sandstone and overlies the Yankeetown Formation.

CHAPTER III

DESCRIPTION AND CORRELATION OF QUARRIES

Four quarries were studied for this thesis. Figure 1 shows the general location of the quarries. They are precisely located in these figures: Cave in Rock Quarry, Cave in Rock, Illinois--Figure 4; Franklin Quarry, Smithland, Kentucky--Figure 7; Three Rivers Quarry, Smithland, Kentucky--Figure 7; and Fredonia Valley Quarry, Fredonia Kentucky--Figure 11.

Each quarry is described, and geomorphic columnar sections, which show prominent bedding planes, relative rock resistance, quarry levels, stratigraphic nomenclature, and the quarry units of the quarry face (Lahee, 1952, p. 690), and measured sections which give thicknesses and lithologies of the quarry units of each quarry are included.

A. Cave in Rock Quarry

The Cave in Rock Quarry is owned and operated by the Missouri Portland Cement Company of St. Louis, Missouri. It is one of several quarries owned by this company, and it provides limestone suitable for the manufacture of portland cement.

Initial exploration of the quarry site was begun in the summer of 1959 with reconnaissance geology and surface mapping. In the spring and summer of 1960, exploration drilling began, and a total of 12 holes were drilled and cored. Excavation for the preparation of the quarry face was begun in the spring of 1963 (Plate I). The storage shed, maintenance building, crusher, conveyor-belt system, and specially designed barges were completed during the spring and summer of 1963. The quarry is now in full production.

Factors that were instrumental in choosing the location of the quarry and crusher site were: the availability of a large quantity of limestone, the nearness of the site to the Ohio River which made barge transportation possible, the subsequent development of a new cement plant 75 miles down river at Joppa, Illinois, and (of minor importance) the nearness of this operation to an already operating quarry--the Rigsby-Barnard Quarry--from which it could obtain construction material.

The quarry is located on the Ohio River $2\frac{1}{4}$ miles upstream from Cave in Rock, Illinois (Figure 4) (SW$\frac{1}{4}$ NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 17, T. 12 S., R. 10 E. of the Cave in Rock Quadrangle, Hardin County, Illinois).

The Fredonia Oolite Member (Weller et al. [1952] nomenclature), which is the most important rock unit in this quarry, was subdivided by the Missouri Portland Cement Company into five distinct zones on the basis of two locally important dolomitic horizons. The five zones (discussed in Chapter II), are, in ascending order: the Lower Fredonia, Lower Dolomite, Middle Fredonia, Upper Dolomite, and Upper Fredonia. Figure 6 relates this classification with that of D. H. Swann (1963). The units thicken and thin considerably throughout the immediate area; thus there are variations in the unit thicknesses.

When the section was measured at the quarry site in July, 1963, the stratigraphic column continued (according to the Missouri Portland Cement Company's nomenclature) from the upper portion of the Middle Fredonia at the base into the Rosiclare Sandstone at the top (Table II). Figure 5 is a geomorphic columnar section of the quarry showing the various levels present at that time.

Northeast from the quarry, drill hole no. 8, located in the SW$\frac{1}{4}$ SE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 8, T. 12 S., R. 10 E. (Repton Quadrangle, Hardin County, Illinois) is stratigraphically complete from the top of the St. Louis Formation through the Ste. Genevieve Formation to the basal portion of the Bethel Sandstone. An extremely generalized log of this core is shown in Figure 6, giving the stratigraphic divisions according to both the Missouri Portland Cement Company and D. H. Swann (1963), the depth to the top of the various units, and the unit thicknesses. A complete and detailed log of this core can be found in the Appendix. Table III lists the results of chemical analyses on this drill-core.

PLATE I

Cave in Rock Quarry as the quarry face is being opened. The truck is parked on the Upper Dolomite.

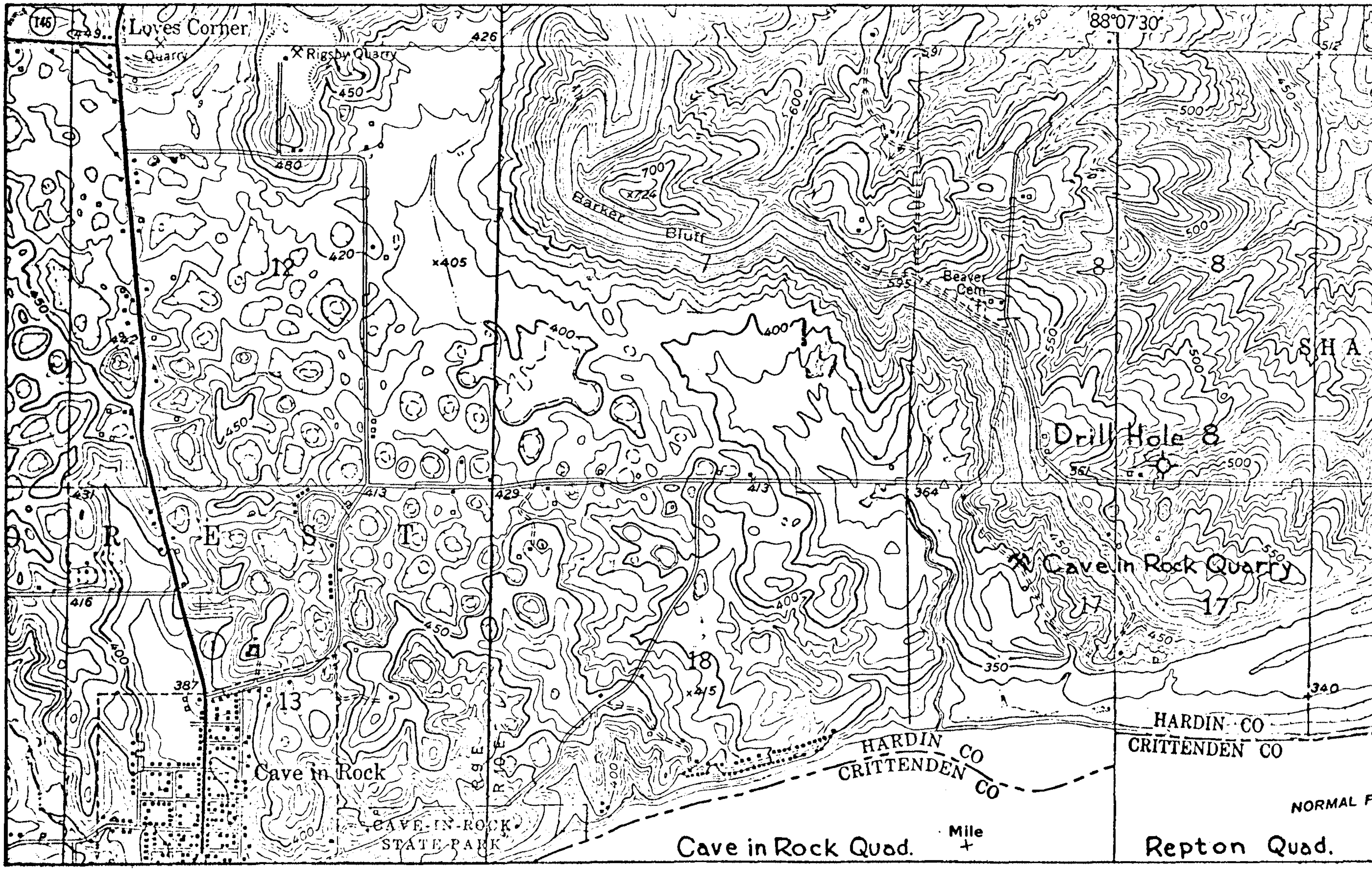

Fig. 4. Portion of Cave in Rock, Illinois $7\frac{1}{2}$-minute topographic quadrangle (U. S. Geological Survey, 1954) and adjacent portion of Repton, Illinois $7\frac{1}{2}$-minute topographic quadrangle (U. S. Geological Survey, 1954) showing locations of Cave in Rock Quarry and Drill Hole 8.

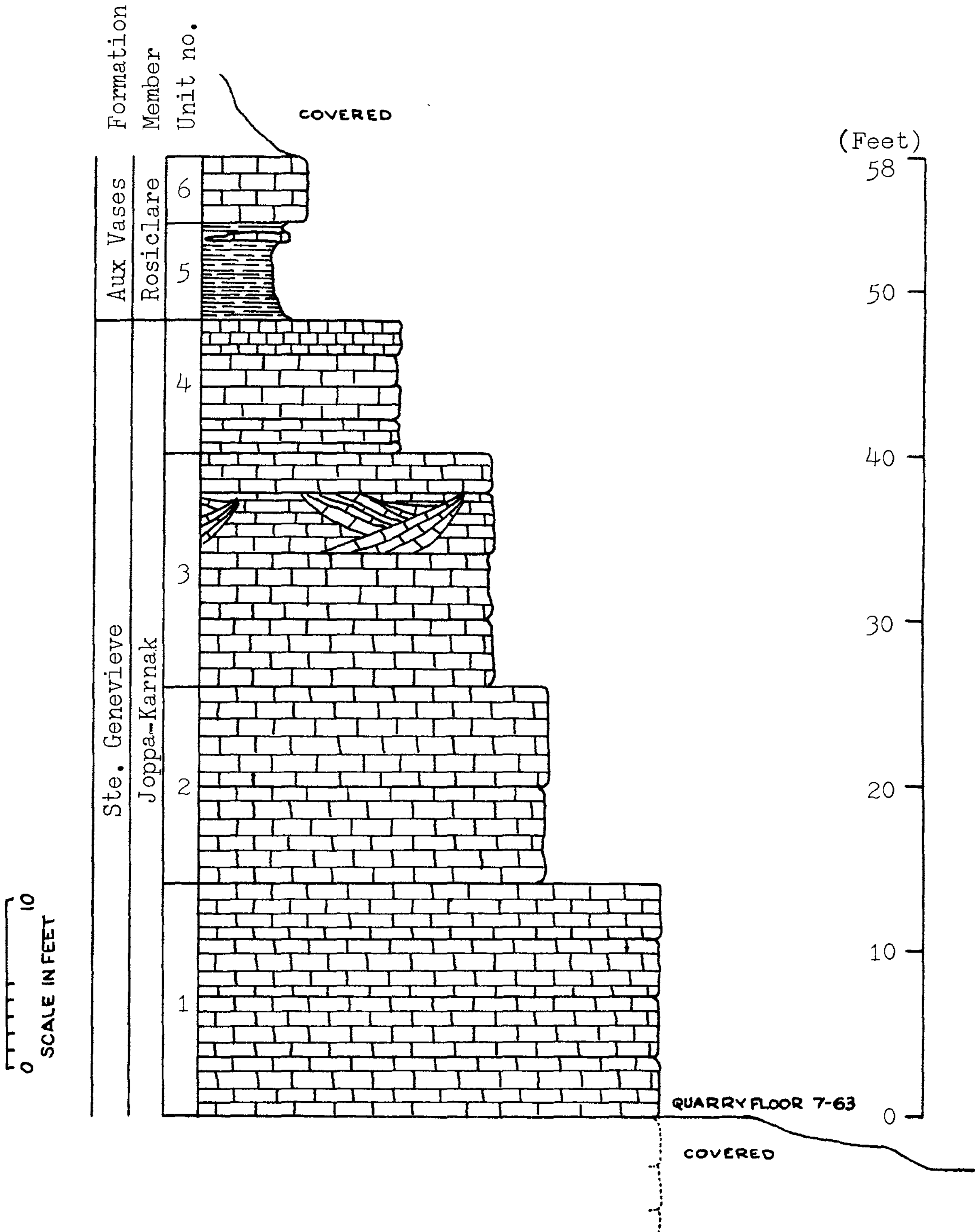

Fig. 5. Geomorphic columnar section of Cave in Rock Quarry. See Table II for a complete description of the quarry units.

TABLE II

Measured Section at the Cave in Rock Quarry

Unit No.	Description	Thickness (Feet)
	Aux Vases Formation Rosiclare Sandstone Member	
6.	Sandstone, calcareous, grayish orange pink (dry), moderate brown (wet), arenaceous, porous, bedded	4.0
5.	Shale, calcareous, light green gray (dry), greenish gray (wet), friable, flakey, arenaceous, unfossiliferous. Limestone lens, medium gray (dry), light olive gray (wet), unfossiliferous, fine-grained, even textured, occurs at 53.0'*.	6.0
	Ste. Genevieve Formation Joppa-Karnak Member	
4.	Limestone, medium light gray (dry), light olive gray (wet), sparsely oolitic, sparsely fossiliferous, fine-grained, even textured, vuggy with iron stains. Thin Section 3 from 42.5'	8.0
3.	Limestone, light gray (dry), light olive gray to light gray (wet), abundantly oolitic, fossiliferous--fragments of crinoids and brachiopods and whole brachiopods--calcite veins cut bedding, iron stains frequent. Thin Sections 4 from 36.5', 5 from 35.6'	14.0
2.	Limestone, medium light gray (dry), olive gray (wet), sparsely oolitic near base, abundantly oolitic at top, fossiliferous--fragmental and whole brachiopods, fragmental crinoids (<u>Platycrinites penicillus</u>)--crystalline, fine- to medium-grained, vertical calcite veins, vugs filled with calcite crystals, limestone fragments near top. Thin Section 6 from 24.5'	12.0
1.	Limestone, medium to light gray (dry), olive gray (wet), sparsely oolitic, fossiliferous--crinoidal fragments--crystalline, medium-to coarse-grained. Thin sections 7 from 10.7', 8 from 9.5'	14.0

*Indicates height above quarry floor.

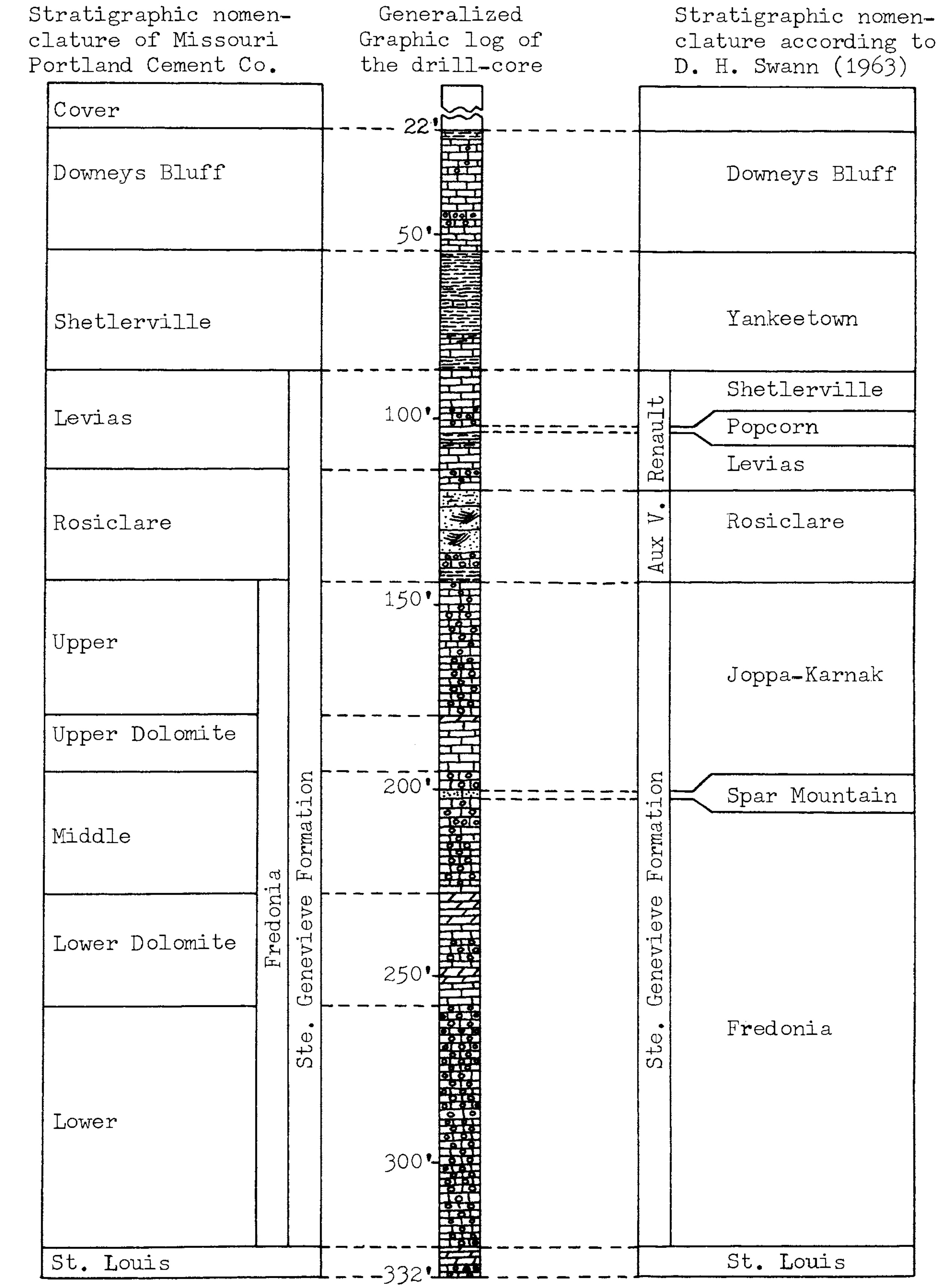

Fig. 6. Generalized graphic log of the drill-core showing the correlation between the nomenclatures of Mo. Portland and Swann (1963).

TABLE III

Chemical Analyses[1] of Drill-core No. 8[2], Cave in Rock, Illinois[3]

Unit[4]	Thickness[5]	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Ign Loss	Total
Downeys Bluff	400	13.25	.61	1.88	45.50	1.18	37.68	100.10
Shetlerville	387	36.94	3.65	4.25	26.55	3.11	26.90	101.40
Levias	293	8.34	.98	1.25	45.95	3.11	39.69	99.32
Rosiclare	382	27.42	5.00	8.34	26.65	5.90	24.33	97.64
Upper Fredonia	386	4.75	.65	.89	49.80	1.84	41.77	99.70
Upper Dolomite	225	9.50	.72	1.43	45.15	3.46	39.80	100.06
Middle Fredonia	413	2.36	.25	.38	52.50	1.24	43.12	99.85
Lower Dolomite	368	5.63	.71	.51	44.40	6.47	42.38	100.10
Lower Fredonia	752	1.18	.18	.09	53.80	.80	43.48	99.53
Weighted Average	3606	11.21	1.32	1.95	44.36	2.72	38.15	99.71

Notes to Table III

1. Nonignited

2. A detailed log of this drill-core is in the Appendix. See Figure 6 for stratigraphic terminology.

3. Furnished through the courtesy of the Missouri Portland Cement Company.

4. Stratigraphic unit terms are those used by Missouri Portland Cement Company, and not the current terminology of the Illinois State Geological Survey; see Figure 6.

5. Measured in inches.

B. Franklin Quarry[1]

The exposed rock section represented in the Franklin Quarry contains beds from the middle of the Fredonia Member (Ste. Genevieve Formation) at the base into the Renault Formation at the top with Bethel Sandstone found cropping out in the hillside above the quarry.

Franklin Quarry is located in the Burna Quadrangle, Livingston County, Kentucky on the north side of Horseshoe Bend in the Cumberland River. It can be reached from Smithland, Kentucky by taking U. S. Highway 60 northeast for 4.8 miles and then a gravel secondary road east for 1.8 miles. Figure 7 is a portion of the Burna and adjacent Smithland Quadrangles which shows the location of this quarry.

The quarry is somewhat linear in shape, and it parallels the river for approximately a half mile. At the west end the bluffs do not exactly follow the present river course but bend to the north. Plate II gives two views of the quarry (looking east and north respectively) from nearly the same vantage point.

The quarry presently is abandoned due to the tremendous amount of overburden, the many and thick shale horizons encountered, and the lack of modern facilities. No accurate information as to when the quarry operations ceased is available, but it must have been within the last ten years. Rock from the Franklin Quarry was transported both by truck and by river barge.

A report on the Franklin Quarry, which includes a chemical analysis,

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[1]Stokley (1953), in his report on "Industrial Limestones of Kentucky," refers to the quarry as the Ward & Montgomery Quarry. The name Franklin Quarry is used, however, on the more recently published map of the Burna Quadrangle, Kentucky ($7\frac{1}{2}$-minute topographic quadrangle, U. S. Geological Survey, 1954). The more recent designation Franklin Quarry will be used in this thesis.

may be found in Stokley (1953, pp. 32-35).

Figure 8 presents a geomorphic columnar section of the quarry near its west end. The stratigraphic terminology presented for this quarry is based on Stokley's (1953), report, a comparison with descriptions and intervals of established sections, and Swann (1963). Table IV is a detailed description of the measured section illustrated in Figure 8, including thicknesses, lithologic descriptions, and thin section locations.

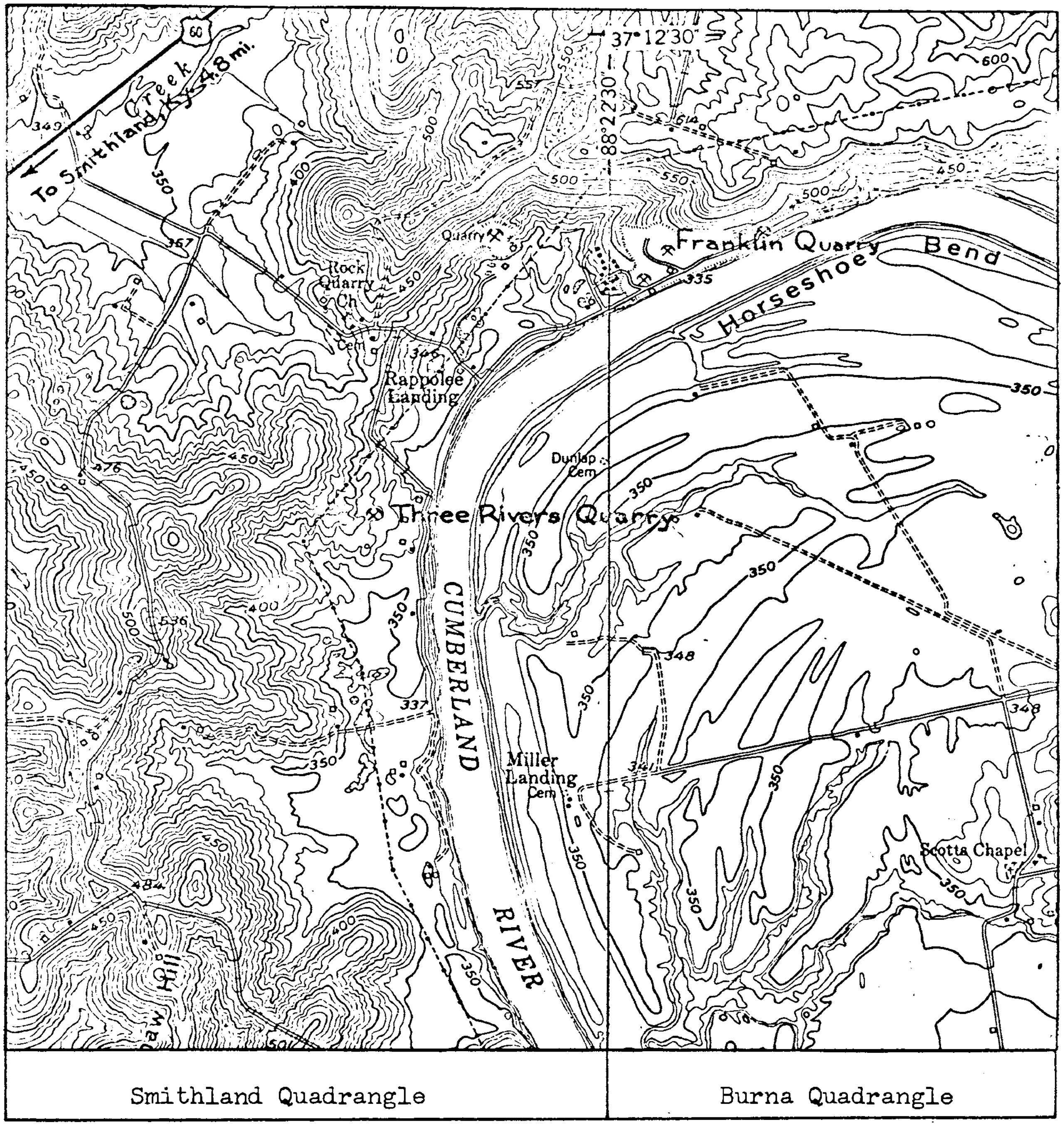

Fig. 7. Portion of Smithland, Kentucky $7\frac{1}{2}$-minute topographic quadrangle (U. S. Geological Survey, 1954) and adjacent portion of Burna, Kentucky $7\frac{1}{2}$-minute topographic quadrangle (U. S. Geological Survey, 1954) showing locations of Franklin Quarry and Three Rivers Quarry.

