

ABSTRACT

Theodore E. Bedell III. Petrology, depositional environments and diagenesis of the Ste. Genevieve Limestone (Upper Mississippian), Washington County, Virginia. (Under the direction of Dr. Donald W. Neal) Department of Geology, East Carolina University.

The Ste. Genevieve Limestone of Washington County, Virginia, is a mixed carbonate/siliciclastic unit. Lithologies vary from detritus-free limestones to rocks with virtually equal parts of primary carbonate and siliciclastic detritus to clean sandstones. The Ste. Genevieve documents continued carbonate production with high terrigenous influx, a condition typically thought to preclude production of carbonate.

Observed carbonate lithologies include wackestones, packstones, grainstones, oolites and oncolites. Siliciclastic lithologies are mudrocks, siltstones and sandstones. Siliclastic and carbonate components are commonly present in roughly equal abundances, either due to reworking of carbonates with terrigenous sediments or to carbonate production accompanied by terrigenous influx. In such cases it is difficult to classify the rock as carbonate or siliciclastic. This exemplifies a nearly complete mixing of carbonate and siliciclastic detritus. Less complete mixing is characterized by frequent interlamination and/or interbedding of carbonate and siliciclastic lithologies.

Depositional environments recognized include: 1) a beach characterized by sandstones, grainstones and oolites which exhibit extensive mixing; 2) a back bar, semi-restricted, subtidal zone

marked by the presence of calcarenaceous mudrocks often interlaminated with siltstone; 3) a carbonate sand bar of skeletal grainstones and oolites; and 4) a subtidal, open marine, low energy environment represented by packstones and wackestones. These environments are transitional and arranged in an overall regressive sequence.

Diagenesis is extensive and varied in the Ste. Genevieve. The most ubiquitous features are related to compaction/pressure solution and silicification. Other features which are independent of depositional environment are pyritization, equant calcite cement, allochem recrystallization, dolomitization and X-type matrix. Remaining diagenetic features are controlled, at least to some degree, by depositional environment. These include the formation of iron oxides and fibrous, bladed and syntaxial calcite cements; neomorphism of unstable constituents; sericitization; vacuolization; chloritization; authigenic clay formation; corrosion of quartz and replacement of detrital grains by calcite and/or dolomite. Penecontemporaneous diagenesis began in the marine environment followed by freshwater infiltration and pervasive calcite cementation that continued through deep burial. As cementation occluded porosity, overburden stresses were dispersed, alleviating pressure solution and initiating reduction of rock volume through the formation of stylolites. Freshwater was introduced during a Late Mississippian regression followed by uplift during the Alleghanian orogeny.

PETROLOGY, DEPOSITIONAL ENVIRONMENTS, AND DIAGENESIS
OF THE STE. GENEVIEVE LIMESTONE (UPPER MISSISSIPPIAN),
WASHINGTON COUNTY, VIRGINIA

A Thesis Presented to
the Faculty of the Department of Geology
East Carolina University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Geology

by
Theodore E. Bedell III

November, 1986

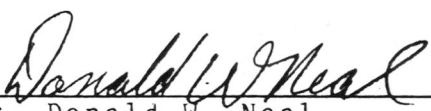
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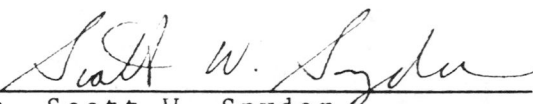
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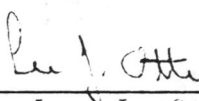
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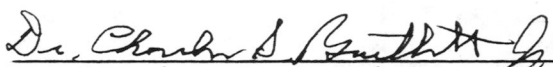
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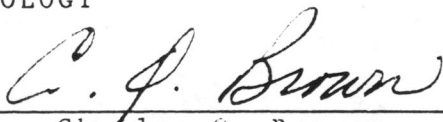
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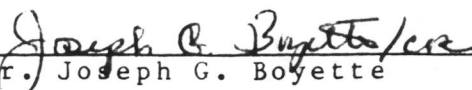
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ACKNOWLEDGMENTS

I would like to extend my gratitudes to all the staff and faculty of the East Carolina geology department for making my stay enjoyable, memorable and the most intensive learning experience of my life. I would like to especially thank my mentor and advisor Dr. Donald W. Neal for all his support and guidance. I also extend my appreciation to the rest of my thesis committee for their time and effort: Dr. Scott Snyder, Dr. Lee Otte and Dr. Charles Bartlett.