PLATE II

A. Franklin Quarry, looking east, showing portion of quarry that parallels the Cumberland River. The prominent shale seam two-thirds up the quarry face is Unit 14 (Figure 8).

B. Franklin Quarry, looking north, showing the west end of the quarry. The quarry follows the bluff as it bends away from the present course of the Cumberland River. Break (dark line) indicates top of main quarry face (top of Unit 15, Figure 8).

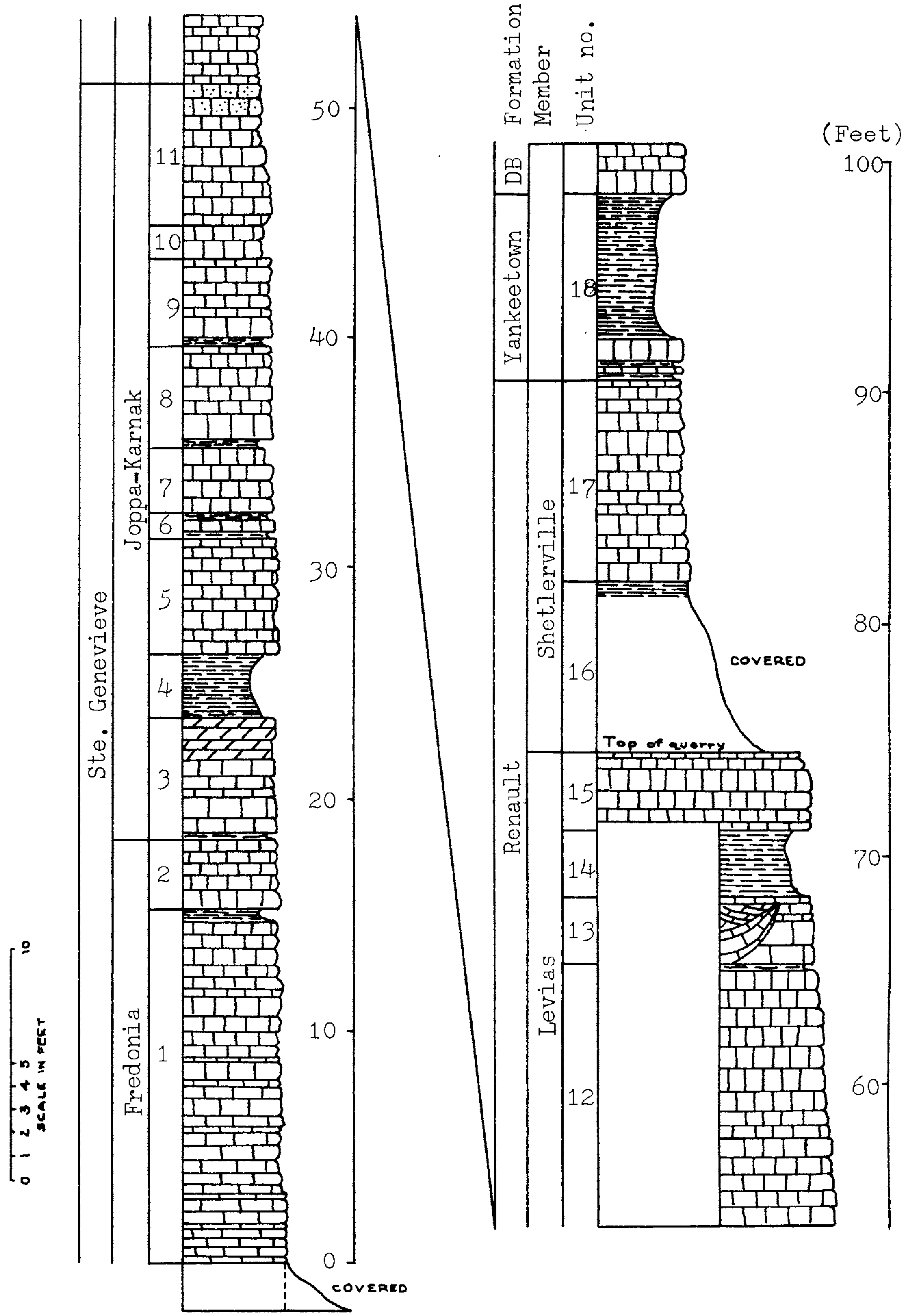

Fig. 8. Geomorphic columnar section of Franklin Quarry. See Table IV for a complete description of the quarry units.

TABLE IV

Measured Section at Franklin Quarry

Unit No.	Description	Thickness (Feet)
	Yankeetown Formation	
18.	Shale, pale red (dry), grayish red (wet), thin-bedded, friable, medium- to fine-grained, even textured, unfossiliferous. Medium gray limestone at base	8.0
	Renault Formation Shetlerville Member	
17.	Limestone, medium light gray (dry), olive gray (wet), fairly oolitic, fossiliferous--crinoid and brachiopod fragments (*Punctospirifer transversa*)--crystalline, weathers to buff. Several friable shale seams present .	8.6
16.	Covered	7.5
	Levias Member	
15.	Limestone, medium gray (dry), olive gray (wet), oolitic, abundantly fossiliferous--gastropods, bryozoans, crinoids, and brachiopods--which weather out on exposed surfaces (*Pentremites*, *Platycrinites*, *Composita*, and *Cliothyridina* are present), limestone fragments occur in a sandy phase 1.5' below the unit top, weathered surfaces are buff to dark gray	2.2
14.	Shale, medium gray (dry), dark gray (wet), platy, fossiliferous, thin bedded	3.8
13.	Limestone, medium gray (dry), olive gray (wet), oolitic, fossiliferous--crinoidal fragments--limestone fragments, cross-bedded	3.0
12.	Limestone, medium gray (dry), olive gray (wet), oolitic (except for lower part, which is fine-grained and nonoolitic), fossiliferous, few shale seams	14.2
	Ste. Genevieve Formation Joppa-Karnak Member	
11.	Limestone, medium gray (dry), dark greenish gray (wet), nonoolitic, unfossiliferous, arenaceous. Weathers buff .	6.2

TABLE IV (cont.)

Unit No.	Description	Thickness (Feet)
10.	Limestone, medium light gray (dry), light olive gray (wet), abundantly oolitic, sparsely fossiliferous, crystalline, weathers to buff	1.4
9.	Limestone, medium light gray (dry), olive gray (wet), abundantly oolitic, fossiliferous--fragments of brachiopods and crinoids--limestone fragments, crystalline. Calcareous platy shale seam at base. Thin Sections 25 from 42.8', 24 from 41.9'	3.8
8.	Limestone, light gray (dry), light olive gray (wet), nonoolitic, unfossiliferous, fine- to medium-grained, crystalline, calcareous shale layer 0.4' thick occurs at base	4.5
7.	Limestone, medium light gray (dry), olive gray (wet), nonoolitic, sparsely fossiliferous, medium textured . . .	2.7
6.	Shale, calcareous and intercalated limestone. Shale is platy, medium gray (dry), dark gray (wet). Limestone light gray (dry), light olive gray (wet), oolitic, fossiliferous, with thin vertical calcite veins . . .	1.1
5.	Limestone, dark gray, nonoolitic, unfossiliferous, medium grained	5.1
4.	Shale, slightly calcareous, medium dark gray, platy . . .	2.8
3.	Limestone, slightly dolomitic, medium light gray (dry), dark gray (wet), nonoolitic, sparsely fossiliferous, massively bedded, even textured. Lower portion grades to shale at base. Thin Sections 23 from 23.3', 22 from 21.1'	5.2
	Fredonia Member	
2.	Limestone, light to medium gray (dry), olive gray (wet), abundantly oolitic, fossiliferous--fragments of bryozoan, crinoids, and brachiopods--limestone fragments at top, crystalline, vuggy--filled with crystalline calcite, thin vertical calcite veins, cross-bedding. Thin Sections 21 from 15.5', 20 from 13.7'	3.5
1.	Limestone, light gray (dry), light olive gray (wet), abundantly oolitic, fossiliferous--fragments of bryozoan, crinoids, and brachiopods--limestone fragments	

TABLE IV (cont.)

Unit No.	Description	Thickness (Feet)
(1.)	near the top--crystalline, stylolites are frequent. Top of ledge is friable, calcareous shale (0.5' thick), Thin Section 19 from 3.9'	14.8

C. <u>Three Rivers Quarry</u>[2]

At the Three Rivers Quarry, the rock section which is quarried is part of the Ste. Genevieve Formation. Three Rivers is only 0.9 of a mile southwest of Franklin Quarry, but the two are separated by a fault. Although the lithologies and horizons are similar, direct correlation is difficult.

Three Rivers Quarry is located in the Smithland Quadrangle, Livingston County, Kentucky. From Smithland, Kentucky the route to the quarry is 4.8 miles northeast on U. S. Highway 60 and then 1.4 miles east on a gravel secondary road. The location of the quarry is indicated in Figure 7.

Figure 9 is a sketch map illustrating the outline of the quarry. Two different views of the Three Rivers Quarry are shown in Plate III. Both the areal and the vertical dimensions of this quarry are smaller than those of the Franklin Quarry. Three Rivers is able to maintain operations because of the high calcium carbonate percentage in its limestone and because it has fewer shale horizons. The main product is crushed rock; this material is transported from the quarry by truck. No published data is available at this time on the Three Rivers Quarry.

A geomorphic columnar section with stratigraphic names, unit numbers, and thicknesses is given in Figure 10. The stratigraphic names have been assigned by a comparison of the lithologies and stratigraphic successions of this quarry with those of established sections. Table V presents the lithologic description of the units; it also indicates the

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[2]This quarry is named the Badgett Quarry on the Smithland Quadrangle, Kentucky map ($7\frac{1}{2}$-minute topographic quadrangle, U. S. Geological Survey, 1954). Since the publication of this map, the management and name of the quarry have been changed.

beds from which thin section samples were taken.

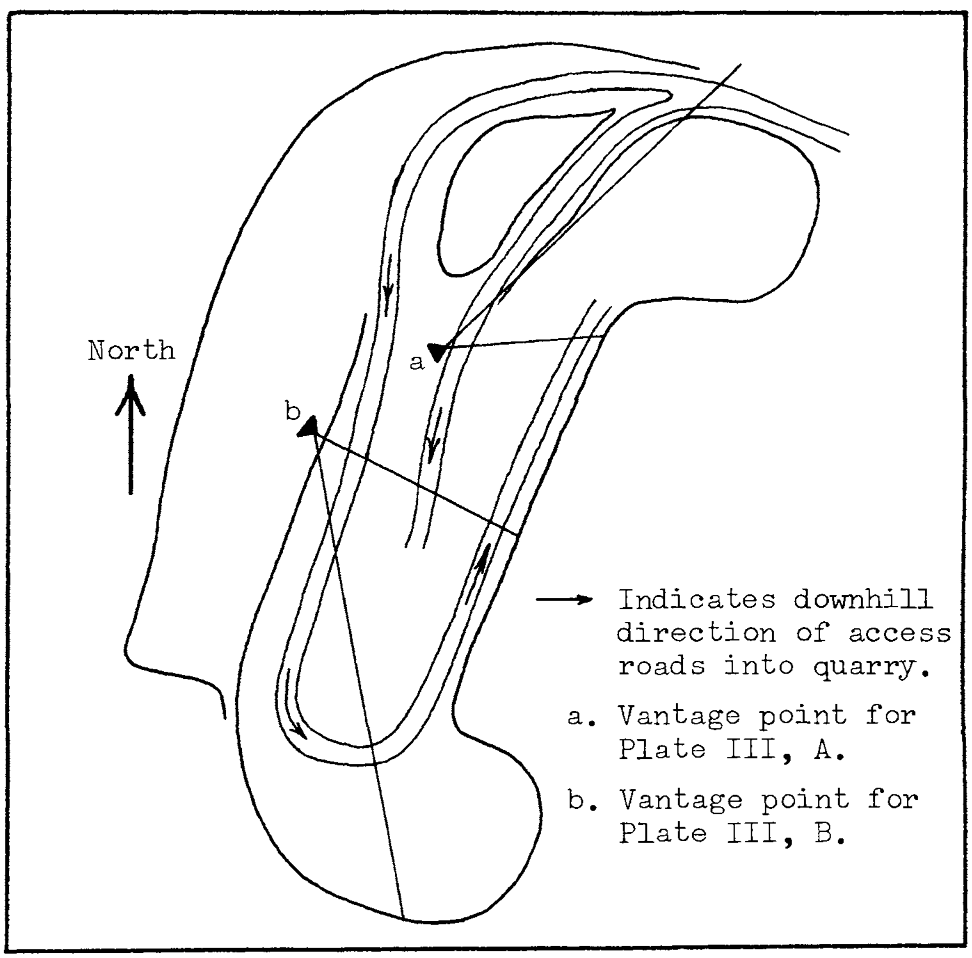


Fig. 9. Sketch map of Three Rivers Quarry.

PLATE III

A. View of Three Rivers Quarry, looking northeast (see Figure 9). Prominent black stratum midway up quarry face is Unit 9 (Figure 10).

B. View of Three Rivers Quarry, looking southeast (see Figure 9).

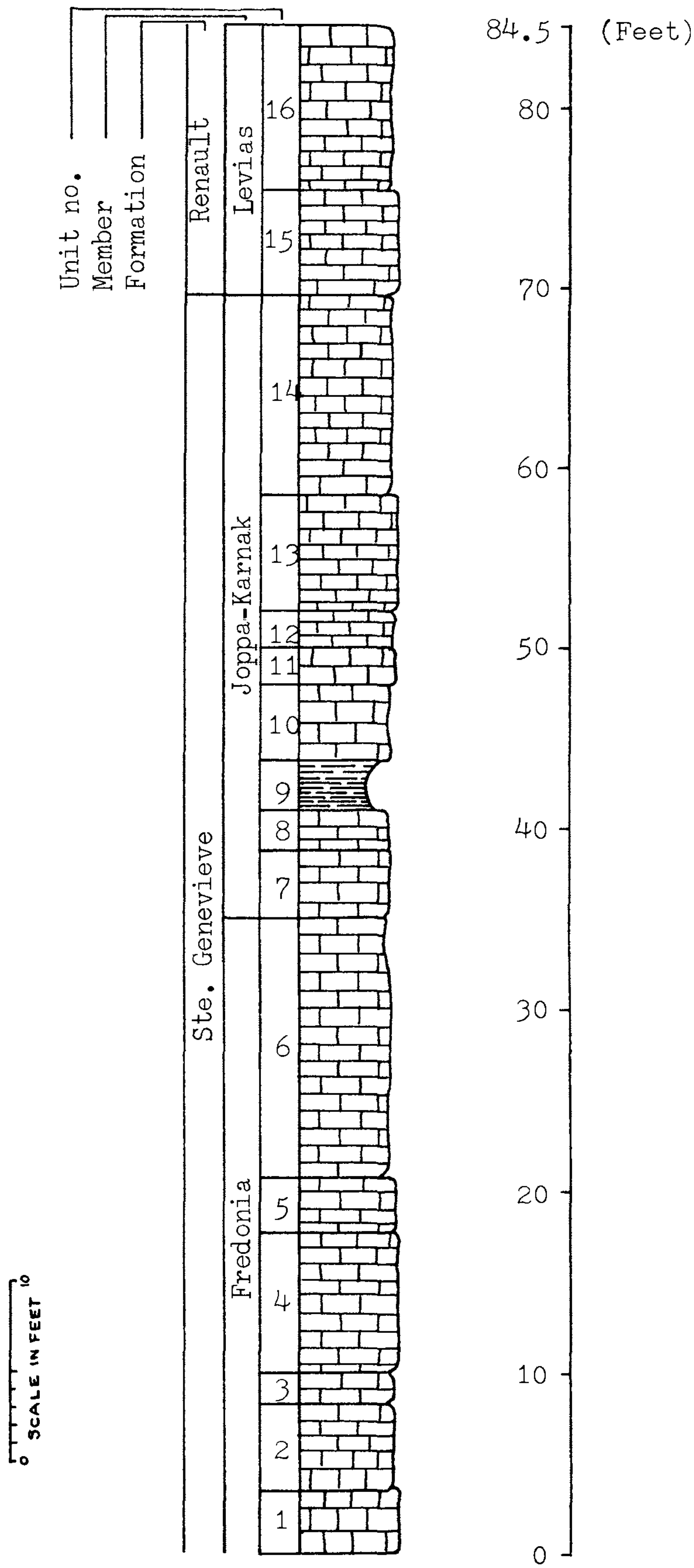


Fig. 10. Geomorphic columnar section of Three Rivers Quarry. See Table V for a complete description of the quarry units.

TABLE V

Measured Section at Three Rivers Quarry

Unit No.	Description	Thickness (Feet)
	Renault Formation Levias Member	
16.	Limestone, medium gray (dry), olive gray (wet), oolitic, fossiliferous--fragments of bryozoan, crinoids, and brachiopods--limestone fragments near top. Crystalline. Weathers to buff. Fine-grained dolomitic bed exists at 76.3'. Thin Sections 48 from 79.4', 47 from 75.8' . .	9.1
15.	Limestone, medium gray, oolitic, fossiliferous, crystalline, and medium-bedded	5.9
	Ste. Genevieve Formation Joppa-Karnak Member	
14.	Limestone, medium gray (dry), olive gray (wet), nonoolitic, unfossiliferous, irregular, coarse, dark laminations	9.0
13.	Limestone, medium gray (dry), olive gray (wet), upper portion nonoolitic, unfossiliferous, laminar, lower portion oolitic, fossiliferous, crystalline, medium-grained with frequent stylolites. Thin Section 46 from 56.5'	6.5
12.	Limestone, medium gray (dry), olive gray (wet), nonoolitic, unfossiliferous, wavy, irregular laminations. Large limestone fragments near top	2.0
11.	Limestone, medium gray (dry), olive gray (wet), oolitic, fossiliferous--fragments of bryozoan, crinoids, and brachiopods--crystalline, laminar, alternating beds recess upon weathering. Thin Sections 45 from 49.5', 44 from 48.4'	2.0
10.	Limestone, medium gray (dry), olive gray (wet), oolitic, fossiliferous, crystalline, fine- to medium-grained. Weathers to buff. Lower portion laminar. Thin Section 43 from 44.5'	4.2
9.	Shale, black (fresh), gray to buff (weathered), thinnly bedded, flaky	2.8

TABLE V (cont.)

Unit No.	Description	Thickness (Feet)
8.	Limestone, medium gray (dry), dark greenish gray (wet), oolitic, fossiliferous, crystalline, coarse-grained, Thin Section 42 from 40.9'	2.1
7.	Limestone, medium gray (dry), olive gray (wet), nonoolitic, unfossiliferous, crystalline, medium bedded, stylolitic	4.0
	Fredonia Member	
6.	Limestone, medium gray (dry), olive gray (wet), sparsely oolitic, fossiliferous--bryozoan and brachiopods--crystalline	14.2
5.	Limestone, medium gray (dry), olive gray (wet), nonoolitic, sparsely fossiliferous, crystalline, fine-grained, Thin Section 40 from 20.6'	3.0
4.	Limestone, light gray (dry), olive gray (wet), abundantly oolitic, fossiliferous--brachiopod and crinoid fragments--crystalline, stylolitic. Thin Section 39 from 15.4'	7.7
3.	Limestone, light gray (dry), light olive gray (wet), abundantly oolitic except near base, fossiliferous--bryozoan and brachiopod fragments--crystalline, fine- to medium-grained, thin vertical calcite veins, vugs filled with crystalline calcite, Thin Section 38 from 9.3'	1.7
2.	Limestone, medium light gray (dry), olive gray (wet), oolitic, fossiliferous--fragments of bryozoan, brachiopods, and crinoids--crystalline, thin calcite veins vertically cutting beds, stylolites at frequent intervals. Thin Sections 37 from 8.2', 36 from 6.1', 35 from 5.4', and 34 from 4.8'	4.8
1.	Limestone, light gray (dry), olive gray (wet), nonoolitic, unfossiliferous, fine- to medium-grained, massively bedded, weathers to buff. Thin Section 33 from 2.7'	3.5

D. Fredonia Valley Quarry[3]

The Fredonia Valley Quarry is located in the Fredonia Quadrangle, Caldwell County, Kentucky. It is 2.4 miles south of Fredonia, Kentucky by way of U. S. Highway 641 and 0.5 of a mile east by way of a secondary gravel road. (See Figure 11 for the location of the quarry in respect to Fredonia, Kentucky and the Bethel Sandstone [Dripping Springs] escarpment).

The quarry is situated on the southeast side of a small knob which rises above the level of the topography of the immediate area. Stokley (1952, p. 9), states that because of its topographic situation, the life-expectancy of the quarry is limited. But by means of a simplified cross section (Figure 12), he shows that quarry operations could continue to the northeast beneath the Bethel Sandstone (Dripping Springs) escarpment.

The entire quarry operation is presently confined to the Fredonia Oolite Member (old usage) of the Ste. Genevieve Formation. Because of the nature of the Fredonia Member in this area, two distinct horizons--upper and lower--cause it to have three subdivisions. The upper high-calcium limestone zone and the lower high-calcium zone are quite local and are easily recognized. The middle portion has no local designation. The terms used on Stokley's (1952, p. 11), cross section of the quarry are used in this report (Figure 12).

According to Stokley (1952), the calcium carbonate content is 98.2% in the upper high-calcium limestone horizon and 97.2% in the lower horizon. That author gave the measurements for the upper and lower zones as

[3]Stokley (1952), uses the name Baker and Barnes for this quarry. The name has since been changed to Fredonia Valley Quarry.

36 feet and 30 feet respectively; my measurements showed the upper zone to be 24.9 feet and the lower zone to be 32.0 feet (see Figure 13 and Table VI).

The main function of the Fredonia Valley Quarry is the production of agricultural lime. The two high-calcium limestone horizons provide the calcium carbonate; processing and packaging is done at the quarry. The intervening material is crushed and used for various construction purposes.

The quarry has two major levels (Figure 13). The lower quarry face is approximately 35 feet high and is composed almost exclusively of the lower high-calcium limestone zone of the Fredonia Member. The upper quarry face includes almost all of the intervening material plus the upper high-calcium limestone zone. Quarrying is now done mainly on the upper face (Plate IV).

Stokley (1952, p. 9), believes that the area should be investigated further because:

1. Deposits of high-calcium limestone up to 36 feet in thickness are known and may have considerable areal extent.
2. It is near T. V. A. electric power (Kentucky Dam).
3. It is near railroad and highway transportation.
4. Most of the accompanying limestone is suitable for the usual construction purposes. However, the volume of the reserves of high-calcium limestone is yet to be determined.

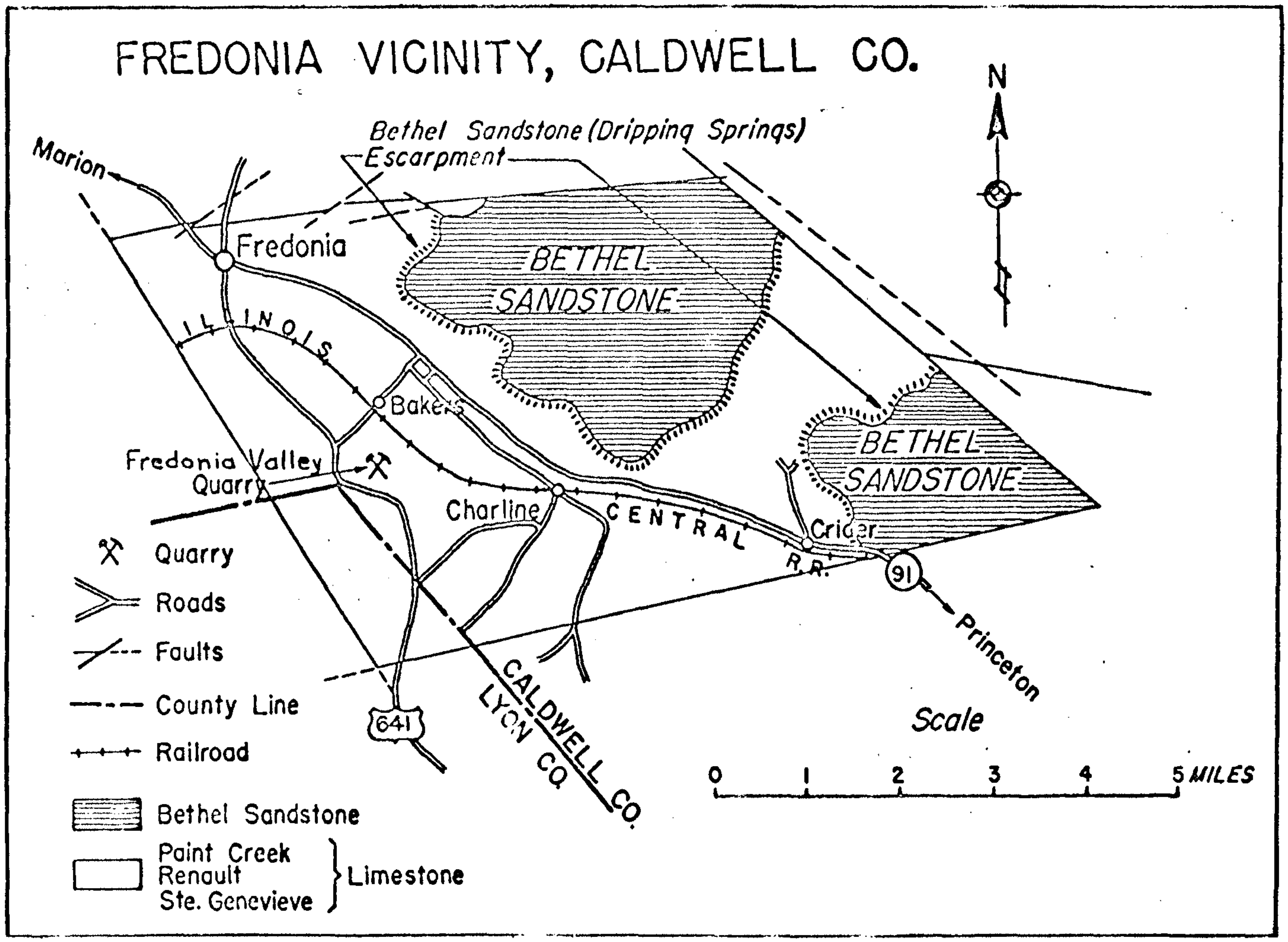


Fig. 11. Map showing the location of Fredonia Valley Quarry in relation to Fredonia, Kentucky and the Bethel Sandstone (Dripping Springs) escarpment. Reproduced, with the permission of the Kentucky Geological Survey, from Stokley (1952), Industrial Limestones of Kentucky No. 2, Kentucky Geological Survey, Series IX, Report of Investigations no. 4, p. 10.

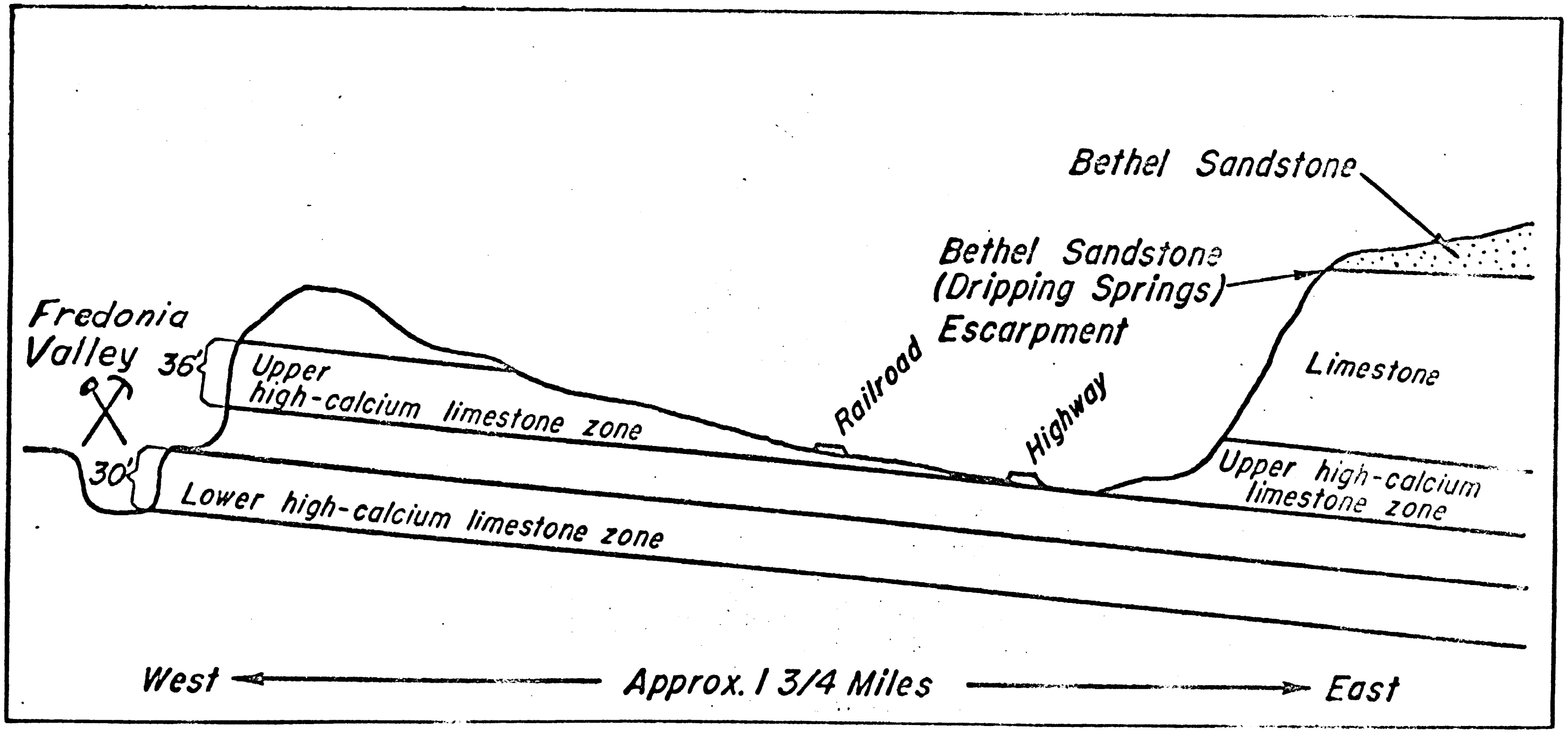


Fig. 12. Cross-section through Fredonia Valley Quarry and nearby Bethel Sandstone (Dripping Springs) escarpment. Reproduced, with the permission of the Kentucky Geological Survey, from Stokley (1952), Industrial Limestones of Kentucky No. 2, Kentucky Geological Survey, Series IX, Report of Investigations no. 4, p. 11.

PLATE IV

Upper quarry face of the Fredonia Valley Quarry showing the "upper high-calcium limestone zone" of the Ste. Genevieve Formation.

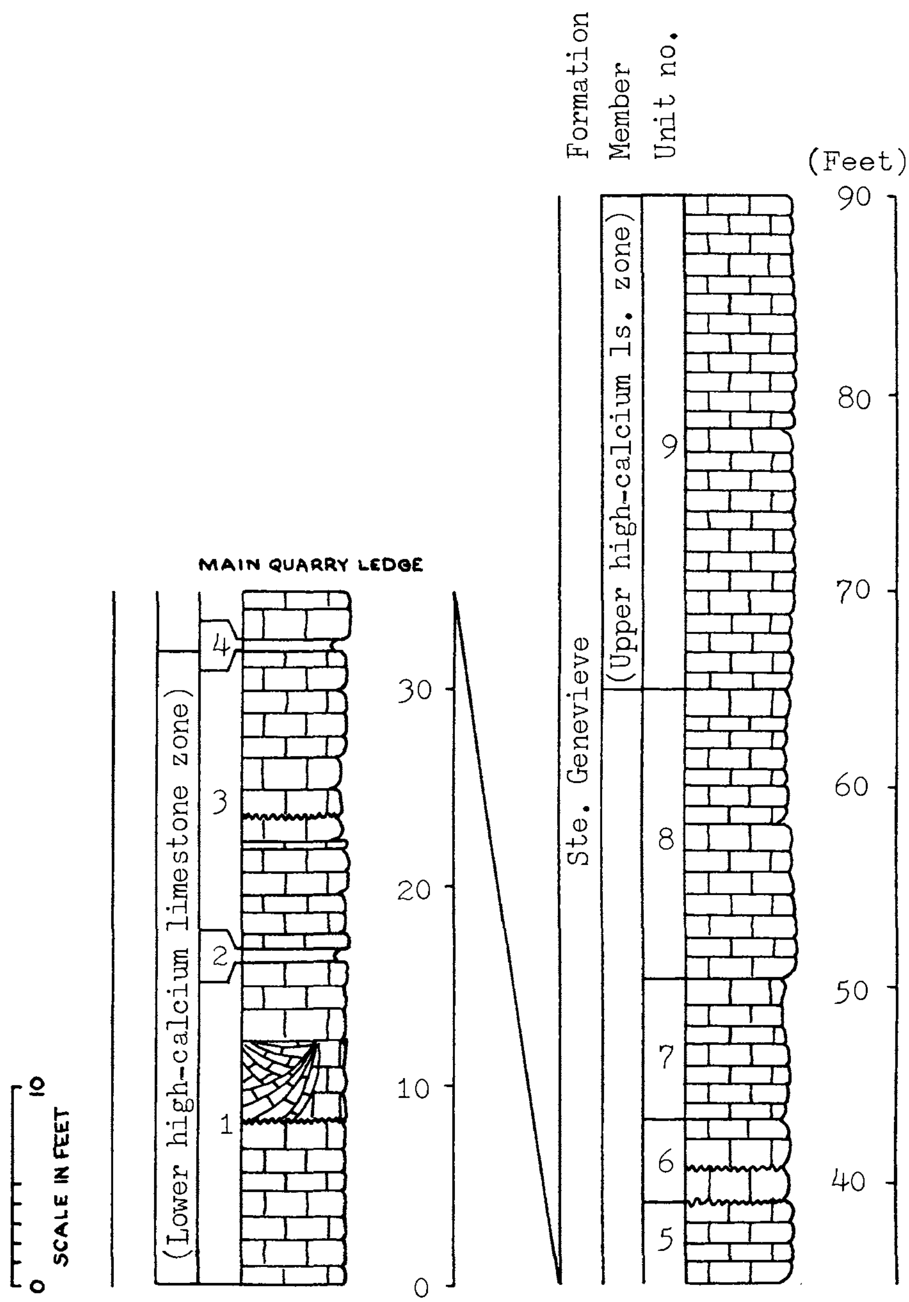


Fig. 13. Geomorphic columnar section of Fredonia Valley Quarry. See Table VI for a complete description of the quarry units.

TABLE VI

Measured Section at Fredonia Valley Quarry

Unit No.	Description	Thickness (Feet)
	Ste. Genevieve Formation "Upper high-calcium limestone zone"	
9.	Limestone, very light gray to white (dry), light olive gray to light gray (wet), abundantly oolitic, abundantly fossiliferous--mostly fragmental--fragments of limestone near top, porous, medium- to coarse-grained, weakly cemented, crystalline. Vugs calcite filled, stylolitic, limonite stains. Weathers to buff. Thin Sections 17 from 89.0', 16 from 87.9', and 32 from 66.7'	24.9
	"Middle Portion"	
8.	Limestone, medium gray (dry), light olive gray (wet), oolitic, sparsely fossiliferous, crystalline, medium-grained	14.4
7.	Limestone, medium light gray (dry), olive gray (wet), nonoolitic, fossiliferous--crinoidal fragments--medium-grained	7.4
6.	Limestone, medium light gray (dry), olive gray (wet), moderately oolitic, fossiliferous (fragmental), laminations, medium-grained. Thin Section 15 from 39.3'	4.2
5.	Limestone, medium light gray (dry), light olive gray (wet), abundantly oolitic, fossiliferous, crystalline, medium- to coarse-grained, dense	6.5
4.	Shale, black to dark gray, platy, thinly bedded. This unit is quite outstanding through the quarry face, but it pinches out at the west end of the quarry	0.5
	"Lower high-calcium limestone zone"	
3.	Limestone, light gray (dry), light olive gray (wet), abundantly oolitic, fossiliferous, crystalline, fine- to medium-grained, fragments of limestone near unit top, vugs calcite filled, limonite stains, stylolitic (some having large amplitude). Thin Sections 14 from 25.1', 13 from 22.4', 12 from 22.2', and 11 from 18.7'	15.0

TABLE VI (cont.)

Unit No.	Description	Thickness (Feet)
2.	Shale, black to dark gray, platy, thinly bedded	0.5
1.	Limestone, very light gray (dry), light olive gray (wet), abundantly oolitic, fossiliferous--fragments of brachiopods, bryozoa, and crinoids, and some whole brachiopods--crystalline, medium-grained, vugs calcite filled, limonite stains, stylolitic, cross-bedding. Thin Sections 10 from 16.1' and 9 from 1.6'.	16.5

E. Correlation

In Figure 14 the stratigraphic sections of the four quarries and the drill-core (studied for this thesis) are correlated. The Ste. Genevieve Formation (the topic formation of this thesis) is exposed in all of the quarries, but only the drill-core contains a complete section. Because exposures of either the top or the bottom of the members are absent in different quarries, it is difficult to correlate the units of this formation. The "base" of the lowermost and the "top" of the uppermost unit in each stratigraphic section shown in Figure 14 are not necessarily the actual top or base of that particular unit. No datum plane could be established for the chart because no single contact exists in all of the sections. It is notable in the correlation chart that the Aux Vases (Rosiclare) Sandstone and the Spar Mountain Member are absent in the Franklin and Three Rivers Quarries.

At Fredonia Valley the section could not be subdivided according to Swann's (1963), terminology, because the lithologic breaks are not obvious and do not conform to the new nomenclature. This section is correlated with the other quarries only as the Ste. Genevieve. The local designations "Upper" and "Lower high-calcium limestone zones" (Stokley, 1952), are used in this thesis. According to the old usage, this section is wholly Fredonia Oolite, but recently new limits have been placed on this member in the fluorspar district by Swann (1963), and undoubtedly the applied stratigraphic terminology will be changed. The old limits of the Fredonia Oolite are now the new limits of the Ste. Genevieve Formation in the fluorspar district.

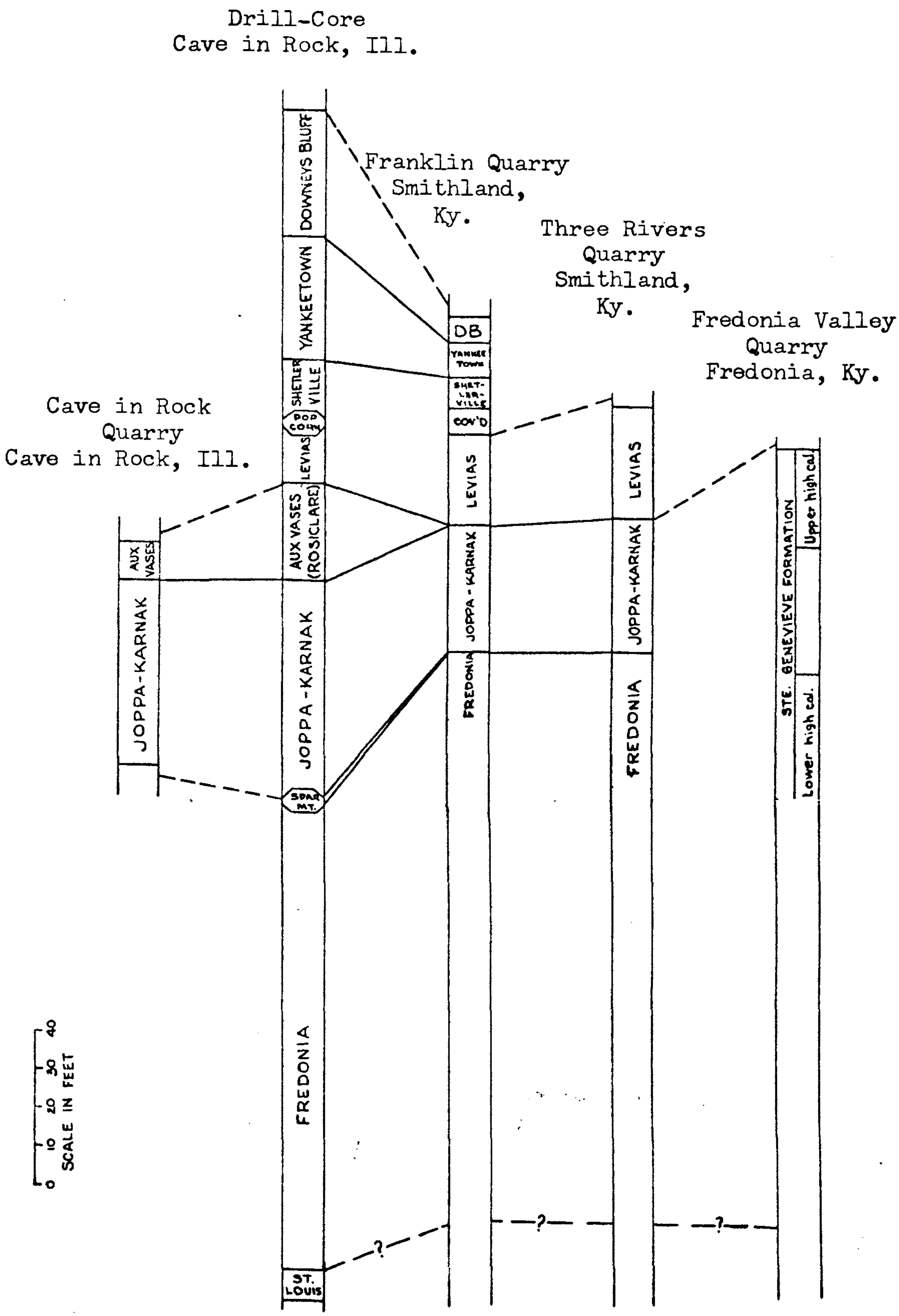


Fig. 14. Correlation Chart

CHAPTER IV

CARBONATE CLASSIFICATION

In the field of the geological sciences, it seems odd that certain phenomena, occurrences, and major divisions are overlooked or put aside for many years. This has been the situation with the interpretation and classification of the carbonate rocks--limestones and dolomites. An estimated 75% of the earth's exposed land is underlain by sedimentary rocks, and of this total, one-fifth is carbonates (Ham, 1962a, p. 2). Though several important and enduring studies, e. g., the writings of Grabau, Twenhofel, and Cayeux, were made of the carbonates in the early twentieth century, these rocks were largely overlooked before c. 1940. Greater emphasis has recently been placed on the study and classification of carbonate rocks. The economic importance of the carbonates is an important factor behind this interest; these rocks provide reservoirs of oil, mineral deposits, and construction materials. As a result of the new classifications, the geologist of today is provided with many specific terms to use in his descriptions of carbonate rocks.

The carbonates are an extremely complex group of rocks. Pettijohn (1957, p. 389), states, "Because of the polygenetic origin of the carbonate rocks--in part detrital, in part chemical and biochemical, and in part metasomatic--they exhibit a variety of textures and structures unequalled by any other group of rocks." The early classifications of carbonate rocks were based more on philosophical concepts than on an intimate knowledge of the rocks themselves (Ham, 1962, p. 3). "Modern" classifications of limestones began to develop during the years 1940-1960. Important influences in this trend were the writings of R. L.

Folk (1959), and R. W. Powers (in Bramkamp and Powers, 1958). These men made comprehensive and intensive studies of a large number of samples.

"The outstanding distinctive aspects of carbonate rocks is their intrabasinal origin, their dependence on organic activity, and their susceptibility to post-depositional modification" (Ham, 1962a, p.4). The parameters used in classifying carbonate rocks can be developed from the three preceeding general aspects.

There are two main types of carbonate classifications--genetic and descriptive. Efforts have been made to combine the two but have been generally unsuccessful, usually resulting in one main classification with overtones of the other. The genetic classification is a direct interpretation of the origin of the rock. The textbook classifications of these authors are genetic: Grabau (1904), Black (1938), Krumbein and Sloss (1951), and Pettijohn (1949, 1957). A set of parameters (depending on the purpose of the classification) is used to group similar occurrences in limestones and dolomites in order to form a descriptive classification. Parameters are the rock's observable features, e. g., chemical, mineralogical, physical, textural, etc. Interpretation of the parameter is not part of a descriptive classification.

Modern genetic and descriptive classifications appear in Ham (1962). The descriptive classification is generally the more popular of the two. The most widely referred to modern descriptive classification is by R. L. Folk (1959). In Ham (1962b), Folk presents and supplements his 1959 work.

Folk's (1959 and 1962) descriptive classification is concerned with limestones of clastic origin. For this reason, the author of this thesis has chosen to employ Folk's classification in the identification of the carbonate thin sections of the Ste. Genevieve.

Folk's Classification

The classification by Folk concerns limestones of clastic origin, not those formed in situ by organic growth or those altered by diagenesis or recrystallization. He believes that limestones are deposited in essentially the same manner as sandstones and shales and that their textures are controlled by current action.

Major Constituents

All pure limestones (limestones with appreciable terrigenous or recrystallized material are not considered "pure") are composed of three end members--allochems, microcrystalline calcite ooze, and sparry calcite.

Allochems

Folk (1959), coined the term allochem to describe the chemical constituents which make up the bulk of carbonate rocks (thus replacing the terms particle and grain). Allochem is a composite term--"allo" (from the Greek allos) means out of the ordinary; "chem" is short for chemical precipitate. The word allochem also implies that these chemical constituents are not normal precipitates but are precipitates of a high order or organization and have probably undergone some transportation. Folk recognizes four allochems which are volumetrically important in carbonate rocks--intraclasts, oolites, fossils, and pellets.

Four allochems are important in limestones; they are 1) intraclasts, 2) oolites, 3) fossils, and 4) pellets.

1. Intraclasts

This term refers to material that is reworked within the basin of deposition before becoming consolidated. Mud, coherent on the ocean bottom, may be ripped up by storm action and redeposited within the same basin. This fragment which shows transportation is termed an intraclast. Individual fossils, oolites, or pellets resting on the surface and suddenly moved are not intraclasts, but if several of these particles were held together by a binding material not yet consolidated, this would be an intraclast.

2. Oolites

Oolites are small, spherical bodies exhibiting radial and/or concentric structures which may or may not have a nucleus. They are typically less than 2.0 mm. in size and calcareous or siliceous in composition.

3. Fossils

Fragments or whole forms from all phyla, which can be and are transported, can be preserved as distinct allochems within a carbonate rock.

4. Pellets

Spherically shaped masses showing no internal structure are believed to be invertebrate fecal pellets. They typically show a rich concentration of organic matter and are dark brown when viewed with convergent light.

Microcrystalline Calcite Ooze

This material is extremely fine-grained (1-4 microns) calcite often referred to as lime mud. (Folk [1959] uses the contraction "micrite" for microcrystalline calcite). "Micrite" is used 1) as a name for microcrystalline calcite matrix, 2) as a combining term to name a rock type, and 3) as a name for a rock wholly made up of microcrystalline calcite. In thin section it is a brownish color and generally subtranslucent.

Sparry Calcite Cement

Crystalline calcite which fills the pore space of a carbonate rock is sparry calcite. The crystals are larger and more translucent than micrite crystals.

Limestone Families

The major rock constituents are allochems, micrite, and sparry calcite. They can be mixed in various ways, and form three main families depending on their relative proportions. The main framework of limestone consists of allochems just as sand particles form the bulk of sandstone. Microcrystalline ooze is the matrix which indicates a poorly washed sediment; when the microcrystalline ooze has been removed, sparry calcite fills the pore spaces.