Another group I want to thank is the entire graduate student body. Their support and criticism added immensely to this project and my entire graduate career. Special thanks go to Vince DiRenzo, Mark Purser, Tom Danahy and Carlo Rossi for their great help in my feild work.

The person who deserves the most thanks is my wife, Kelly. For her undying support and patience I dedicate this thesis to her.

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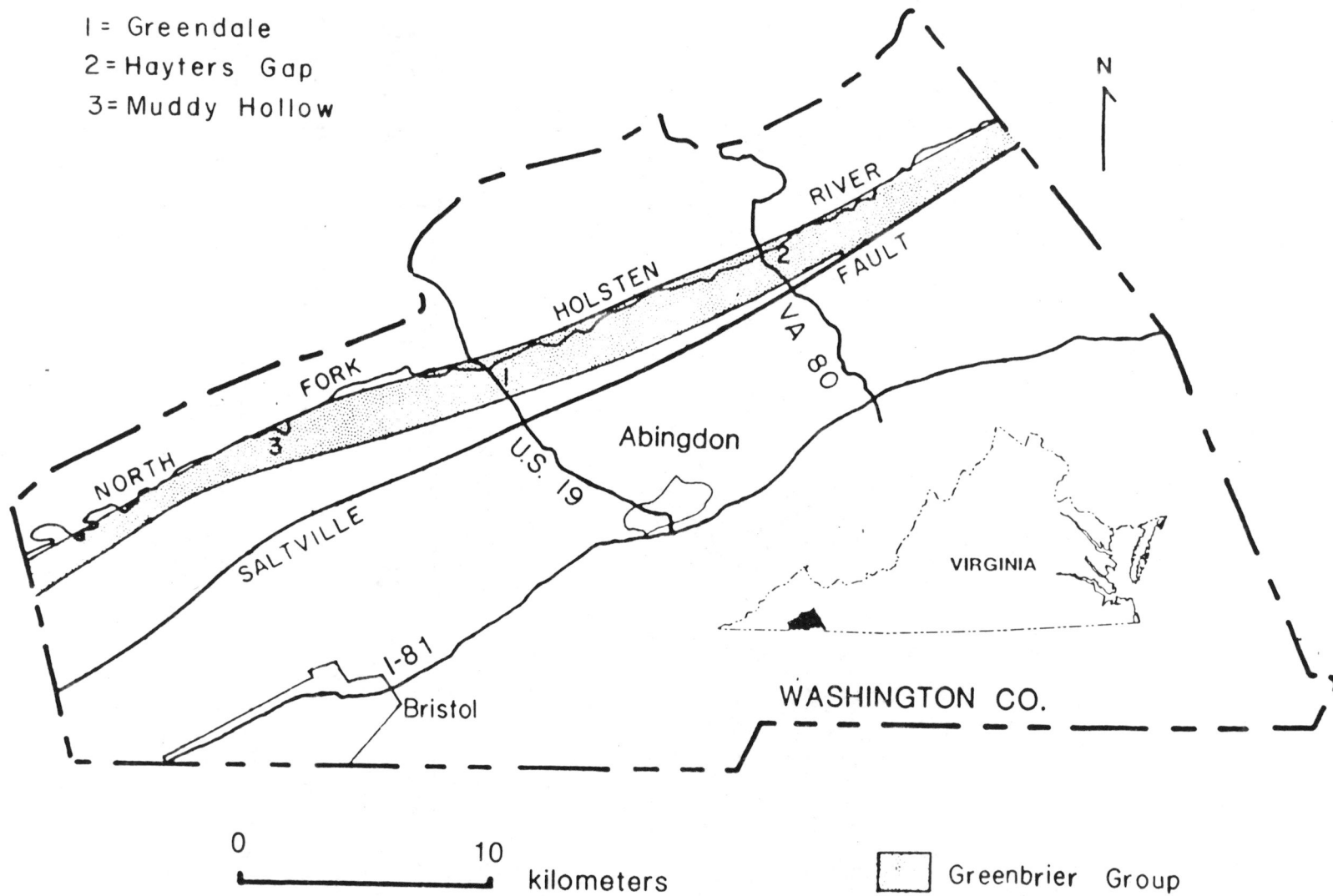
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INTRODUCTION

General Statement

The Upper Mississippian Ste. Genevieve Limestone of southwestern Virginia is well exposed at several localities within Washington County. Three of the best exposed and most complete outcrops of this unit occur along: 1) U.S. Highway 19 (Alt. 58) approximately 8 kilometers northwest of Abingdon, 2) Virginia State Route 80 approximately 9 kilometers northeast of Abingdon and 3) Virginia State Route 798 approximately 10 kilometers north of Bristol (Fig. 1). These outcrops are part of a larger belt that represents the easternmost exposure of Upper Mississippian rocks in the Central Appalachians. They provide an excellent opportunity to study 1) depositional environments as a function of the tectonic regime and 2) the petrology and subsequent diagenesis of these rocks.