Limestones of Type I are called "Sparry Allochemical rocks." These consist of allochemical material cemented by sparry calcite cement. No micrite is present in this limestone type.

Limestones of Type II are "Microcrystalline Allochemical rocks." These are mostly made up of allochems, but an appreciable amount of micrite is present. Sparry calcite cement may or may not be present.

Limestones of Type III are the Microcrystalline rocks which represent the opposite extreme of Type I. They are almost pure micrite with little or no allochemical material and no sparry calcite. The lithographic limestones belong to this group.

Subdivisions of the Limestone Families

The most important of the four major allochems is the intraclast. If intraclasts make up 25% of a rock it is an intraclastic rock and implies shallow water, lowered wave base, or tectonic uplift. When a rock contains less than 25% intraclasts, the oolitic percentage is determined; if it contains 25% or more oolites, it is an oolitic rock. Succeedingly a rock which has less than 25% oolites must contain mainly fossils or pellets. If the volume ratio of fossils to pellets is greater than 3:1, the rock is biogenic; if the ratio is less than 1:3, it is a pellet rock; if the ratio is between 3:1 and 1:3, it is a biogenic pellet rock (Folk, 1962, p.71).

Rock Names

A composite term is used to designate rocks of family Types I and II. The prefix of the term designates the dominant allochem (determined as above). <u>Intra</u>- is the prefix which indicates that the most plentiful allochem is the intraclast, <u>oo</u>- is the prefix for oolites, <u>bio</u>- for fossils, and <u>pel</u>- for pellets. The suffix of the term refers to the type of limestone. Type I limestones, composed mainly of sparry calcite, end in -<u>sparite</u>; Type II limestones, mostly microcrystalline calcite, end in -<u>micrite</u>. Eight different rock types can thus be named by combining the preceeding terms, e. g., oosparite--oolites cemented by spar, biomicrite --fossils in micrite, intrasparite--intraclasts cemented by spar, etc. A second suffix, -<u>rudite</u>, is added if the fact that a rock is a calcirudite is important, e. g., intramicrudite.

Only the term micrite is used for Type III rocks.

Special modifiers are added to the above rock terms for further clarity. To indicate a biosparite consisting exclusively of brachiopods, the term brachiopod-biosparite is used. The rock is classified according to its dominant allochem; when it contains an additional allochem of equal importance, this name is added as a modifier, e. g., fossiliferous-oosparite. Special shorthand notations have been developed for this classification, but these are not discussed because they are not used in this thesis.

CHAPTER V

LITHOLOGIC ASPECTS OF THE STE. GENEVIEVE FORMATION

The lithology (petrology) of the Ste. Genevieve Formation was studied both megascopically and microscopically for this thesis. The megascopic study involved preparing field descriptions of four quarries (the measured sections are presented in Chapter III), logging a drill-core from Cave in Rock, Illinois (see Appendix), and describing large sedimentary features--stylolites, cross-bedding, and fracture-filling (in this chapter).

Seventy-four thin sections from samples collected at the four quarries and from the drill-core were studied microscopically; Table VII is a summary of the findings. The thin sections were chosen to illustrate the general characteristics of a quarry or core unit, a particular feature, or a lithologic change within a unit. R. L. Folk's (1959) classification of carbonate rocks was referred to exclusively for identification of the components and for classification of the thin sections. The lithologic name of each thin section (Table VII) is also according to Folk (see previous chapter).

Previous petrological studies of the Ste. Genevieve Formation were made by: D. L. Graf and J. E. Lamar (1950), "Petrology of the Fredonia Oolite in Southern Illinois"; N. M. Short (1962), "Ste. Genevieve (Mississippian) Formation at Its Type Locality in Missouri"; and W. C. Park (1962), "Stylolites and Sedimentary Structures in the Cave in Rock Fluorspar District Southern Illinois." D. L. Graf and J. E. Lamar (1950) cogently presented a series of historical events for the Fredonia Oolite Member (old usage); their work was substantiated with many photomicrographs. Their samples, however, were widely spaced, and the stratigraphic position was not accurately known. (Their series of historical events is discussed in greater detail later in this chapter). N. M. Short (1962) executed a thorough petrographic study of the Ste. Genevieve Formation to enable stratigraphic correlation of this unit at its type locality. Though Short's lithologies were named according to Folk's terminology, Short's terms differ greatly from those used in this thesis because the Ste. Genevieve is much more fossiliferous and less oolitic in Missouri than it is in southern Illinois, because crinoidal fragments coated with a single layer of fine-grained calcite were considered fossil material by Short (the author of this thesis considers them superficial oolites), and because more lime mud (micrite) in Missouri sediments was reported by Short than was found by the present author. W. C. Park (1962, unpublished Master's thesis) used thin sections of the Fredonia Oolite (old usage) to describe the mineralization features and stylolitic patterns of the fluorspar district.

Because of the abundance of light gray to white oolites and fossil fragments, the Ste. Genevieve Formation is typically light gray to white when viewed megascopically in reflected light. A close inspection reveals that the oolite cores, the cement, and the fine-grained matrix material are a medium light gray to medium gray. The more abundant oolites and fossil fragments are, the lighter the color. The lower phase of Franklin Quarry and the upper phase of Fredonia Valley Quarry are so oolitic that even hand samples appear to be pure white. When a thin section is viewed with strongly convergent light, the oolites, fossil fragments, and fine-grained matrix are various shades of brown, and the sparry calcite cement appears colorless or white.

A. Microscopic Features

1. Major Constituents

The major constituents of the Ste. Genevieve Formation are: the allochems--intraclasts, oolites, and fossils--and the orthochems--sparry calcite cement (spar), and microcrystalline ooze (micrite). Oolites form the bulk of the constituents. They occur in 53 of the 74 thin sections studied, and are dominant in 41. Each major constituent group is discussed (in the order mentioned above).

a) Allochemical Constituents

Folk (1959) recognizes four allochems which are volumetrically important in carbonate rocks--intraclasts, oolites, fossils, and pellets.

In this thesis the most important allochems of the Ste. Genevieve Formation are found to be (in order of abundance): oolites, fossils, and intraclasts. Several thin sections contain pellets, but the percentage is so small that they do not warrant placement in Table VII.

(1) Intraclasts

An intraclast is a fragment of contemporaneous sediment which has been picked up and transported within the basin of deposition and then redeposited. The intraclast is the least common allochem found in the thin sections studied for this thesis. Intraclasts range in size from less than 0.5 mm. to 1.0 mm. or larger. Smaller intraclasts are rare because they are usually coated with a thin, fine-grained layer of dark brown calcite and thus become superficial oolites.

A great variety of fragments--fossil debris, oolites which have a well-rounded core encircled by radial concentric bands, and other rock particles (possibly from pre-existing limestones)--compose intraclasts; the fragments of an intraclast are held together by a medium to dark brown, fine-grained matrix (Plate V, A). Many times small euhedral quartz grains are internal components of intraclasts.

Intraclasts are commonly transported great distances. Movement tends to round intraclasts, and internal particles often become truncated at the intraclast margin. Angular intraclasts suggest minimal transportation.

(2) Oolites

The term oolite is a derivative of Greek words meaning egg and rock; oolites resemble fish eggs (Lamar, 1925). Pettijohn (1957, p. 95) states "Oolites are small spherical or subspherical, accetionary bodies, 0.25 to 2.0 millimeters in diameter, most commonly they are 0.5 to 1.0 millimeter in size."

Although oolites are usually spherical, they can be oblate or ellipsoidal. In thin section, the apparent shape may be misleading and erroneous due to the position of the cut through an oolite; e. g., an elongate oolite cut perpendicularly to its longest axis would look circular in thin section and might appear to have been spherical originally.

A cross sectional cut through the center of an oolite displays its two important components--the nucleus (sometimes called the core) and the concentric rings surrounding the nucleus. Pettijohn (1959, p. 95) did not mention these two components because (as shown below) an oolite need not necessarily contain either.

An oolite is formed by the accretion of calcite material around a nucleus. The nucleus is usually obvious--it may be a mineral grain, a detrital fragment, an organic remain (perhaps a fragmental invertebrate hard part), an intraclast, etc. It is impossible, however, to distinguish the nucleus of oolites formed by the accretion of calcite around an air bubble, around an individual particle of the material which comprises the layers, or around a particle of submicroscopic size. Oolites which have been cut "off center" are often erroneously classified as having an unobservable core. Unless a definite nucleus is exposed, it is difficult to prove that a thin section cut passes through or near the center of an oolite.

Calcite adheres to the core in concentric layers (sometimes called rings or bands). Often these layers show a radial structure--minute thin lines normal to the periphery of the layer. In some cases this radiating structure is confined to single layers; in other examples it appears to pass through several layers (Plate V, D). There is no relationship in the thickness of layers around a single core--some may be thick, others thin. Different layers are easily distinguishable when there are differences in color, opacity, or internal structure. An oolite core may be coated with material that shows no concentric pattern, or perhaps only a very thin band is visible near the margin of the oolite. This type of oolite can show radial structure, but generally does not. The first layer adhering to an irregular core reflects the core outline in a subdued manner. Succeeding layers tend to make the oolite a spherical mass. When a curved, elongate shell fragment becomes an oolite nucleus, the layers are thick on the concave side and thin on the convex side, thus forming an elliptical to spherical body (Plate V, C).

A. V. Carozzi's textbook, MICROSCOPIC SEDIMENTARY PETROGRAPHY (1960), contains a thorough discussion of oolites. Carozzi (p. 238), suggests that there are three types of oolites, distinguishable by the physical characteristics of the spherical bodies: the pseudoolites, the superficial oolites, and the normal oolites. The pseudoolite is defined as a calcareous grain, usually cryptocrystalline, of spherical or elliptical shape which displays no concentric rings or outer coatings. A pseudoolite might have been a potential oolite, but it was too large for the oolitization process. The superficial oolite is defined as a spherical or subspherical body possessing only one concentric layer with a mineral or an organic grain for its nucleus. Normal oolites possess two or more concentric layers.

Oolites are the dominant allochem in the thin sections studied for this thesis. The percentage of superficial and normal oolites and the total oolite percent of each thin section are listed in Table VII. In order to classify and name the lithologies of the thin sections according to Folk's (1959), classification, the two types of oolites--superficial and normal--are combined in the calculation of the oolite allochem fraction. Slide 100 contains the highest percentage of oolites--74%--found within one slide. Slide 101 possesses the lowest percentage found--1%. Fifty-three of the 74 thin sections studied contain oolites; oolites are the dominant allochem in 41 thin sections. Pseudoolites are quite rare in the thin sections, and a measurable quantity can be recorded in only two thin sections (Slide 95 contains 1.7%, and Slide 100 possesses 5.7%). These two are included in the total oolite percentage, because a special column was not established in Table VII for such a rare occurrence.

Superficial oolites are present in all the oolite-bearing thin sections. The single concentric ring is uaually dark brown under convergent light, and it possesses no internal structure. The most common nucleus is a crinoidal fragment, recognizable by its pitted appearance (Plate V, B). Intraclasts, rock fragments, and various invertebrate hard parts also serve as nuclei of superficial oolites. The maximum percentage of superficial oolites--42%--occurs in Thin Section 16. The minimum percentage found in the oolite-bearing thin sections is 2% in Slide 73.

Normal oolites (associated with superficial oolites) are found in all of the oolitic thin sections studied. They are calcareous and commonly exhibit both radial and concentric structure; however oolites with only radial and with only concentric structures are also found.

A fairly wide size range exists in oolites of each individual thin section. Because oolites are three-dimensional (spherical), the placement of the thin section cut can cause an erroneous impression of sizes and shapes; therefore, no attempt was made to measure the dimensions of the oolites in the thin sections or to determine the maximum and minimum sizes. Shrode (1949), used the crystallization of sodium sulfate to free oolites from their cement and matrix; by screening the particles he obtained, he observed that the grain size of the Ste. Genevieve oolite was between 0.25 and 0.83 of a mm.

Almost all of the normal oolites of the Ste. Genevieve Formation possess a nucleus. Some of the cores are: intraclasts, small detrital fragments, fossil debris, and occasionally small quartz grains (Plate V, F). Angular or well rounded fragments often serve as nuclei of the normal oolites of the Ste. Genevieve. The nucleus of a normal oolite is considerably smaller than that of a superficial oolite.

The rings or layers of concentric calcite surrounding the core vary in thickness. Some rings possess radial structure; others do not. The rings are obvious when there is a difference in thickness, color, opacity, or structure. Normal oolites which have an angular core generally contain from three to six layers. The greatest number of rings observed in the slides was nine. The variety with a rounded nucleus usually possesses from three to five rings; as many as seven, however, have been recorded in those pertinent to this thesis. Normal oolites within the same thin section show a constancy in oolite size and nucleus size, and also in the number of concentric rings.

The highest percentage of normal oolites in an individual thin section is 55% in Slide 100. The lowest percentage in an oolitic bearing thin section is 1% in Slide 101.

The packing of oolites varies within the individual thin sections and from one thin section to another. This is undoubtedly a primary feature of deposition but may also result from compaction after solutions have attacked and weakened the interstitial calcite cement. (Graf and Lamar, 1950, p. 2320).

Pressure on the Ste. Genevieve Formation oolites results in the interpenetration of oolites, the breaking off of the outer rings of both normal and superficial oolites, and twinning and undulose extinction in the coarse, subtranslucent calcite cement (Graf and Lamar, 1950, pp. 2331-2332). The rupturing of the outer ring of both superficial and normal oolites (an abnormal occurrence) is observable in a number of the thin sections studied for this thesis (Plate VI, A, B). Often when the outer ring is deformed and pulled away from the adjacent ring,

EXPLANATION OF PLATE V

A. Intraclast, dark brown; fine-grained calcite cementing fossil fragments, well-rounded, enclosed in sparry calcite. Slide 104, X 22.

B. Superficial oolite (center), with crinoid columnal as a center. Single coating of dark brown calcite. Slide 105, X 25.

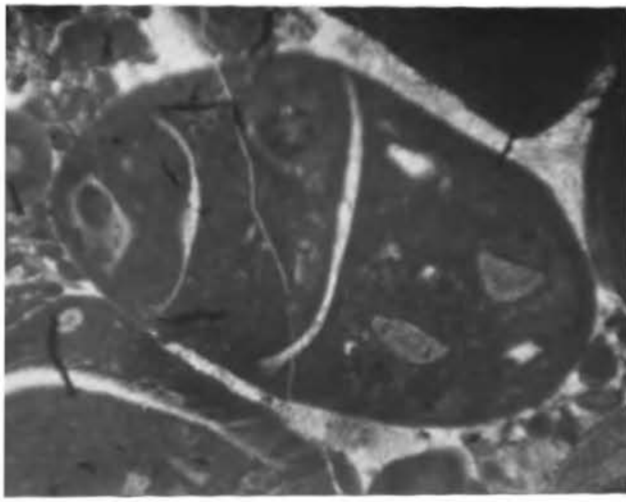
C. Normal oolite (center left), with brachiopod shell fragment as a nucleus. Cemented by sparry calcite. Slide 80, X 46.

D. Normal oolite (center), ellipsoidally shaped, showing radial-concentric structure. Cemented in sparry calcite. Slide 100, X 43.

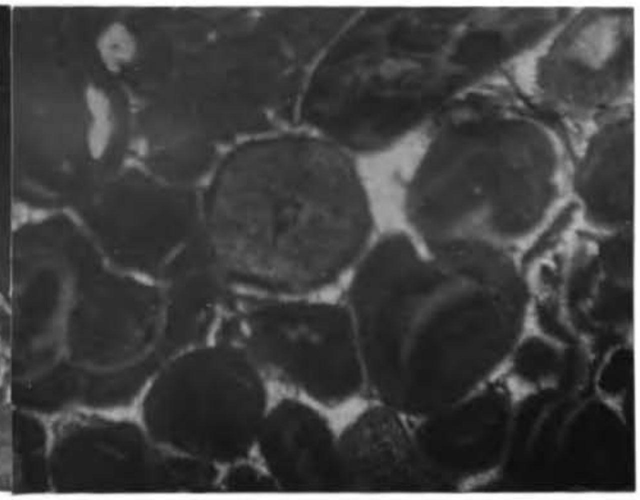
E. Normal oolite (lower center), spherically shaped, showing radial-concentric structure. Sparry calcite cement. Slide 80, X 64.

F. Normal oolite (upper right), with quartz grain nucleus. Cemented in sparry calcite. Slide 80, X 56.

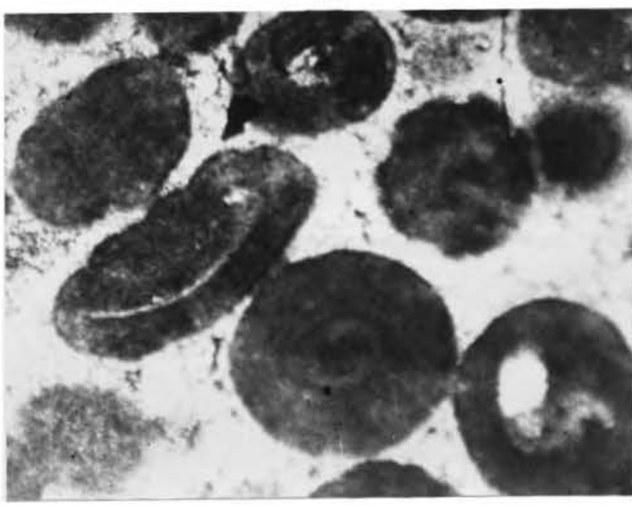
PLATE V



A



B



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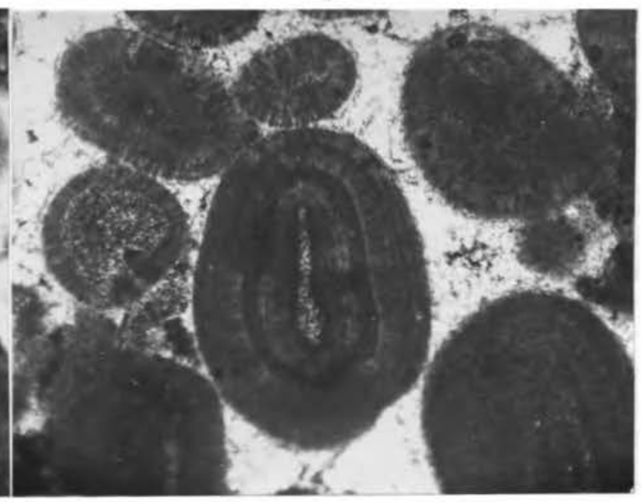
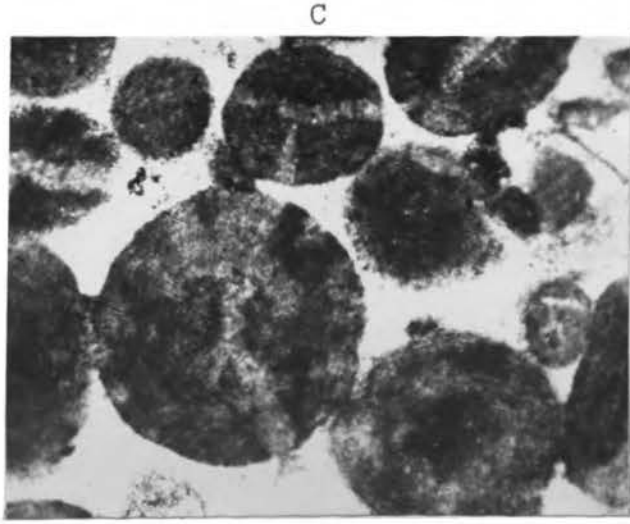
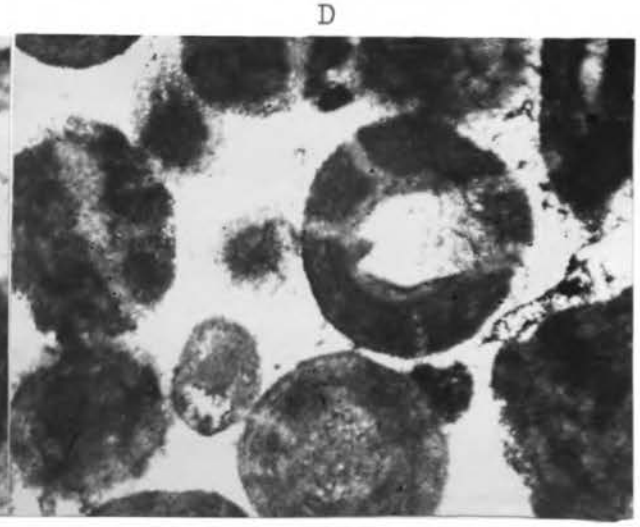


D



E



F

EXPLANATION OF PLATE VI

A. Normal oolite with detached outer ring (center), cemented in sparry calcite. Slide 96, X 46.

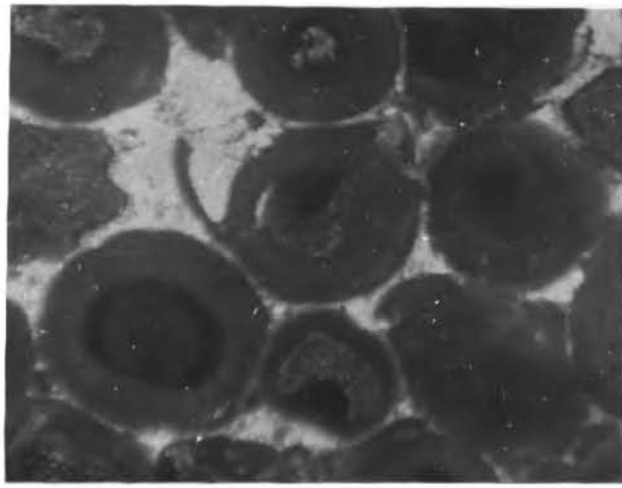
B. Normal oolite with deformed outer ring, cemented in sparry calcite. Slide 105, X 39.

C. Fracture pattern extending to adjacent oolites. White areas are spar. Slide 80, X 28.

D. Normal oolite with cerebroid margin. Cemented in sparry calcite. Slide 80, X 60.

E. Oolites transected by a thin calcite veinlet. Passage through spar is difficult to see because the two calcites are in optical unity. This is Event 7 (White Calcite C) from Graf and Lamar (1950). Slide 105, X 39.

PLATE VI



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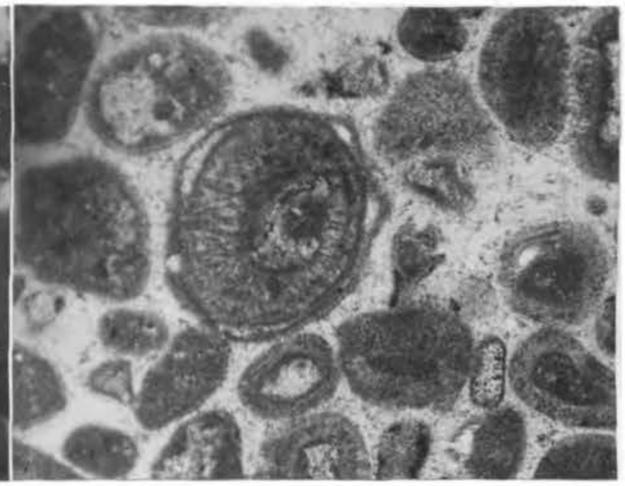

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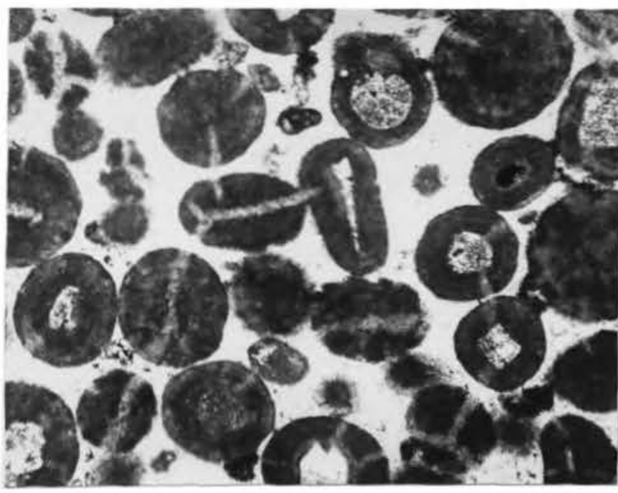

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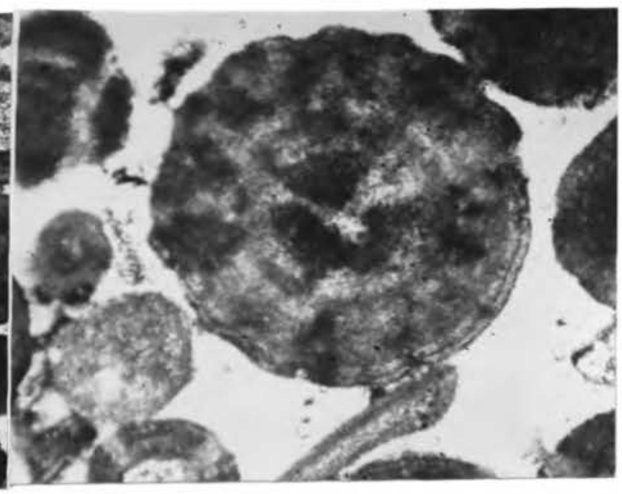

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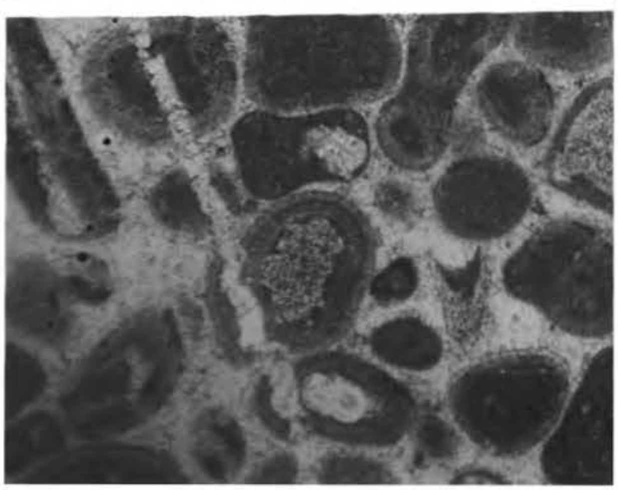


E

it remains intact. At other times a rupture occurs in the ring, and the two ends are displaced. In both types of deformation, sparry calcite invades the area between the oolite and the severed ring.

The penetration of one oolite into an adjacent oolite is also an implication of external pressures on the oolites. Only the penetrated oolite is deformed or crushed; the penetrating oolite remains whole and undamaged. This phenomenon appears in several of the slides. Graf and Lamar (1950, p. 2332), describe chains of four or more penetrated oolites; chains of more than three oolites are not observable in the slides studied for this thesis, however.

The principle binding material of the oolites studied for this thesis is sparry calcite. Only one thin section (16) has microcrystalline ooze (micrite) as the binding agent.

(3) Fossils

Folk (1959, p. 6) classifies both sedentary and transported fossils as allochemical constituents. Transported fossils fit well here because, like oolites and intraclasts, they are current sorted, broken, and abraded. Though sedentary fossils do not fit as well (they are not transported), they are presently included as allochems in order to "keep the fossils together."

The fossils studied for this thesis are almost exclusively fragmental except for some brachiopods, ostracods, gastropods, and pelecypods found in the whole state.

Crinoidal fragments are the most abundant fossil form observed in the thesis thin sections. Other forms found in the slides are: brachiopods, bryozoan, echinoderms (in addition to crinoids), ostracods, pelecypods, and gastropods (see Table VII).

The highest percent of fossils--found in Slide 84--is 36%. Slide 14 contains 40%, but this is due to a poor placement of the thin section cut and is not descriptive of the rock from which the thin section was taken. The lowest percent of fossils--2%--exists in Slide 12. Table VII lists the total percentage of fossiliferous material in each thin section.

i) Crinoids

Crinoids are the most abundant fossil in the thin sections examined for this thesis. This form is exclusively fragmental--stem segments (columnals), arm plates, and calyx plates. In thin section these fragments are readily distinguishable because of their conspicuous reticulate pattern and perforated structure (Johnson, 1949, p. 62). See Plate VII, A, B.

Small crinoidal fragments frequently become the cores of normal oolites; larger fragments, coated with a single layer of calcite, form superficial oolites.

An infinite number of shapes is exhibited by crinoidal fragments in the thesis thin sections: some (longitudinal sections of columnals) are round and possess a small opening (lumen), see plate VII, A; some are elongate, thin fragments (cross sections of columnals); and fragmental plates exist in various shapes and sizes and show several degrees of rounding (Plate VII, B).

The highest percentage of crinoids in an individual thin section (among those studied) is 18% in Slide 18. The lowest--1%--is found in Slide 16.

The thin sections were chosen to illustrate carbonate features and not particular taxonomic groups. Thus, the maximum and minimum percentages of the fossils and other particles represent those found and not necessarily the maximum or minimum of the formation.

ii) Brachiopods

Numerous brachiopods in cross section appear within the thesis thin sections. Most commonly a single valve distinguished by a convex shape (Plate VII, C), undulating margin, and laminar interior structure occurs. Several whole brachiopods are observable with the two valves closed. Sparry calcite completely fills some of these whole brachiopods; others contain small fossil debris and sometimes oolites held by sparry calcite or lime mud (Plate VII, D).

Slide 74 contains the largest amount of brachiopodal material--18%--found in the thin sections under discussion. The slightest amount, which is less than 0.5%, is found in Slide 80.

iii) Echinoids

Spines of Echinoids (both longitudinal- and cross-sections) appear in the thesis thin sections, but they are not common (Plate VIII, C). Echinoids in thin section show a great variety of detailed structural patterns in the plates and spines. Their plates are similar to crinoid plates except that echinoids display various textural patterns. The spines have an intricate, radiating interior pattern (Johnson, 1949, p. 62). The maximum amount of echinoids--6%--occurs in Thin Section 43, but this number is unusually high. Most often the abundance is only 1 to 2% per slide.

iv) Bryozoa

Bryozoa, longitudinally cut parallel to the surface of the colony appear in thin section as lacy, branching, delicate structures (Plate VIII, A). Cross-sectional cuts of this fossil resemble long strings of beads. Bryozoa are not commonly found in the thesis thin sections; when they occur it is usually in micrite instead of sparry calcite. The largest amount of bryozoa in the thesis thin sections exists in Slides 38 and 71, both of which contain 12%. (Slide 14 contains 40%, but it is not representative of the rock from which the thin section was made). The least amount--1%--occurs in Slides 7, 9, 25, and 99.

v) Ostracods

Ostracods occur in most of the fossiliferous thin sections studied. When cut cross-sectionally, ostracods appear to be thin, white to light gray bands that are quite convex; often the convexity is reversed due to the position of the thin section cut. They can be differentiated from brachiopods because they do not show the laminar structure and are usually smaller. In some cases, due to the position of the thin section cut, they appear as round or elliptical masses (resembling oolites), but unlike oolites, they are filled with sparry calcite or micrite. The maximum amount is in Slide 37, which contains 12%. The minimum amount--1%--is shown by Slides 13, 41, and 73.

vi) Other Fossils

Other fossils in the thin sections studied for this thesis include gastropods (Plate VII, E), cephalopods (Plate VII, F), and foraminifera (Plate VIII, D). These fossils are not present in

EXPLANATION OF PLATE VII

A. Broken crinoid columnal (center), dark area is lumen; notice the characteristic pitted surface. Cemented in sparry calcite. Slide 96, X 36.

B. Two crinoid fragments (center) cemented in sparry calcite. Slide 105, X 30.

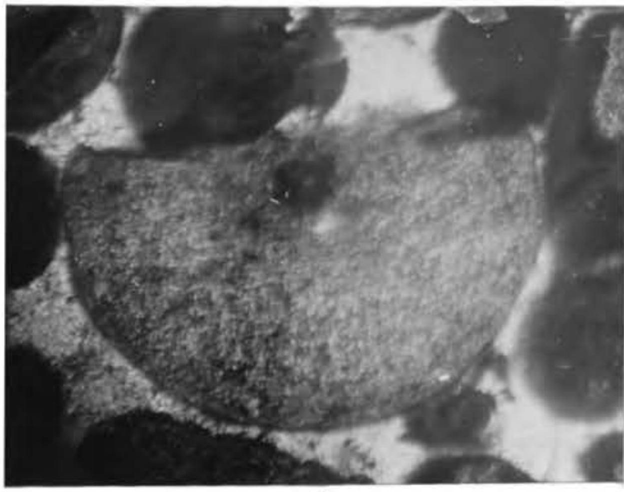
C. Brachiopod shell in micrite. Slide 40, X 28.

D. Brachiopod shell, showing both valves in closed position. Fossil and oolitic debris on the interior. Sparry calcite cement. Slide 104, X 18.

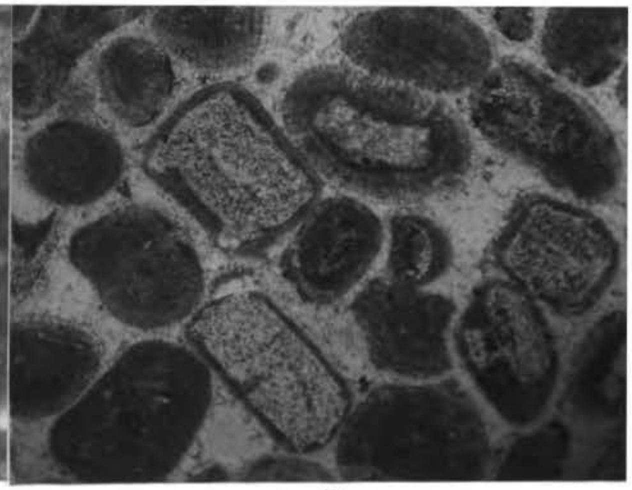
E. Gastropod cross-section (center). Slide 105, X 46.

F. Cephalopod cross-section (center). Slide 105, X 42.

PLATE VII

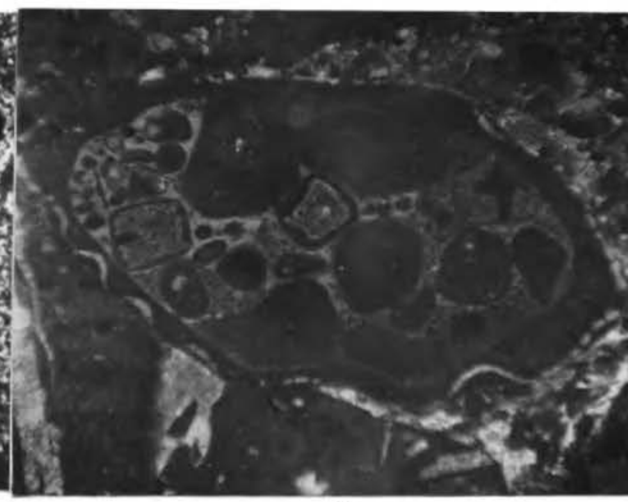


A

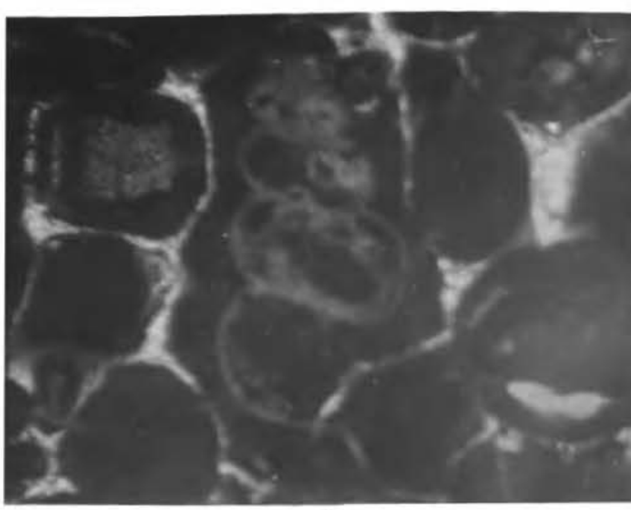


B

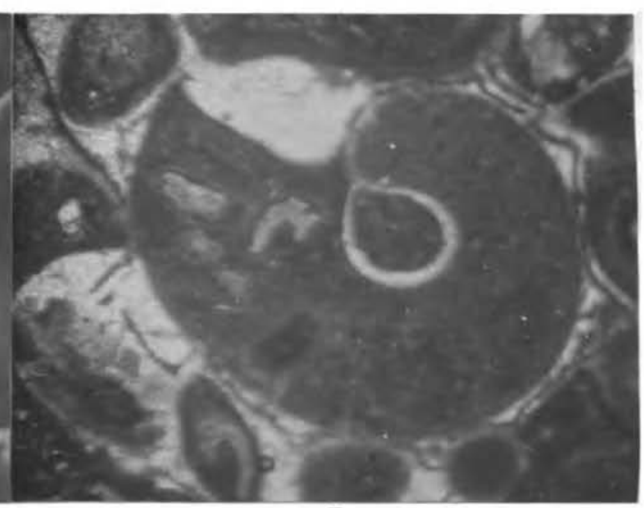
C



D



E



F

EXPLANATION OF PLATE VIII

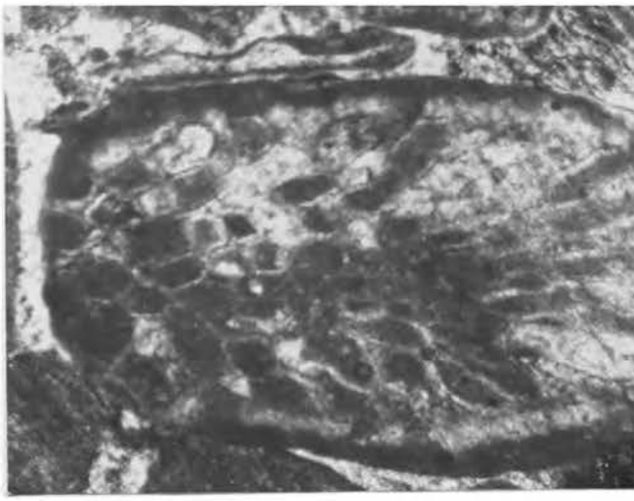
A. Bryozoa cross-section. Slide 18, X 29.

B. Bryozoa, longitudinal cut parallel to colony. Slide 14, X 23.

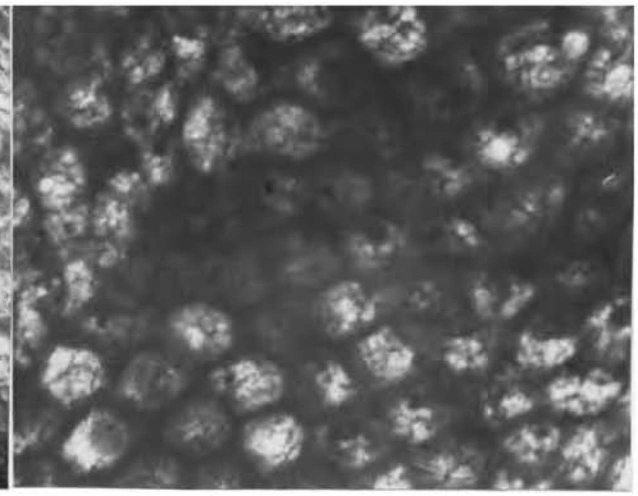
C. Echinoid spine, cemented in sparry calcite. Notice small calcite crystals encrusting oolite at left. This is the White Calcite A described by Graf and Lamar (1950).

D. Foraminifera (center), *Endothyra* (?), cemented in sparry calcite. Slide 80, X 78.

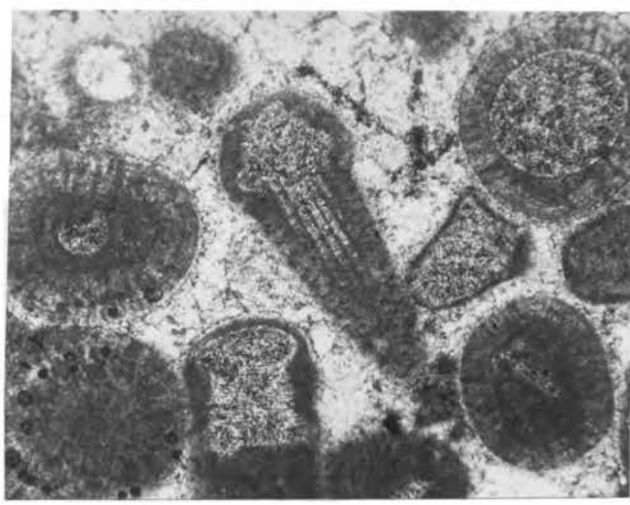
PLATE VIII



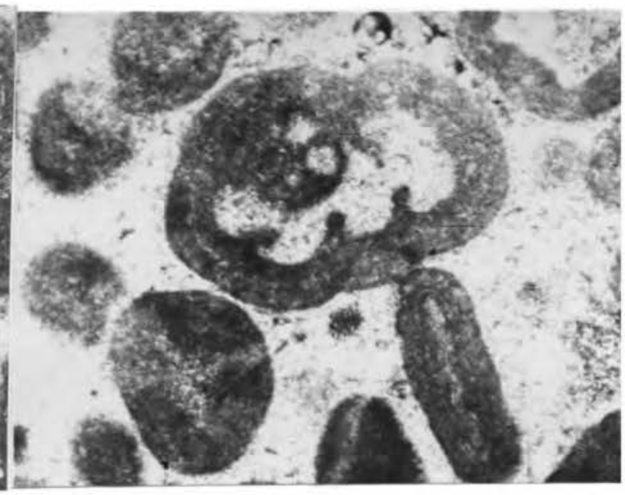
A



B



C



D

enough slides for them to warrant individual columns in Table VII, so they are included in the total percentage of fossil-allochems.

b) Orthochemical Constituents (Orthochems)

"This term includes all essentially normal precipitates formed within the basin of deposition or within the rock itself and showing little or no evidence of significant transportation" (Folk, 1959, p. 7). There are two main types of orthochemical constituents--microcrystalline ooze (micrite), see Plate IX, E, and sparry calcite cement (spar). Both of these normal precipitates are observable in the thesis thin sections.

(1) Sparry Calcite Cement (Spar)

Sparry calcite cement is crystalline calcite of transparent to subtransparent clarity. Individual crystals are 10 microns or larger. This calcite is a pore filling material in some of the thin sections under discussion; in others it is the result of the recrystallization of microcrystalline calcite. In thin section, medium to high birefringence and well-developed cleavage can easily be observed in large areas of spar. The largest amount of sparry calcite in an individual thin section (of those pertinent to this thesis) is 42% in Slide 13. The smallest amount is 2% in Slides 76 and 78.

(2) Microcrystalline Calcite Ooze (Micrite)

This type of calcite is extremely fine-grained (1 to 4 microns) and can be the sole constituent of a rock (lithographic limestone). In thin section, micrite is light brown and subtranslucent to opaque. This constituent is fairly common, but it is not a dominant element in most of the thin sections studied for this thesis. Several thin sections are dominantly micrite--Slides 47, 90, and 101. Some slides are dolomicrite (a fine-grained equivalent of micrite, in which the carbonate is dolomite or abundantly dolomitic); see Plate IX, F. Slides 85, 89, and 93 are dolomicrite. The greatest percent of micrite in the thesis slides appears in Slide 47 which is exclusively micrite. The smallest percent--less than 1%--is in Slide 99.

2. Minor Constituents

Noncarbonate minerals (present in only small quantities in the slides studied for this thesis) and dolomite (a fairly high percentage exists in several of the slides) form the minor constituents of the thin sections under discussion.

a) Noncarbonate Minerals

Several noncarbonate minerals appear in the thesis thin sections. The most important of these are pyrite, quartz, and limonite. These minerals appear in the majority of the thin sections but only in small amounts.

(1) Pyrite

Pyrite appears as small, disseminated crystals throughout the majority of the slides studied for this thesis. Under reflective light, the crystals are a typical brass-yellow color; under convergent light, they look black. The cubic crystal outline can be observed with high magnification.

Individual crystals do not occur in an ordered pattern but are disseminated throughout the sparry calcite cement; this suggests that pyrite crystallization succeeded the formation of the oolites. In one case, however, a small crystal can be seen within the core of an oolite. This crystal is larger than other pyrite crystals, which suggests that it did not have the same origin as the others.

(2) Quartz

Small crystals of quartz appear as nuclei of oolites and within intraclasts. Examples of both euhedral and anhedral crystals are observable. In Slides 103 and 105, crystalline quartz, occurring in the intrices between oolites, was secondarily enlarged and thus produced an euhedral crystal that invaded the adjacent oolites (Plate IX, A, B).

Quartz is identifiable by its clarity, crystal shape, and birefringence and parallel extinction under crossed-nicols.

(3) Limonite

Limonite is observable in Slides 4 and 32. It appears as irregular shaped, orange-yellow stains, which are confined to the interstitial sparry calcite cement. No pattern occurs in the distribution of this material.

b) Dolomite

The suspected presence of dolomite in four thin section slides was verified by staining these slides with alizarin red. The dolomite was unaffected by the stain and remained white while the calcite turned red. Slides 79, 85, 89, and 93 (from the drill-core) showed minor amounts of secondary crystallized dolomite. In Slides 85, 89, and 93 dolomite crystals were solitary and were surrounded by fine-grained calcite (micrite). Some of the crystals were rhombohedral shaped; others were irregularly shaped. No large area of dolomite mosaic was observed. In Slide 79 the dolomite also occurred in the interior of fossils and grew outward into the surrounding calcite material. None of the slides contained more than 10% of dolomite.

3. Secondary or Post-depositional Changes

The original character of a sedimentary deposit is often greatly modified by subsequent internal or external forces. The microscopic results of these forces are secondary porosity, fracture-filling, stylolites, and shrinkage cracks.

a) Porosity

Porosity in sedimentary rock may be primary (original) or secondary. Primary porosity is an inherent feature of the original deposition of the sediment. It is affected by uniformity of grain size, grain shape, method of deposition and packing of the sediment, and compaction during and after deposition (Pettijohn, 1957, pp. 85-86). Primary porosity is wholly between grains; secondary porosity, introduced later, may increase the primary porosity or remove original material. It can be recognized because it invades particle margins.

D. L. Graf and J. E. Lamar (1950, p. 2336) state that the porosity of the Fredonia Oolite (old usage) "...is the result of one or more of the following factors: variable packing during deposition; the extent to which original pores were filled by lime mud (Brown Calcite C)[4]; locally, the removal of Brown Calcite C in an early period; the degree to which deposition of interstitial White Calcite B[5] filled pre-existing

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[4]This term is discussed in section 4 of this chapter.

[5]Sparry calcite. Also discussed later in this chapter.

pores; and locally, the later solution of all forms of brown and white calcite."

Original porosity--the voids between oolites and/or other particles--which are not filled with lime mud can be identified when euhedral sparry calcite crystals coat the margin of the void, decreasing the original size but not filling it. The same procedure, however, takes place when solutions remove all traces of lime mud before sparry calcite is deposited. The author of this thesis found only this type of porosity in the thin sections which were prepared for this thesis.

Secondary pores post-date the deposition of the Fredonia Oolite (old usage). These pores cut across the lime mud and the sparry calcite, and even invade the oolites. Whether these pores are entirely secondary or are only enlargements of primary pores is not positively known. The author found no secondary porosity in the thesis thin sections. The porosity of the thin sections studied for this thesis is given in Table VII.

b) Fracture-filling

Fractures are small breaks that occur within a rock but show no movement. They provide excellent avenues for the passage of solutions and often become filled with minerals. A small fracture filled with crystalline material is called a veinlet (Plate VI, E).

In the thin sections under discussion, only veinlets of coarse crystalline calcite are observable. Usually these veinlets are only 0.3 to 0.5 mm. wide, but larger veinlets do occur; Slides 82 and 100 possess veinlets which are 1.0 mm. wide (Plate IX, D).