Several reasons justify a detailed study of the Ste. Genevieve in Washington County, Virginia. No detailed study of these rocks has ever been performed, and a thorough study will provide additional understanding of the Central Appalachian Basin during the Late Mississippian. A detailed outcrop-based study of the Ste. Genevieve, a known producing unit in counties to the north and west, may provide further insights into the controls over this production. Finally, the Ste. Genevieve, although labeled a limestone, is actually a mixed carbonate/siliciclastic unit. Lithologies vary from detritus-free limestones and to rocks with virtually equal parts of primary



SAMPLING LOCATIONS

(Figure 1)

carbonate and siliciclastic detritus to clean sandstones. These compositionally mixed rocks have been neglected in the past and any detailed study of them may lead to a better understanding of the interplay between carbonate production and siliciclastic deposition.

Geologic Setting

The study area is situated within the Valley and Ridge province of the Appalachians. Within this province Mississippian strata are only found infolded in the structurally deeper synclines (deWitt and McGrew, 1979). In the Greendale Syncline, which contains the thickest accumulation of these strata, the Mississippian is bound to the southeast by the Saltville thrust (Fig. 1). This fault, as well as the Mississippian outcrop belt, trends northeast-southwest with a southeasterly dip. The Ste. Genevieve in Washington County, Virginia, has an average strike of N30 E and dip of 25 SE.

Stratigraphically, the Ste. Genevieve Limestone, a member of the Greenbrier Group, is situated between the Girkin Limestone above and the Hillsdale Limestone below. Historically, controversy has existed as to the placement of the Meramecian-Chesterian boundary. However, this boundary has recently been placed at the top of the Ste. Genevieve (Patchen, et. al., 1984 and others). Figure 2 illustrates the Mississippian stratigraphy of the Greendale Syncline.

MISSISSIPPIAN	CHESTERIAN	PENNINGTON FORMATION		
		COVE CREEK LIMESTONE		
		FIDO SANDSTONE		
		GREENBRIER GROUP	GIRKIN LIMESTONE	
	MERAMECIAN		STE. GENEVIEVE LIMESTONE	
			HILLSDALE LIMESTONE	
			LITTLE VALLEY LIMESTONE	
	OSAGEAN	MACCRADY SHALE		
		PRICE FORMATION		
	KINDERHOOKIAN	BIG STONE GAP SHALE		

Figure 2. Mississippian stratigraphy of the Greendale Syncline.

Previous Work

The type locality for the Ste. Genevieve Limestone is in Ste. Genevieve County, Missouri. The formation was named by Shumard (1859) for exposures along the bluffs of the Mississippi River, 1 - 2 miles below the town of Ste. Genevieve. Butts (1927) recognized "Limestones and other rock formations of Ste. Genevieve and Gasper ages" in Scott County, Virginia. In 1940, Butts separated these units primarily on the basis of fauna and extended the limits of the Ste. Genevieve into the Appalachian Valley of southwestern Virginia. Bartlett and Webb (1977) stated that precise correlation with the type section is questionable; however, as no other suitable name is available, they agree with the informal use of the name Ste. Genevieve for this unit.

Only very limited reconnaissance work has been done on the Ste. Genevieve in southwestern Virginia. Rocks of Ste. Genevieve and Gasper age in Scott County were described by Butts (1927). In 1940 he divided these units and measured and described sections from Tazwell, Washington and Scott Counties. This work included identification and description of major fossil types. He found the Ste. Genevieve to be a minimum of 450m thick along U.S. Highway 19. Averitt (1941) described a composite section of limestone of Gasper and Ste. Genevieve age along U.S. Highway 19 in Washington County. Bartlett and Webb (1971), in a report on the Bristol and Wallace Quadrangles made brief mention of the Ste. Genevieve. Bartlett (1981) measured and described the exposure of Ste. Genevieve along

U.S. Highway 19, finding slightly more than 300m of section. deWitt and McGrew (1979), in a report on the entire Appalachian Basin region, described a basic tectonic framework.