Two types of veinlets were observed in the thin sections pertinent to this thesis. The first type follows a straight line, bisecting all particle types (oolites, fossil fragments, etc.) in its path through the host rock. The second type bisects some particles and curves around others. The path of both types is difficult to follow through sparry calcite cement because the veinlet and the spar are in optical continuity. Two reasons which indicate that the veinlets do pass through the spar are: discontinuous sections of the veinlet lie in a straight line, and under high power, a slight color difference becomes apparent. These observations suggest that the calcite veins occurred after the rock was consolidated.

Though the original fracture does not show movement, mineral filling may force the fracture to widen. Oolites and other particles cut by the veinlet can be matched across the veinlet with little loss of material. Thus, the growth of the calcite crystals within the veinlets is limited to the fracture and does not invade the host rock.

The slides pertinent to this thesis which contain veinlets are indicated in Table VII.

c) Stylolites

Although stylolites were frequently found in the field and the drill-core, only a few thin section cuts from this material contain them. The most popular opinion concerning the origin of stylolites is that they are a pressure-solution phenomenon and were formed in the consolidated rock (Pettijohn, 1957, p.215). They are irregularly shaped with troughs and peaks, and resemble an oscillogram or a suture. In thin section they appear as irregular zones of dark brown to black material (Plate IX, C). Although most geologists believe that they are

EXPLANATION OF PLATE IX

A. Secondary euhedral enlargement of interstitial quartz crystal. Notice the invasion of adjacent oolites by this crystal. Slide 105, X 28.

B. Above, under crossed-nicols. Slide 105, X 30.

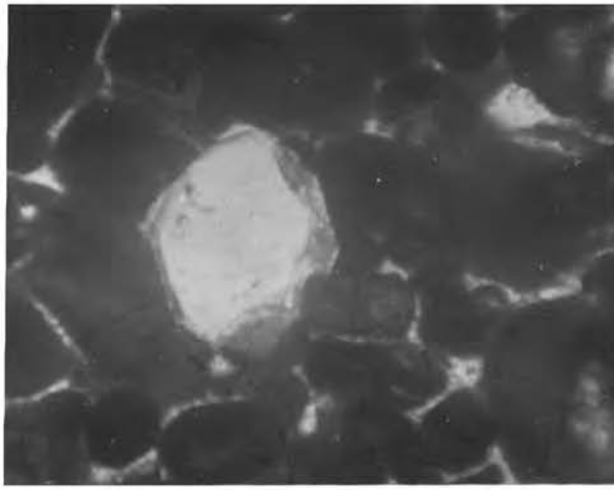
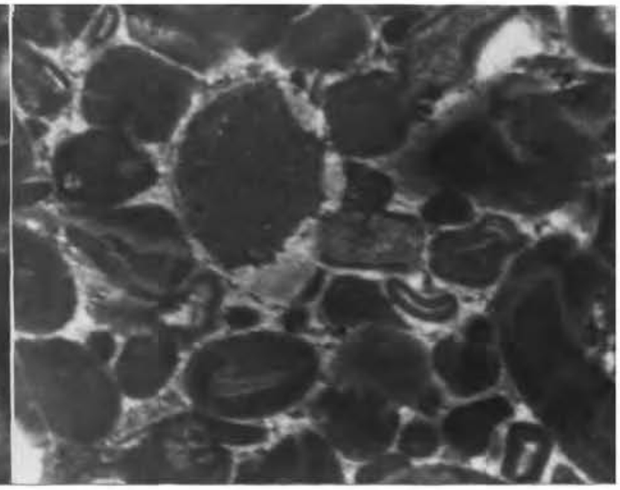
C. Stylolite seam (dark, clayey material) through oosparite. Small quartz grains can be seen in the seam. Slide 44, X 28.

D. Vein of calcite cutting through oosparite. Slide 105, X 25.

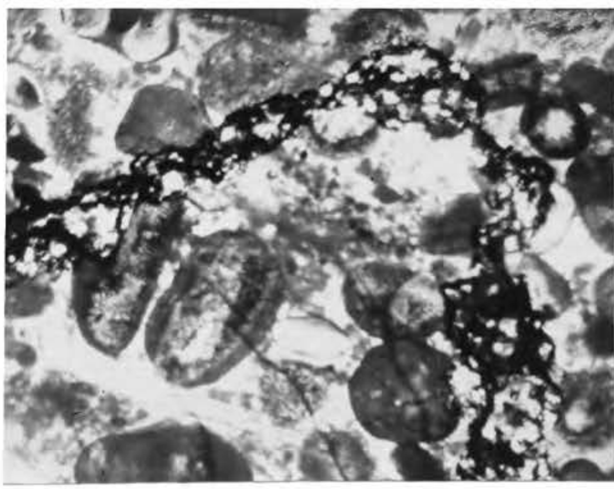
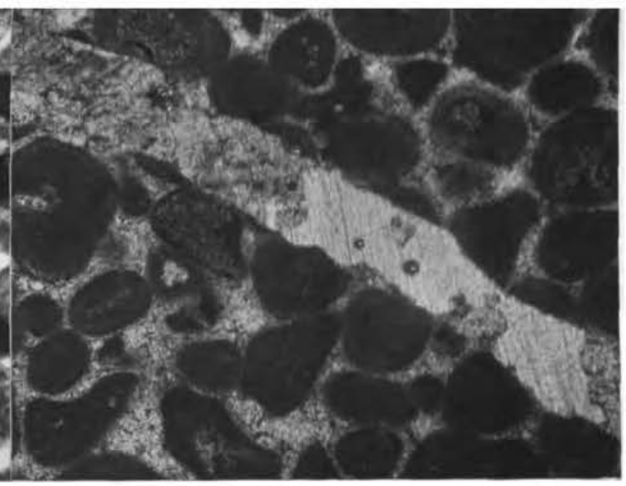
E. Micrite. Slide 40, X 57.

F. Dolomicrite, stained with alizarin red. Light areas are dolomite; dark area is fine-grained lime mud. Slide 93, X 25.

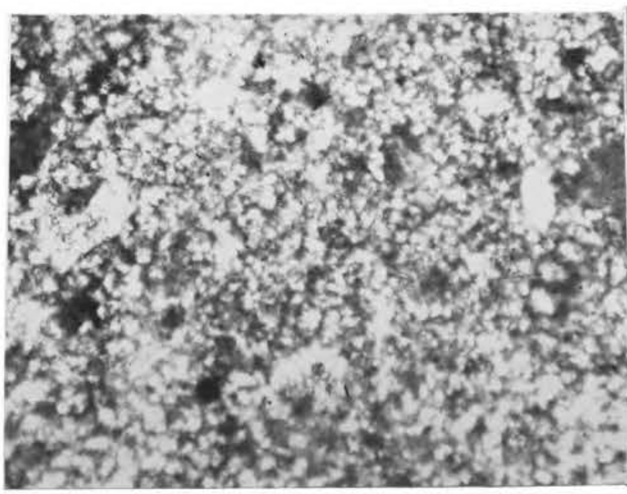
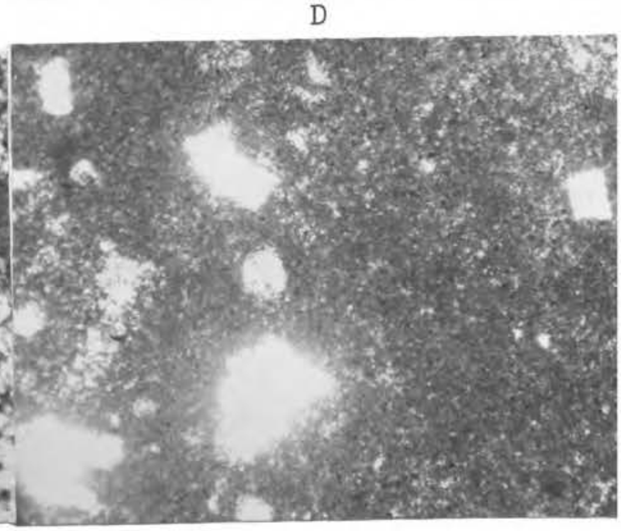
PLATE IX

A B

C D

E F

NOTES TO TABLE VII

1. Location: MPQ = Missouri Portland Cement Company Quarry
   FVQ = Fredonia Valley Quarry
   FrQ = Franklin Quarry
   TRQ = Three Rivers Quarry
   MPc = Missouri Portland Cement Company; Exploration Drill-core # 8

2. Horizon: JK = Joppa-Karnak Member
   SM = Spar Mountain Member
   FO = Fredonia Oolite Member
   SG = Ste. Genevieve (not subdivided)

3. Position in feet: d = depth from surface in drill-core
   h = height above 0.0' reference in measured section

Percentage of Major Constituents (Allochems and Orthochems):

A = Abundant
B = Common
C = Uncommon
D = Rare
E = Not observed

4. Intraclasts: A = greater than 25%, B = 12 to 25%, C = 5 to 12%, D = less than 5%

5. Superficial Oolites: A = greater than 30%, B = 20 to 30%, C = 10 to 20%, D = less than 10%

6. Normal Oolites: A = greater than 40%, B = 25 to 40%, C = 10 to 25%, D = less than 10%

7. Brachiopods: A = greater than 8%, B = 4 to 8%, C = less than 4%

8. Bryozoa: A = greater than 8%, B = 4 to 8%, C = less than 4%

9. Crinoids: A = greater than 12%, B = 6 to 12%, C = less than 6%

10. Echinoids: B = greater than 3%, C = less than 3%

11. Ostracods: A = greater than 5%, B = 3 to 5%, C = less than 3%

12. Spar: A = greater than 30%, B = 15 to 30%, C = 5 to 15%, D = less than 5%

13. Micrite: A = greater than 70%, B = 20 to 70%, C = 10 to 20%, D = less than 10%

14. Porosity: L = low, M = medium, H = high

15. Fracture-filling and stylolites: P = present, E = not present

TABLE VII SUMMARY OF PETROGRAPHIC STUDY

Thin section or Slide number	Location[1]	Horizon[2]	Position[3]	Allochems										Orthochems	
					Oolites			Fossils							
				Intraclasts[4]	Superficial[5]	Normal[6]	Total %	Brachiopod[7]	Bryozoan[8]	Crinoid[9]	Echinoid[10]	Ostracod[11]	Total %	Spar[12]	Micrite[13]
3	MPQ	JK	42.5h	E	E	E	--	E	E	E	E	E	--	D	A
4	"	"	36.5h	C	B	C	41	C	A	C	E	B	27	B	E
5	"	"	35.6h	B	B	C	44	C	E	C	E	B	11	B	D
6	"	"	24.5h	D	A	C	55	C	E	B	C	C	15	B	D
7	"	"	10.7h	E	E	E	--	C	C	C	E	C	10	D	A
8	"	"	9.5h	C	D	C	12	B	E	A	E	B	30	A	D
9	FVQ	SG	1.6h	C	A	C	52	B	C	C	E	C	4	A	E
10	"	"	16.1h	B	B	D	36	C	B	B	C	C	21	B	E
11	"	"	18.7h	C	B	D	30	B	B	B	B	B	30	B	E
12	"	"	22.2h	C	E	E	--	E	E	C	E	E	2	D	A
13	"	"	22.4h	C	C	C	38	E	E	C	E	C	6	A	D
14	"	"	25.1h	E	E	E	--	E	A	E	E	E	40	B	B
15	"	"	39.3h	D	D	C	20	A	B	B	E	A	30	A	C
16	"	"	87.9h	E	A	B	72	E	E	C	E	C	3	B	B
17	"	"	89.0h	C	B	B	55	E	E	E	E	A	11	A	E
18	"	"	90.0h	D	B	D	35	C	C	A	E	C	26	A	D
19	FrQ	FO	3.9h	C	D	A	52	C	B	A	E	C	21	B	D
20	"	"	13.7h	C	C	B	49	C	C	C	E	B	17	B	D
21	"	"	15.5h	C	E	E	53	C	C	C	E	C	10	A	E
22	"	JK	21.1h	E	E	E	--	E	E	E	E	E	--	E	A
23	"	"	23.3h	E	E	E	--	E	E	E	E	E	--	E	A
24	"	"	41.9h	C	D	C	20	C	C	B	C	A	30	A	E
25	"	"	42.8h	B	C	B	42	C	C	C	E	A	10	A	E
32	FVQ	SG	66.7h	B	A	C	55	C	E	C	E	B	10	B	D
33	TRQ	FO	2.7h	E	E	E	--	E	E	E	E	E	--	D	A
34	"	"	4.8h	C	A	C	57	C	E	C	E	C	4	B	E
35	"	"	5.4h	C	B	B	55	E	B	E	E	A	5	B	E
36	"	"	6.1h	C	C	C	30	C	A	B	B	A	25	B	C
37	"	"	8.2h	A	D	C	20	C	C	B	B	A	30	B	D
38	"	"	9.3h	B	D	B	33	C	A	C	E	A	25	B	E
39	"	"	15.4h	B	D	C	30	A	C	C	C	A	30	B	D
40	"	"	20.6h	E	E	E	--	E	E	C	E	C	4	D	A
41	"	"	25.6h	E	E	E	--	C	A	B	E	C	17	B	B
42	"	JK	40.9h	D	E	D	5	B	B	A	E	A	45	B	B
43	"	"	44.5h	B	D	C	29	C	E	E	B	A	20	B	B
44	"	"	48.4h	D	B	B	52	C	E	C	E	A	6	B	C
45	"	"	49.5h	E	E	E	--	E	E	C	C	E	3	D	A
46	"	"	56.5h	B	C	C	25	E	C	C	C	A	15	A	D
47	"	L	75.8h	E	E	E	--	E	E	E	E	E	--	E	A
48	"	"	79.4h	C	C	B	40	A	C	B	C	B	30	B	E
71	MPc	JK	147.6d	C	C	C	30	B	A	B	C	A	25	B	D
72	"	"	162.8d	C	B	C	30	A	C	B	E	C	30	B	C
73	"	"	171.1d	E	D	D	8	C	E	C	E	C	9	C	A

Name according to R. L. Folk's classification of carbonate rocks (1959)[14]	Porosity	Fracture-filling[15]	Stylolites[15]	Other observations	Thin section or Slide number
micrite	L	P	E		3
oosparite	M	E	P	hematite stains	4
oosparite	M	P	E		5
oosparite	L	P	E		6
fossiliferous-dismicrite	L	E	E	interlaminated	7
biosparite	L	E	E		8
oosparite	H	E	E		9
oosparite	L	E	E		10
bio-oosparite	L	E	E		11
dismicrite	L	P	P		12
oosparite	L	P	E		13
bryozoan-biosparite	L	E	E		14
biosparite	L	E	E		15
oomicrite	M	E	E		16
oosparite	H	E	E		17
bio-oosparite	L	E	E		18
oosparite	L	E	E		19
oosparite	L	P	E		20
oosparite	L	P	P		21
micrite	L	E	E	sandy	22
dismicrite	L	E	E	sandy	23
biosparite	L	E	E		24
oosparite	L	E	E		25
oosparite	M	E	E	hematite stains	32
micrite	L	E	E		33
oosparite	M	E	E		34
oosparite	L	E	E		35
oosparite	L	E	E		36
biosparite	L	P	E		37
oosparite	L	E	E		38
oosparite	H	E	P		39
fossiliferous-micrite	L	E	E		40
bryozoan-biomicrite	L	E	P		41
biomicrite	L	E	E		42
oomicrite	L	E	E		43
oosparite	L	E	P		44
laminated-biomicrite	L	E	E		45
oosparite	L	E	P		46
micrite	L	E	E		47
oosparite	L	E	E		48
bio-oosparite	L	E	E		71
oosparite	L	P	E		72
dismicrite	L	E	E		73

TABLE VII (cont.)

Thin section or Slide number	Location[1]	Horizon[2]	Position[3]	Allochems										Orthochems	
				Intraclasts[4]	Oolites			Fossils						Spar[12]	Micrite[13]
					Superficial[5]	Normal[6]	Total %	Brachiopod[7]	Bryozoan[8]	Crinoid[9]	Echinoid[10]	Ostracod[11]	Total %		
74	MPc	JK	175.4d	C	D	C	20	A	C	C	C	C	30	A	C
75	"	"	177.0d	E	E	E	--	A	E	E	E	E	15	C	A
76	"	"	180.5d	E	E	E	--	C	E	E	E	E	7	D	A
77	"	"	183.1d	C	D	D	8	B	A	B	E	B	30	A	D
78	"	"	185.8d	E	E	E	--	C	C	E	E	E	7	D	A
79	"	"	194.8d	C	C	C	30	B	C	C	E	B	17	C	B
80	"	"	197.7d	D	C	A	60	C	C	C	E	E	2	A	E
81	"	FO	203.6d	C	D	C	15	C	C	B	E	A	30	A	B
82	"	"	213.1d	C	C	C	28	B	C	A	C	A	32	B	C
83	"	"	221.7d	B	C	B	52	C	E	C	E	C	3	B	E
84	"	"	227.7d	B	C	C	27	A	C	B	C	A	36	B	C
85	"	"	235.8d	E	E	E	--	E	E	C	E	E	3	D	A
86	"	"	236.9d	C	B	B	55	C	E	A	E	E	15	B	E
87	"	"	240.4d	E	E	E	--	C	E	C	E	E	5	C	A
88	"	"	247.3d	C	B	B	46	C	C	B	E	C	15	B	D
89	"	"	250.5d	E	E	E	--	E	E	E	E	E	--	E	A
90	"	"	251.3d	E	E	E	--	E	E	E	E	E	--	E	A
91	"	"	253.5d	E	E	E	--	E	E	E	E	E	--	E	A
92	"	"	258.8d	C	C	D	25	B	C	A	E	A	25	A	D
93	"	"	259.7d	E	E	E	--	E	E	E	E	E	--	E	A
94	"	"	261.5d	C	C	B	50	C	E	C	C	E	6	A	E
95	"	"	271.1d	C	B	A	70	C	E	C	E	E	3	B	E
96	"	"	271.5d	B	B	D	31	C	B	B	C	B	20	B	D
97	"	"	279.7d	B	B	C	52	C	E	C	E	E	5	B	E
98	"	"	283.6d	B	A	C	48	C	E	C	C	C	10	B	E
99	"	"	289.6d	B	C	A	57	C	E	C	C	E	6	B	D
100	"	"	291.6d	C	C	A	74	C	E	A	E	E	3	C	D
101	"	"	300.4d	E	E	D	1	E	E	E	E	E	--	E	A
103	"	"	314.3d	A	B	C	38	C	E	C	E	C	9	B	E
104	"	"	319.6d	A	E	D	3	A	E	E	E	E	10	A	B
105	"	"	320.4d	B	B	C	50	C	C	C	C	B	16	B	E

Name according to R. L. Folk's classification of carbonate rocks (1959)	Porosity[14]	Fracture-filling[15]	Stylolites[15]	Other observations	Thin section or Slide number
biosparite	L	P	E		74
fossiliferous-dismicrite	L	P	E		75
intra-pelmicrite	L	E	E		76
biosparite	L	P	E		77
biomicrite	L	E	E		78
bio-dolomicrite	L	P	E	dolomite	79
oosparite	M	E	E		80
biosparite	L	P	E		81
oosparite	L	P	E		82
oosparite	L	P	E		83
bio-oosparite	L	P	E		84
dolomicrite	L	E	E	dolomite	85
oosparite	L	E	E		86
fossiliferous-micrite	L	E	E		87
oosparite	L	P	E		88
dolomicrite	L	E	E	dolomite	89
micrite	L	P	E		90
dismicrite	L	E	E		91
bio-oosparite	L	P	E		92
dolomicrite	L	E	E	dolomite	93
oosparite	M	E	P		94
oosparite	M	E	E		95
oosparite	H	P	E		96
oosparite	H	E	E		97
oosparite	L	P	E		98
oosparite	M	P	E		99
oosparite	L	P	E		100
micrite	L	P	E		101
oolitic-intrasparite	H	P	E		103
intrasparite	M	P	E		104
oosparite	M	P	E		105

composed mostly of clay, Park (1962, p. 217), believes that the Fredonia Oolite stylolites are bituminous material and associated submicroscopic quartz with coarse calcite in the crests and valleys.

The thin sections under discussion often possess small quartz and pyrite crystals along the margins of stylolites; oolites, fragments, and etc. are truncated by the stylolite seam.

Park (1962) throughly describes the stylolites occurring in the Fredonia Oolite Member (old usage). Table VII indicates the thin sections containing stylolitic material.

4. Historical Events of the Ste. Genevieve Formation

D. L. Graf and J. E. Lamar (1950) studied nineteen thin sections from quarry samples and drill-cores taken from widely dispersed locations in southern Illinois in order to develop a sequence of historical events for the Fredonia Oolite Member (old usage). This sequence is summarized in Table VIII.

These authors describe two major types of calcite--brown and white--that can be seen in thin sections of the Fredonia Oolite (old usage). Brown calcite makes up the oolites, and the white calcite occurs in the interstices. Each type has three varieties--designated by the letters A, B, and C.

Brown Calcite A:	Detrital calcite (fossil debris and rock fragments) which form the oolite cores.
Brown Calcite B:	Concentric-radial deposits around the oolite cores.
Brown Calcite C:	Interstitial, fine-grained, lime mud cementing together oolites and other debris.
White Calcite A:	A thin layer of fine- to medium-sized crystals encrusting earlier brown calcites.
White Calcite B:	Coarsely crystalline interstitial cement.
White Calcite C:	Late calcite veinlets cutting all previous structures.

(Graf and Lamar, 1950, p. 2320)

TABLE VIII[6]

Outline of Major Events in Composite History of Fredonia Limestone

Brown calcite deposition	Event 1. FORMATION OF OOLITES. Brown Calcite B deposited around cores of Brown Calcite A and detrital quartz grains
	Event 2. CEMENTATION of oolites and detrital grains by Brown Calcite C
	Event 3. GROWTH OF SMALL EUHEDRAL TO SUBHEDRAL QUARTZ CRYSTALS cutting all earlier structures. Probable enlargement of detrital quartz grains
	Event 4. SOLUTION of interstitial Brown Calcite C, possibly weakening the limestone and causing closer packing of oolites
White calcite deposition	Event 5. DEPOSITION OF WHITE CALCITE A as a thin coating around oolites; possibly a preliminary phase of Event 6; slight deformation may have occurred
	Event 6. MAJOR WHITE CALCITE DEPOSITION, White Calcite B
	Event 7. POSSIBLE SLIGHT DEFORMATION
	Event 8. SOLUTION of Brown Calcites A, B, and C, and White Calcites A and B

The history of the Fredonia Oolite begins with the formation of Brown Calcite B, Event 1, Table VIII. Graf and Lamar do not discuss the origin of Brown Calcite A.

Graf and Lamar include in their publication a table which lists the frequency of the historical events for each of their thin sections. For comparison with Graf and Lamar's work, the author of this thesis

[6] Reproduced (with permission from J. E. Lamar) from Graf and Lamar (1950), p. 2321.

compiled a similar table using the thesis thin sections to determine if stratigraphic sequence has any effect upon the frequency of occurrence of the events.

Though the work by Graf and Lamar is very thorough, it could not be applied in its entirety to the thesis thin sections because of these prominent differences: quartz deposition (Event 3) is only rarely observable, but secondary enlargement of interstitial quartz is found in several slides; remnants of the solution of Brown Calcite C exist only as coatings on debris; deposition of White Calcite A (Event 5) is observable in only a few slides; spar, recrystallized from lime mud, appears in some slides instead of the second generation cementation of spar; no effects of the deformation of White Calcite B (Event 7--twinning and undulose extinction) are observable, but numerous veinlets of White Calcite C are present; and late solution does not appear in any of the slides. An event which probably occurred late in the history of the formation was the development of small cracks radiating from the centers of some oolites and joining adjacent oolites (see Plate VI, C). This feature is quite common in the lower Ste. Genevieve. Some of the thesis slides are totally micrite (lime mud), and others have been dolomitized. Graf and Lamar do not include either of these rock types, therefore no comparison of these features can be made.

Slides 21, 44, 72, and 105 illustrate all of the events proposed by Graf and Lamar except the deformation of White Calcite B; Event 7 in these slides is shown by the deposition of White Calcite C.

Thus it would not be feasible to use Graf and Lamar's sequence of events for stratigraphic work because of these local irregularities:

the local abundance of lime mud, prominent dolomite zones, and various periods of solution.

B. Megascopic Features

Megascopic features observable in the drill-core and in exposures of the Ste. Genevieve Formation (in the four quarries studied) are bedding, intercalations, grading, and fossils. These features are included in the geomorphic columnar sections and measured sections of each quarry (Chapter III) and in the Appendix. Other sedimentary features, which merit brief discussion, are veins, stylolites, and cross-bedding. Additional minerals found in the megascopic study of the drill-core but not apparent in the thin sections are: minor amounts of chalcopyrite, fluorite, chert (nodules), and hydrocarbons.

1. Fracture-filling (Veins)

Many large veins of calcite can be seen cutting vertically through beds of the Ste. Genevieve Formation in the quarries studied. In Three Rivers Quarry, especially wide crystalline calcite veins--one to two inches thick--are in sharp contact with the host rock. Some of these veins consist of euhedral crystals as much as one inch in length. The host rock weathers more rapidly than the veins, thus leaving the veins elevated. When freshly exposed, these veins are colorless to white; they brown with weathering.

2. Stylolites

Stylolites are common in the Ste. Genevieve Formation. They range in size from very small (1.0 mm. or less) to very large; a stylolite seam in the Fredonia Valley Quarry has an amplitude of 30 cm.

Usually stylolitic seams parallel the bedding, but small seams which parallel cross-bedding exist. Stylolites can ordinarily be traced for many feet before they disappear, split, or become truncated.

The seams are typically less than 1.0 mm. thick, and are composed of clayey appearing material. Park (1962) believes that this material is bituminous; but the author of this thesis, after testing for organic material, believes the material in the seams is clay.

3. Cross-bedding

"Cross-bedding is true bedding that resulted from interrupted or variable sedimentary deposition on inclined surfaces," (Weller, 1960, p. 103). This feature rarely occurs in limestones except those which are abundantly oolitic or fragmentally fossiliferous. The Ste. Genevieve Formation fits this description, and contains cross-bedding produced by current action on oolites.

Cross-bedding is observable in the drill-core and in all of the quarries except for Three Rivers Quarry. The geomorphic columnar sections indicate the stratigraphic location of cross-bedding in the quarries studied (Chapter III).

CHAPTER VI

ENVIRONMENT OF DEPOSITION OF THE STE. GENEVIEVE FORMATION

The Ste. Genevieve Formation in the thesis area is predominantly an oolitic, fragmental-fossiliferous limestone. The drill-core contains the only complete section of the Ste. Genevieve Formation described in this thesis, and it is 178.6 feet thick. Six different Ste. Genevieve lithologies are observable in the drill-core: oolitic, fragmental-fossiliferous limestone (135.8 feet); sandy, oolitic limestone (2.1 feet); fine- to medium-grained limestone (30.7 feet); shaly limestone 0.4 feet); dolomitic limestone (3.1 feet); and dolomite (8.6 feet). Thus the major portion (77.2% of the total thickness) of the Ste. Genevieve in the thesis area is an oolitic, fragmental-fossiliferous limestone. This suggests that the environment was either suitable for the formation of oolites or was a deposition site for transported oolites; the other lithologies represent brief interruptions in the deposition, or changes in local conditions, or are caused by external influences.

There has been much debate about the formation of oolites. Twenhofel (1950, p. 632) states that, "although it is possible that the calcium carbonate of some oolites was precipitated from materials in colloidal form, the actual formation where it has been observed shows that oolites of concentric structure with radiate structure in the laminae may form from precipitation of materials in solution." In the past it was believed that algae played an important role in the formation of oolites; this hypothesis is no longer valid because it is now known that oolitization is an inorganic process. Minute algae can coat oolites (just as they coat other objects), but this material can only be indirectly responsible for oolite formation (Twenhofel, 1950; Weller, 1960).

Oolites usually form in a shallow water, marine environment--in slightly saline water saturated with calcium carbonate. The water must be turbulent and keep them in more or less constant motion to promote continued and uniform growth. The size of an oolite is limited by the lifting power of normal waves in shallow water. When an oolite reaches its maximum size, it remains motionless on the ocean bottom and growth ceases (Weller, 1960, p. 127).

Oolitic deposits commonly show characteristic features of strongly agitated, shallow waters--cross-bedding, uniformity of oolite size, and association with quartz sand grains. Pettijohn (1957, p. 402), also includes the presence of clear crystalline carbonate cement and the absence of fine-grained interstitial carbonate mud as features of an oolitic environment in agitated shallow waters, but he believes the crystalline calcite may be due to the recrystallization of the lime mud.

According to Shrode (1949), the formation of the Ste. Genevieve oolites took place elsewhere (not far from the site of deposition) under conditions which controlled the maximum and minimum oolite size. The oolites were transported to their site of deposition by relatively strong currents or waves. That writer bases his hypothesis on these facts: the bedding characteristics suggest a clastic origin, the particle size indicates a sedimentation condition more selective than that under which a medium- and coarse-grained sand would be deposited, and a high degree of sorting was attained by the transporting agent.

Shrode's theory is also substantiated by the fact that fragmental fossils, usually showing some degree of transportation, are almost always associated with the Ste. Genevieve oolites.

Although Pettijohn believes that interstitial clear calcite results from the recrystallization of lime mud, Graf and Lamar believe that the clear calcite cement of the Ste. Genevieve Formation is a second-generation cement.

Most of the organic material in the thesis thin sections is rounded debris, and the particles (oolites, fossil fragments, etc.) are cross-bedded, thus indicating transportation to the site of deposition. But minor oolitization must have occurred at the site of deposition because these rounded fossil fragments form the cores of superficial oolites. The single coatings are dark brown, and are similar in all of the oolites of this type. According to Graf and Lamar (1950), oolites are cemented by a dark brown lime mud (Brown Calcite C) until solution attacks the deposit and removes most of this interstitial material, making way for a second generation cement (sparry calcite). It is difficult to understand the mechanism of such solution work because if the oolites, fossil fragments, etc. were first cemented by lime mud, more evidence should be present. Also, only fossil fragments and other debris possess this outer coating; it does not surround the oolites. Thus, this author believes that minor oolitization of the smaller transported material occurred at the site of deposition.

The deposition of oolites was frequently interrupted for brief periods, and calcareous shales, arenaceous limestones, and nonoolitic limestones were deposited. The fluctuating shoreline (discussed later) may have caused these intervening depositions. The obvious difference in the maximum oolite size--apparent from bed to bed--indicates that environmental changes took place where the oolites were forming. Whenever the wave action subsided, there was no cross-bedding.

Although organic material is usually fragmental and rounded to well-rounded, whole forms do exist, e. g., brachiopods, ostracods, foraminifera, gastropods, pelecypods, and bryozoa. These forms are not numerous; this suggests that the organic activity was low in this area. The crinoid is the most common form of the fragmental fossil material. Plates from the arms and calyx and columnals are quite commonly found in thin section.

Diagenetic and post-diagenetic changes due to solution work were observed in the Ste. Genevieve Formation. Stylolite seams, frequently seen in exposures, indicate an indeterminable amount of thickness decrease; oolites and other particles are truncated at the stylolite margin and cannot be matched on the other side of the seam. Solution action on the interstitial material undoubtedly caused packing of the oolites and decreased the thickness of the formation.

Other post-depositional changes are dolomitization and fracture-filling. Dolomite is present in two distinct layers in the drill-core from Cave in Rock, Illinois and in Cave in Rock and Franklin Quarrys. These layers are present throughout the Cave in Rock area, in all of the exploratory drill-cores, and to the northeast in the Rigsby-Barnard Quarry. The thickness of the layers is not constant but varies from place to place.

HISTORICAL GEOLOGY

The regional geologic setting of late Meramecan (Genevievian) and Chesterian times has been described by S. Weller (1920), Moore (1933), J. M. Weller (1940), and Swann (1963).

According to Swann (1963, pp. 11-17), the late Meramecan (Genevievian) and Chesterian divisions of the Mississippian Period consisted of a broad embayment of an interior sea which extended from the south and covered three-fifths of Illinois. A structural low (the Illinois Basin) was subsiding at this time, and two high areas (the Ozark Dome and Cincinnati Arch) were shoal areas on the west and east beneath the level of the embayment. The Michigan River entered the embayment as a bird-foot delta, and stayed within the confines of the Illinois Basin (not a part of the embayment) as it moved laterally--northwest to southeast--over a distance of 200 miles. As the river moved laterally, the shoreline transgressed and regressed (northeast-southwest) 600 to 1000 miles. The delta caused the shoreline of the embayment to be convex. When sedimentation of the Ste. Genevieve Formation began, the shoreline was far in the northeast. Until the end of the Spar Mountain sedimentation, the deposition of the Ste. Genevieve Formation was only interrupted once by a transgression of the shoreline. Sedimentation of the Karnak and Joppa Members began with the shoreline in the regressed position; it later transgressed and finally ended with a regression.

Shoreline fluctuations (not pertinent to this thesis) during sedimentation of younger units (Rosiclare Formation through the Chester Series) are discussed in Swann (1963, p. 16).

Genevievian time began with a lowering of sea level and the alternating deposition of shallow water carbonate and alternating clastic material from the Michigan River. This clastic material (sand and mud), represented by the Spar Mountain and the Aux Vases during Genevievian time, is from the highland areas in the eastern part of the Canadian Shield, and could be from the northeastward extension of the

Appalachians rather than from the Ozark or Cincinnati shoal areas. Swann suggests that the Spar Mountain, Aux Vases, and Popcorn Sandstone units are lenses projecting from the west. The alternation of carbonate and clastic sediments continued until the close of the Mississippian Period.

Contrasting lithologies in the Cave in Rock area indicate shoreline changes. A shallow water environment with turbulent wave action existed during the accumulation of transported oolites. Fine-grained (lithographic) limestone was deposited under conditions of quiet waters. Clastic deposits--the Spar Mountain and the Aux Vases--represent periods when the shoreline was farthest to the southwest.

A lack of sandy material is evidence that the shoreline never regressed as far as the Kentucky portion of the thesis area.

CHAPTER VII

ECONOMICS

Each of the four quarries studied for this thesis supplies a particular type of rock quarry product. The Missouri Portland Cement Company, in Cave in Rock, Illinois, uses the rock material from their quarry exclusively for the manufacturing of portland cement (processing is done at Joppa, Illinois). Portland cement is defined by Lamar et al. (1956, p. 6):

> (Portland cement) is a finely pulverized material consisting of certain definite compounds of lime, alumina, and silica, which when mixed with water has the property of combining slowly with the water to form a hard solid mass.

The compounds mentioned above are obtained from limestone, shale, and clay. When relatively pure limestone is used, the raw mix consists roughly of four parts, by weight, of limestone to one part of clay or shale. Chemically the limestone portion of the raw mix should not contain magnesia in excess of 3.2%. Of the total raw mix, the silica ratio (the ratio between the amount of silica present and the total amount of iron oxide and alumina), should be roughly between 2.0 and 3.0; the alkali content (Na_2O and K_2O which, combined, should be less than 0.6%), a low sulfur content, and a low P_2O_5 content (less than 0.5%) are also important (Lamar, 1959).

"The raw materials are finely ground, blended in carefully proportioned amounts, and burned in a kiln. A clinker is formed which is finely ground with the addition of a small amount of gypsum to yield portland cement," (Lamar, 1961, p. 21).

The limestone and shale raw mix used by Missouri Portland Cement Company's cement plant at Joppa, Illinois is obtained exclusively from the Cave in Rock Quarry. After the raw mix is pulverized, ash, obtained from the Electric Energy Company, is added to create the proper silica ratio. The mixture is then burned.

The main product of Fredonia Valley Quarry is agricultural lime, which is obtained from two high-calcium limestone beds. (It is processed and packaged at the quarry site). Material not suitable for agricultural lime is crushed and used for construction materials--crushed stone, aggregate, fill, ballast, etc.

Agricultural lime is added to soils to correct acidity, improve soil structure, and to increase the calcium and magnesium content.

The products of Three Rivers Quarry are used mainly for construction purposes. Franklin Quarry is no longer active.

The Ste. Genevieve Formation is also economically important in two other major industrial fields. The formation is a host rock for bedded and vein deposits of fluorspar in the southern Illinois-western Kentucky area, and it is a reservoir rock for petroleum in the Illinois Basin. These two fields are well discussed in the literature on this area, and are not pertinent to this thesis.

CHAPTER VIII

CONCLUSION

The carbonate rocks of the Ste. Genevieve Formation were studied megascopically and microscopically within a small area of the Illinois-Kentucky fluorspar district. The megascopic study dealt with the field study of four quarries and an exploratory drill-core. The results of the quarry studies were presented in measured sections and columnar sections, and the drill-core study was presented as a detailed log in the Appendix. Correlation between the drill-core and the four quarries was difficult because no datum plane could be established, but the comparison did show the absence of the Aux Vases Sandstone in the Kentucky sections and the variations in unit thicknesses.

D. H. Swann's stratigraphic nomenclature was applied to most of the sections (the Ste. Genevieve Formation subdivisions could not be applied to the Fredonia Valley Quarry), which was the first application of this terminology to these sections.

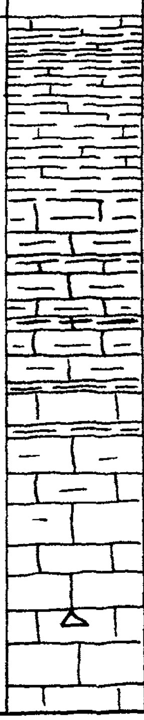
The microscopic investigation was made from seventy-four thin sections. These were classified according to R. L. Folk's classification of carbonate rocks. The most common rock types observed in thin section were oosparite, biosparite, and micrite. The environment has been interpreted as being one of turbulent action, such as strong waves or currents, because of the cross-bedded and fragmentally fossiliferous character of the sediment, however, minor oolitization did occur at the site of deposition. Several dolomite layers in the Ste. Genevieve, found at Cave in Rock Quarry and in the drill-core, indicated post-depositional dolomitization.

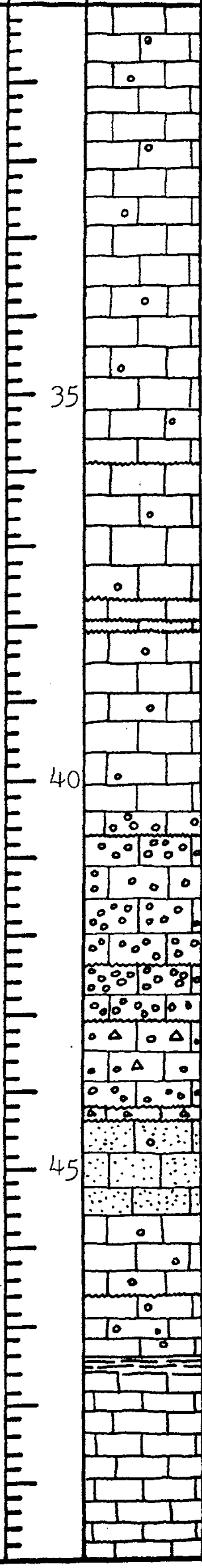
APPENDIX

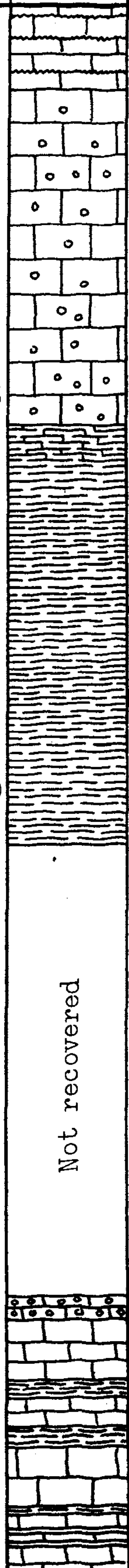
DRILL-CORE LOG

DRILL-CORE LOG

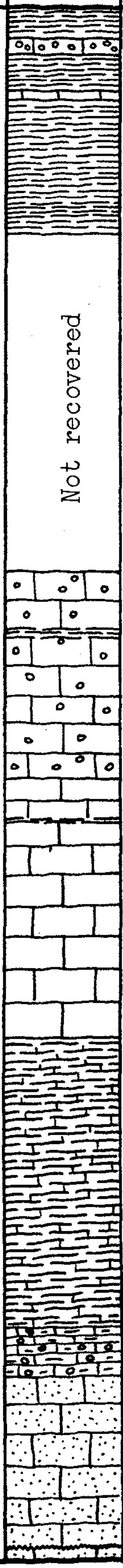
COMPANY: Missouri Portland Cement Co. QUARRY: Cave in Rock	LOCATION: MPC Drill-hole #8 SW$\frac{1}{4}$ SE$\frac{1}{4}$ SW$\frac{1}{4}$ sec 8, T.12 S., R.10 E.
ELEVATION: Top: 502' above Sea Level Bottom: 171.7' above S. L. TOTAL DEPTH: 330.3'	QUADRANGLE: Repton, Illinois-Kentucky COUNTY: Hardin STATE: Illinois
DATE DRILLED: 6-24 to 7-8, 1960 DRILLED BY: Layne-Western Co. CORE SIZE: BX (1 5/8")	LOGGED BY: J. Reinhard SCALE OF LOG: 7/16" = 1.0' FOOT SUBDIVISIONS = 0.2'

Formation	Member	Depth (Feet)	Graphic log	Thin section no.	Unit no.	Description
		22'	Not recovered			Cover (22'), soil, loess, and Bethel Sandstone residuum.
Downeys Bluff		25			1	Shale, calcareous (2.2'), medium gray (dry), dark greenish gray (wet), fossiliferous--fragments of bryozoan, crinoids, and brachiopods, small calcite crystals (up to 1 mm. scattered throughout the unit. Lithology very constant, thinly bedded, fine- to medium-grained. Effervescence medium to high. Brachiopod shells filled with crystalline calcite.
					2	Limestone (4.5'), medium light gray (dry), medium gray to light brownish gray (wet), fossiliferous--fragments of crinoids (occurring as bluish translucent calcite) and brachiopods (occurring as white streaks) and some whole brachiopods. Glauconite spot at top of unit, calcite crystals present throughout but more numerous towards the base. Thin shale partings occur at various intervals. Grain size varies downward through the unit from argillaceous at the top to medium-grained at the base.
					3	

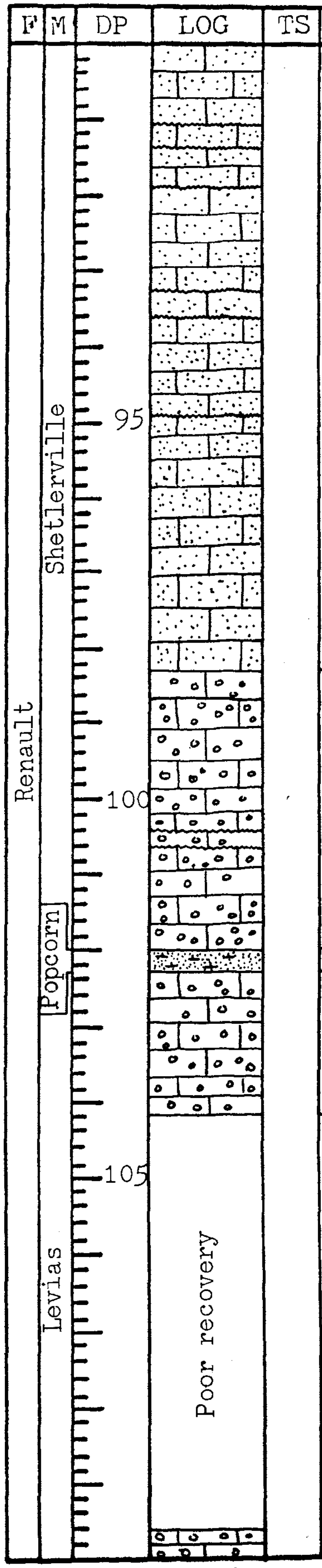
F	M	DP	LOG	TS	U	DESCRIPTION
Downeys Bluff		35 40			3	Limestone (14.35'), made up of three differing lithologic zones--upper, middle, and lower. Upper Zone (1.5'), light gray (dry), light olive gray (wet),with rare and scattered oolites, fossil debris (bluish gray) composed of fragments of crinoids and brachiopods. Near the top is an isolated chert fragment. Limestone fragments are common throughout unit, several minor stylolites are present, effervescence is medium to high. Middle Zone (9.85'), bands of coarse grained limestone alternating with bands having a fine-grained'matrix. Both bands are coarsely crystalline and contain fossil fragments--brachiopods and crinoids. Coarse-grained band is medium gray (dry), and olive gray (wet), and is quite oolitic. Fine-grained matrix bands are medium gray. Lower Zone (3.0'), medium light gray with phases of light olive gray, quite oolitic, sparsely fossiliferous (some zones entirely void of fossils). Vertical streaks of limonite are present and also are found along stylolite planes and in vugs. Effervescence medium. Numerous stylolites are present.
		45			4	Limestone (2.45'), yellowish gray in upper half, medium gray in lower half, somewhat oolitic decreasing in abundance towards the base of the unit where they are rare, fossiliferous, coarse fragments of brachiopods and crinoids in fine matrix and whole brachiopods (replaced, occurring as light blue to white streaks or filled with crystalline calcite). Chert fragments (up to 0.1' diameter in upper 0.4' of unit, sandy throughout, limonite stains in lower part, effervescence high, stylolites present throughout.
					5	



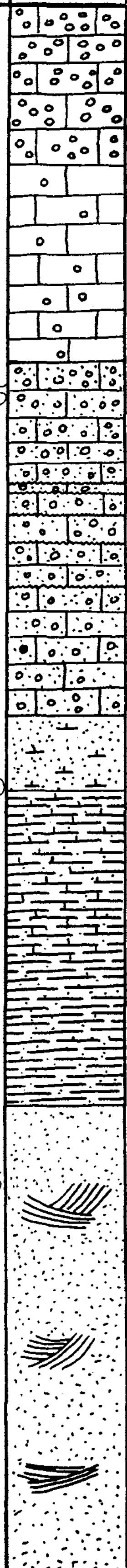
F	M	DP	LOG	TS	U	DESCRIPTION
Downeys Bluff		55			5	Limestone (7.3'), medium gray, upper and lower portions somewhat oolitic, fossil content: mostly fragments of brachiopods or whole brachiopods. Upper and lower portions medium-grained, middle portion fine-grained. Calcareous shale layer 0.3' thick in upper portion greenish gray, somewhat sandy; limonite is present at the base of the shale. Effervescence medium to high in medium-grained portion, low to medium in fine-grained portion. Stylolites present but not dominant.
Yankeetown		60			6	Shale, possibly as much as 11' (much lost in drilling), color quite variable, uppermost 0.5' medium light gray, next lower 1.2' very uniform greenish gray, next lower 1' between a pale red and grayish red, next lower 0.9' mottled grayish red and greenish gray, next lower 1.4' greenish gray with grayish red mottling, bottom 0.4' dark greenish gray. Grain size: uniformly fine. Uppermost 0.5' calcic giving rise to some effervescence whereas the remainder of the unit shows no effervescence.
		65	Not recovered		7	Limestone (3.6'), medium light gray to medium gray, uppermost 0.25' quite oolitic, rest of unit nonoölitic except for thin layer 0.2' thick in lower half; fossiliferous fragments of crinoids and brachiopods and some whole brachiopods which are concentrated in several distinct zones throughout the unit. Shale seams found at frequent intervals throughout unit. Seams are greenish gray and contain whole brachiopods. Calcite crystals present throughout the unit. Limestone portions medium to coarse-grained.



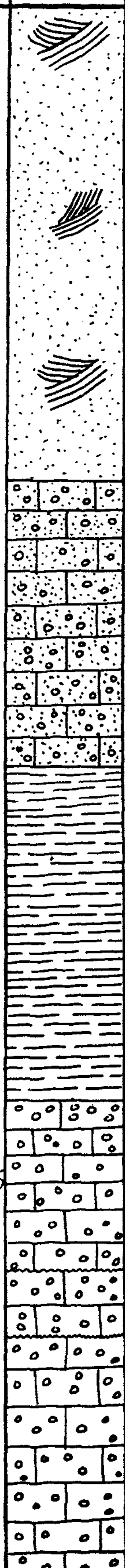
F	M	DP	LOG	TS	U	DESCRIPTION
Yankeetown		75	Not recovered		8	Shale (2.9'), greenish gray to dark greenish gray, somewhat fossiliferous with whole brachiopods and bryozoa. Grain size fine and uniform, upper half is more thinly bedded than lower half. Shale shows no effervescence. Two thin limestone layers present in upper portion. The uppermost layer is 0.2' thick; the lower one 0.1'. Only the uppermost layer is oolitic and both layers contain fragments of pre-existing limestone and fossil fragments. Effervescence is medium to high. Much material was lost during drilling, but is presumed to be shale.
Yankeetown		80			9	Limestone (5.8'), medium gray to medium dark gray, somewhat oolitic in upper half, fossil content: in upper half, only fragmental material; in lower half, white crinoid stems and whole brachiopods (usually calcite filled) plus much fragmental material. Several minor shale seams exist. Calcite crystals found throughout unit. Uppermost 0.5' very coarse; remainder of unit medium- to coarse-grained.
Yankeetown		85			10	Shale, calcareous (4.8'), medium gray to medium dark gray; fossiliferous with fragments of brachiopods and crinoids, whole brachiopods, and bryozoa. Brachiopod shells appear as white streaks when seen in cross-section; whole shells are calcite filled; very thin-bedded; medium effervescence. Bottom 0.7' is shaly limestone, very coarse-grained, and high in fragmental material; oolites are common but not dominant. Calcite crystals can be found throughout unit, especially in lower 0.7'.
Renault	Shetlerville				11	



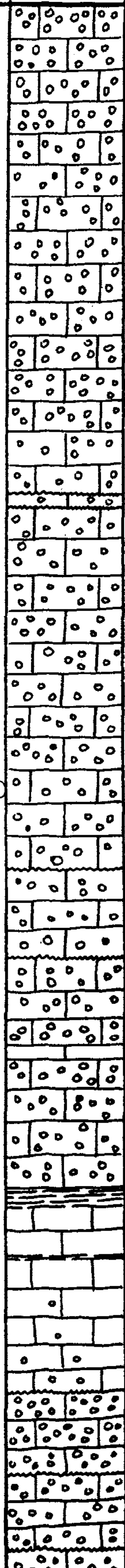
U	DESCRIPTION
11	Limestone (10.7'), medium gray (dry), olive gray to olive black (wet); fossiliferous--some whole brachiopods but mostly fragments of crinoids and brachiopods; sand grains and calcite crystals scattered throughout unit. Unit mostly medium-grained but some fine-grained phases exist; effervescence high throughout unit; many well-defined stylolites characterized by dark gray to black material, usually .25 mm thick but sometimes approaching 1 mm, and small pyrite crystals. Vertical veins of white calcite are frequent sometimes attaining a thickness of 1 mm. Fluorite and calcite crystals found in vugs.
12	Limestone (3.3'), light gray, fossiliferous--fragments of crinoids and brachiopods; quite oolitic; much fragmental limestone material, and calcite crystals very common throughout unit. Coarse-grained; effervescence medium to high. Several stylolites are present.
13	Sandstone, calcareous (0.3'), medium gray, medium-grained, medium effervescence.
14	Limestone (1.9'), medium gray to medium dark gray; oolitic; fossiliferous--crinoidal fragments and calcite crystals throughout unit. Unit is medium- to coarse-grained with medium to high effervescence and numerous small stylolites.
15	Shale and intercalated limestone, thickness possibly 5.45'. Shale is greenish gray, uniformly fine-grained with medium effervescence. Limestone is medium gray, medium- to fine-grained, with medium effervescence. Lowermost material recovered is light olive gray, denser than shale, showing no effervescence. Possibly it is dolomitic. Bedding of shale and limestone is uncertain. The core is not well-defined here because much material apparently was lost.
16	

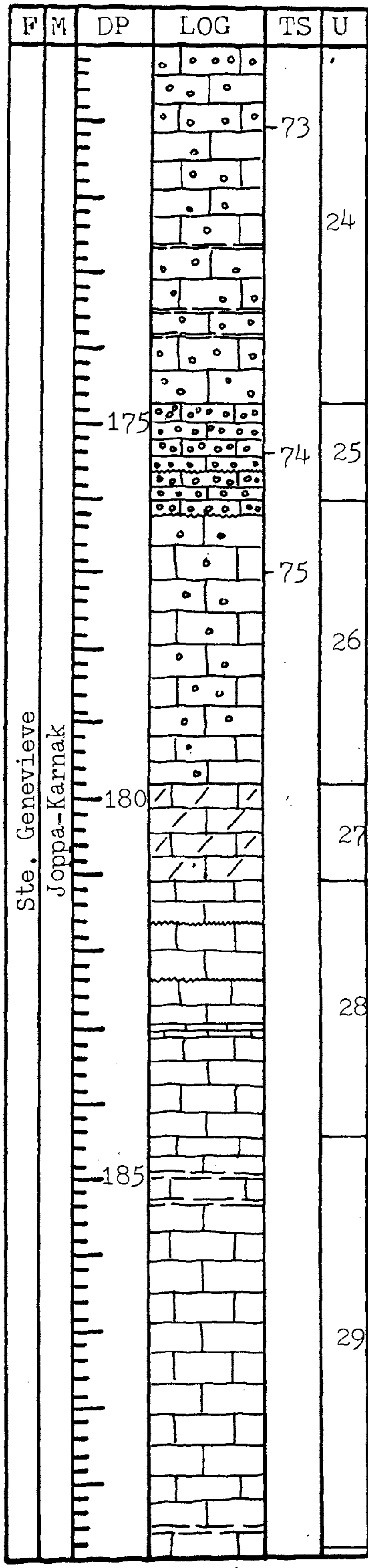


F	M	DP	TS	U	DESCRIPTION
Renault	Levias			16	Limestone (2.3'), yellowish gray, extremely oolitic, some fossil fragments, with random sand grains throughout unit. Much crystalline calcite material throughout unit. Medium-to coarse-grained, effervescence high. Several thin vertical calcite veins present.
Renault	Levias	115		17	Limestone (7.1'), light gray to light brownish gray, oolitic--especially the lower half. Lower portion somewhat sandy, fossiliferous--fragments of crinoids and brachiopods with some whole brachiopods, and calcite crystals found throughout unit. Shale partings occur at several intervals. Stylolites common in lower 3.0'. Texturally the upper portion is somewhat coarse-grained decreasing downward to medium-grained near the base. Effervescence medium to high.
Aux Vases	Rosiclare	120		18	Sandstone (0.9'), greenish gray (dry), olive gray (wet). The unit is medium-grained, effervescence is medium, and several thin vertical calcite veinlets are present.
Aux Vases	Rosiclare			19	Shale (4.0'), upper part greenish gray, with white stringers of calcite; nonfossiliferous, quite calcic showing high effervescence and fine-grained. Lower part low to medium effervescence, laminations of medium gray against greenish gray. The unit is slightly sandy throughout.
Aux Vases	Rosiclare	125		20	Sandstone (10'), light gray (dry), light olive gray (wet). Unit fairly uniform throughout with dark colored, very thin stringers or laminae at differing angles to core, suggesting cross-bedding. Grain size is medium throughout.



F	M	DP	TS	U	DESCRIPTION
Aux Vases	Rosiclare	135		20	
				21	Limestone, arenaceous (3.7'), light olive gray (dry), brownish gray (wet); somewhat oolitic; fossiliferous--fragments of crinoids and brachiopods, and quite sandy. Several thin shale partings are present.
		140		22	Shale (4.1'), greenish gray to dark greenish gray, thin bedded and laminated, noncalcareous.
Ste. Genevieve	Joppa-Karnak	145	71	23	Limestone (6'), light gray, very oolitic, fossiliferous--fragments of brachiopods and crinoids and some whole brachiopods. Unit quite uniform texturally, being medium- to fine-grained. Effervescence medium to high. Stylolites occur at several intervals. Long, thin, vertical calcite veinlets present.

F	M	DP	LOG	TS	U	DESCRIPTION
Ste. Genevieve	Joppa-Karnak	155 160		72	23a	Limestone (15'), light gray, extremely oolitic, fossiliferous--fragments of brachiopods, bryozoans, and crinoids, with some whole brachiopods. Some fragments of pre-existing limestone are present but no sand grains were observed. Grain size is medium to fine, effervescence is high, and there are numerous stylolites and vertical calcite veins which approach a thickness of 1 mm. A nonoolitic zone, 0.3' thick, exists at 163.2'.
		165			24	Limestone (9.7'), greenish gray (dry), olive gray (wet); oolites are dominant from 167.6' downward to base; they are present above this for one foot before becoming indistinguishable. Fragments of brachiopods and crinoids found throughout the unit. The uppermost 0.3' is a greenish gray shale that is fossiliferous showing no effervescence. Several thin shale seams exist at other places in the unit. Texturally, the unit varies from medium to coarse grained, being coarsest between 167.6' and 169.6'. In this zone, also, thin vertical calcite veins exist. Generally a high effervescence is exhibited by the unit, and several vugs lined with calcite crystals are present.



DESCRIPTION

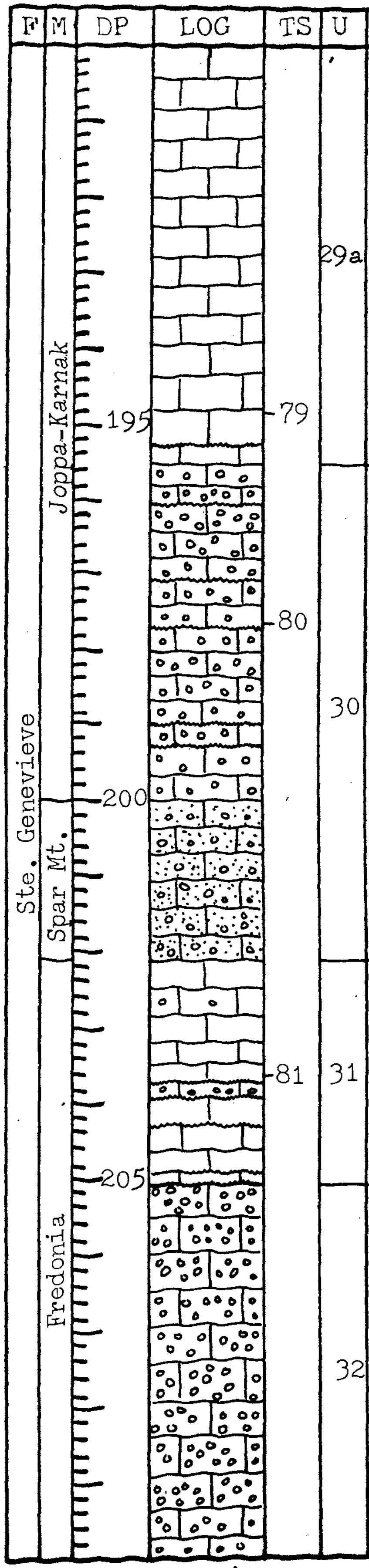
Limestone (1.3'), medium light gray (dry), olive gray (wet), quite oolitic, fossiliferous--fragments of crinoids and brachiopods. Numerous calcite crystals and limestone fragments are present throughout the unit. Effervescence is medium.

Limestone (3.8'), medium gray (dry), olive gray (wet), scattered oolites not dominant in any phase of the unit, crinoidal fragments common, fine- to medium-grained with some coarse phases, effervescence is medium.

Limestone, dolomitic (1.2'), light gray (dry), light olive gray (wet), brachiopod fragments, calcite crystals scattered throughout, effervescence very low. Thin, vertical, calcite veinlets present.

Limestone (3.5'), medium light gray (dry), olive gray (wet), crinoidal fragments throughout unit, calcite grains dominate the unit, oolites are rare to nonexistent. Coarse- to medium-grained. Stylolites present at intervals. Sharks tooth at 183.5'.

Limestone (5.5'), medium gray (dry), olive gray (wet), calcite crystals scattered throughout, fine-grained. Several shale partings present, vertical calcite vein 2mm. wide with oil stain. Effervescence medium.

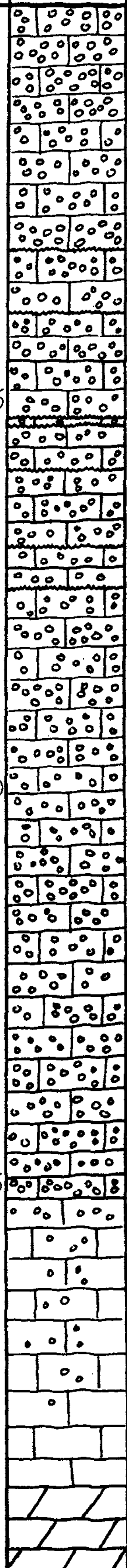


DESCRIPTION

Limestone (5.4'), medium gray (dry), olive gray (wet), calcite crystals (larger than above) scattered throughout, grain size fine to medium. Prominent stylolite near base of unit. Thin, vertical, calcite veinlets present in lower portion. Effervescence medium.

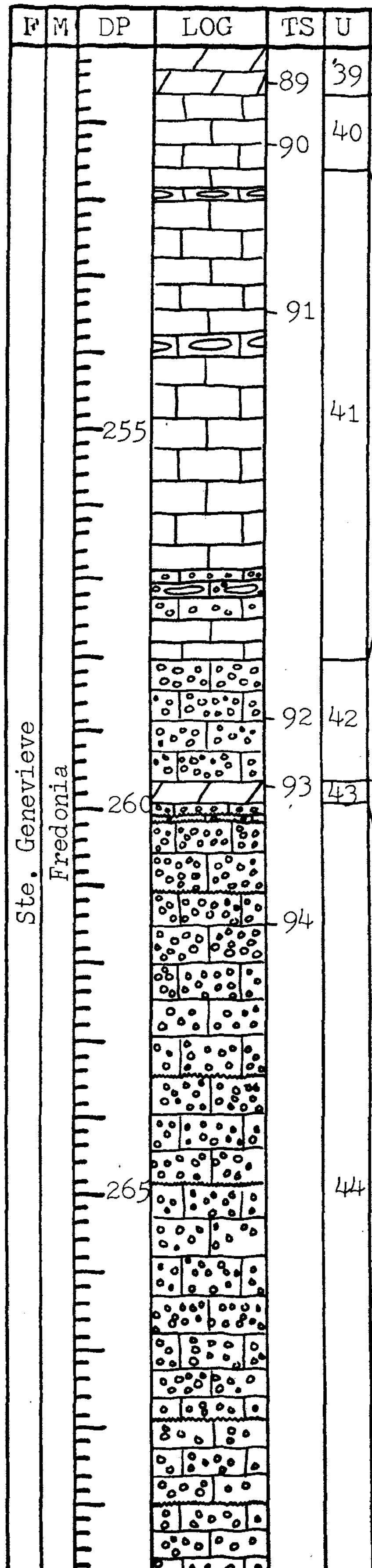
Limestone (6.6'), light gray (dry), olive gray (wet); extremely oolitic, yet less oolitic towards the base of the unit. Sandy in places, especially below 200'. Unit quite uniform in color and fine- to medium-grained texture. Stylolites frequent throughout the unit--some of considerable size and amplitude. Pyritic near base. At 201' sphalerite between oolites.

Limestone (3.4'), light gray, rarely oolitic, fossiliferous--fragments of crinoids and brachiopods. Calcite grains found throughout unit. Grain size medium to coarse; several stylolites present; thick (1 mm.) vertical crystalline calcite veins.



F	M	DP	LOG	TS	U	DESCRIPTION
Ste. Genevieve	Fredonia			82	32	Limestone (9.0'), light gray (dry), olive gray (wet), extremely oolitic, fossiliferous--mostly crinoidal fragments, but some brachiopod fragments. Calcite crystals throughout unit. Some phases are void of oolites (usually quite thin) and have a high effervescence. Lower portion is made up more of fragmental material than oolites. Effervescence is medium to high, and unit is medium-grained. Numerous stylolites present. Long, thin, vertical, white calcite veins present. Many oolites are elongated.
		215, 220		83	33	Limestone (10.7'), light gray (dry), light olive gray (wet), extremely oolitic, fossiliferous--mostly fragmental but some whole brachiopods, calcite crystals very small but persistent throughout unit. Unit quite uniform in color and texture (medium-grained), effervescence is high, stylolites are numerous--many very prominent. Positions of the prominent stylolites are shown in the log.
		225		84	34	Limestone (3.6'), medium light gray to medium gray (dry), olive gray (wet), oolitic at top but after first 0.5', they are hard to distinguish and decrease in abundance until missing near base. Fossiliferous fragments and calcite crystals are scattered throughout the unit. Medium-grained throughout.

F	M	DP	LOG	TS	U	DESCRIPTION
Ste. Genevieve	Fredonia	235		85	35	Dolomite (7.7'), light brownish gray (dry), olive gray (wet), unit uniformly fine-grained and color is consistent. No effervescence. Spotty calcite growths infilling vugs in lower part.
				86	36	Limestone (0.5'), medium gray (dry), olive gray (wet), extremely oolitic in dark matrix, lowermost 0.1' fine-grained where oolites are rare. Unit for most part is medium-grained with high effervescence. Unit is bounded by stylolites.
		240		87	37	Limestone (3.6'), medium light gray (dry), light olive gray (wet), oolites rarely present at top and in middle portions, but nonoolitic at base and somewhat fossiliferous. Many calcite crystals concentrated immediately above 238'. Several stylolites present. Effervescence is medium.
		245		88	38	Limestone (7.5'), medium gray (dry), olive gray (wet), oolites rare to nonexistent in upper 0.2' but they are dominant constituent of the remainder of the unit, fossiliferous--fragmental debris of crinoids and brachiopods with some whole brachiopods, upper 2.2' is medium-grained, the remainder is coarse-grained, crystalline calcite is disseminated throughout the unit. Stylolites present at several intervals.
					39	Dolomite (2.4'), light gray (dry), olive gray (wet), nonoolitic, nonfossiliferous, unit uniform in color and fine- to medium-grained throughout. No effervescence and no stylolites are present.



DESCRIPTION

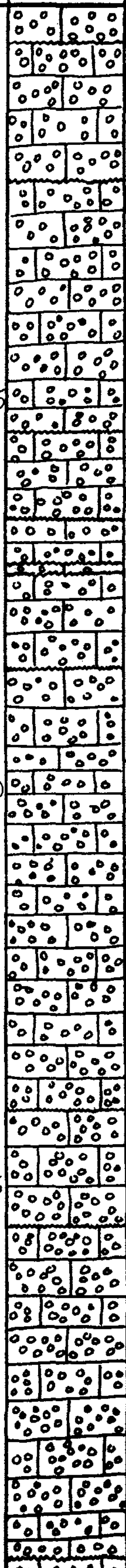
Limestone (1.0'), medium gray (dry), olive gray (wet), nonoolitic, some fossil material, medium-grained, with low to medium effervescence.

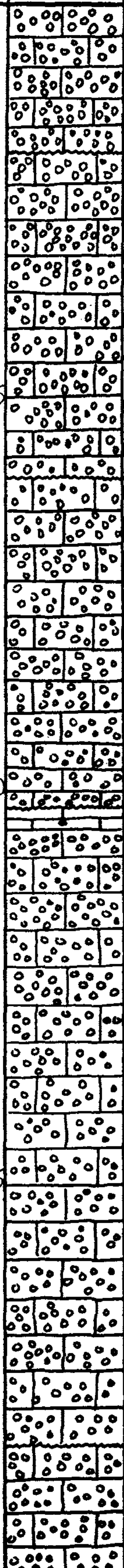
Limestone (6.4'), medium gray (dry), olive gray (wet), nonoolitic except for horizon near the base (256.8' to 257.5'), nonfossiliferous, fine-grained, thinly bedded. Three nodular chert zones present as indicated on the graphic log. The chert is medium to light gray in color.

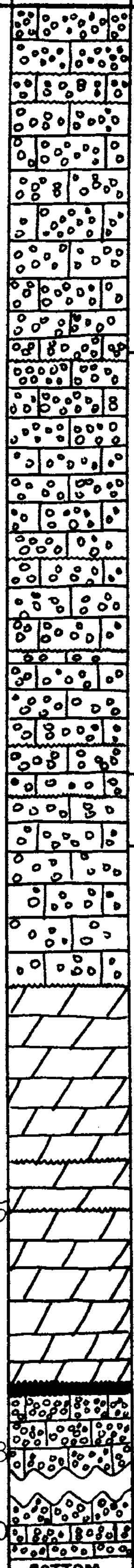
Limestone (1.6'), light gray (dry), olive gray (wet), extremely oolitic, fossiliferous--fragmental material of crinoids, brachiopods, and bryozoa. Also some limestone fragments. Grain size is medium, and effervescence is high.

Limestone, dolomitic (0.25'), light gray (dry), light olive gray to olive gray (wet). Small crystals near base, fine-grained, effervescence very low.

Limestone (10.2'), very light gray (dry), light olive gray (wet), extremely oolitic in darker colored matrix, fossiliferous--fragments of brachiopods and crinoids with some whole brachiopods--small calcite crystals throughout unit. Unit very uniform throughout in regard to color, medium-grained texture, and very high effervescence. Numerous stylolites are present.

F	M	DP	LOG	TS	U	DESCRIPTION
Ste. Genevieve	Fredonia	275 280		95 96 97	44a	Limestone (10.0'), very light gray (dry), light olive gray (wet), slightly darker color in lower 3.0' of unit, extremely oolitic, fossiliferous--fragments of brachiopods and crinoids, and small calcite crystals throughout the unit; upper portion is slightly sandy, grain size is medium to coarse, effervescence is very high, and stylolites are numerous, several being very prominent.
		285		98 99	44b	Limestone (10.0'), very light gray (dry), light olive gray (wet), extremely oolitic, fossiliferous--fragments of brachiopods and crinoids with some whole brachiopods and several brachiopod molds present, and fragments of pre-existing limestone present throughout. Numerous thin layers of fine-grained limestone are present. Near the bottom the oolites appear to be fused together with only their centers visible. Effervescence is very high, stylolites are not too common.

F	M	DP	LOG	TS	U	DESCRIPTION
Ste. Genevieve	Fredonia	295 300		100	44c	Limestone (10.0'), very light gray (dry), light olive gray (wet), extremely oolitic, fossiliferous--fragments of brachiopods and crinoids--small calcite crystals present throughout unit. Several thin laminations of fine-grained limestone are present, efferves-cence is very high, and stylolites present throughout unit.
		305		101	44d	Limestone (10.0'), very light gray (dry), light olive gray wet, extremely oolitic, fossiliferous--fragments of crinoids and brachiopods and some whole brachiopds (usu-ally infilled with calcite, but one shell has an oolitic filling), and small calcite grains occur throughout the unit. Efferves-cence is very high, and generally the unit is medium-grained, but both fine and coarse phases exist. Near the top of the unit, a thin (0.3' thick) bed of fine-grained lime-stone exists. Stylolites are present at frequent intervals in the unit.



F	M	DP	TS	U	DESCRIPTION
Ste. Genevieve	Fredonia	315	103	44	Limestone (8.2'), very light gray (dry), light olive gray (wet), extremely oolitic, quite fossiliferous--fragments of crinoids and brachiopods, and calcite crystals present throughout unit. Effervescence is high, and stylolites are numerous, some with large amplitude.
		320	104 105	45	Limestone (6.3'), light gray (dry), olive gray (wet), extremely oolitic, fossiliferous--abundant fragments of crinoids and brachiopods with some whole brachiopods. Thin laminations of fine-grained limestone (medium light gray) occur in the upper portion, vertical crystalline calcite veinlet 1.0 mm. thick occurs in the lower portion, effervescence is high throughout, several minor stylolites are present.
St. Louis		325		46	Dolomite (4.8'), very light brownish gray (dry), olive gray (wet). Uniformly fine-grained, lowermost 0.1' pure crystalline quartz bounded above and below by stylolites, thin vertical crystalline calcite veinlets in lower portion, no effervescence, few stylolites, and quartz filled vugs in lower part.
		328 330		47	Limestone (3.0'), very light gray (dry), olive gray (wet), extremely oolitic, fossiliferous--fragments of crinoids and brachiopods, and calcite crystals exist throughout the unit. Very fine vertical calcite veinlets occur near top, effervescence is high.

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