All of these studies, although lacking in detail, provided an excellent framework for this investigation.

Objectives

The four primary objectives of this study of the Ste. Genevieve Limestone are:

- 1) to analyze composition, texture and sedimentary structures;
- 2) to interpret depositional environments;
- 3) to characterize diagenetic features and diagenetic environments;
- 4) to relate tectonic history to the depositional system, lithology and diagenesis.

Methods

Field work consisted of detailed description, measurement and sampling of the outcrops cited on page one. Samples were taken at approximately 7.5 m intervals or at major changes in lithology. Outcrop accessibility was also a factor in sample selection. Samples were labeled with a code indicating the section from which they came ("SG" for outcrop 1, "HG" for outcrop 2 and "MH" for outcrop 3) and a number which indicates location within the section. One hundred ninety-seven samples were collected.

In the laboratory, thin sections and polished hand samples were

prepared for all samples. These were examined microscopically under a petrographic and binocular stereoscope. Using the method of Friedman (1977), all thin sections were stained with a solution of Alizarine Red S and potassium ferricyanide to aid in mineral identification. This solution stains iron-free calcite red, iron-poor calcite muave and iron-rich calcite purple; iron-free dolomite remains unstained, while ferroan dolomite stains light blue and ankerite dark blue. Ninety-two representative thin sections were chosen and point counted. A grain-bulk method which provides data as volume percent of individual constituents was employed. A minimum of three hundred points per thin section were counted. This provides a maximum error of less than six percent in calculating the abundance of any given constituent (Flugel, 1982). Scanning electron microscopy and X-ray diffractometry were performed on selected samples to aid in mineralogical identifications. After careful examination, all samples were divided into facies based on constituents, textures and sedimentary structures.

All samples of the Greendale section (outcrop 1) were subjected to acid treatment to determine percent of insoluble material. Approximately 20g of finely crushed sample was added to concentrated hydrochloric acid and digested for 24 hours to allow sufficient time for dissolution. Excess acid and insoluble residue was filtered, washed in water and placed in an oven at 70 C until dry. The dried sample was weighed and percent insoluble residue calculated. These data are presented graphically in Figure 4.

PETROLOGY

At the type locality in Ste. Genevieve County, Missouri, the Ste. Genevieve Formation is typically a biocalcarenitic limestone with a maximum thickness of only 38.1m (Short, 1962). In the Greendale Syncline it greatly thickens to approximately 450m and shows varied lithologies (Fig. 3). So varied are the lithologies that little correlation of units between outcrops within Washington County is rarely possible. Furthermore, as shown by Figure 3, the majority of the formation is non-carbonate. Therefore, referring to this formation as a limestone in the Greendale Syncline is questionable, as is the exact nature of the correlation with the type section.

In the Greendale Syncline the Ste. Genevieve is predominated by silty, calcareous siliciclastic mudrocks often interlaminated with siltstone, sandstone, or lime-grainstone. Other lithologies present are siltstones and sandstones with varying amounts of clay and/or carbonate and lime grainstones, packstones and wackestones that often have a high detrital content.

CONSTITUENTS

Allochems

The allochems within the Ste. Genevieve include various fossil types and non-skeletal grains such as ooids, peloids and intraclasts. They are usually fragmented, abraded and moderately well-rounded. Skeletal material that is unidentifiable due to its small size and/or diagenetic alteration is abundant. In the lower energy facies whole skeletal grains are more frequently preserved, however, the majority are still fragmented.

Ooids (Plates 1 and 2)

Ooids form by accretion of concentric carbonate laminations around a central core, giving rise to a spherical shape. However, if the nucleus is large compared to the collective thickness of laminations, the shape tends to mimic that of the nucleus. When laminations are few the grain may be referred to as a superficial ooid or cortoid. Exactly when a cortoid becomes an ooid is subjective. Occasionally, two or more ooids become cemented together and are subsequently coated, thereby forming compound ooids or grapestones. For purposes of point counting, cortoids, grapestones and ooids were grouped together.

Though all of the above mentioned ooid types are represented, in the Ste. Genevieve, cortoids are the most common. They generally

have only two or three laminations. The diameter of cortoids is totally dependent on the nucleus and, therefore, is highly variable. Cortoid nuclei are usually detrital grains and less frequently skeletal fragments. The diameter of "normal" ooids is dependent on the number of laminations about the nucleus. This reflects both the amount of time the ooid rolled about the sea floor before burial, and the physico-chemical conditions of the environment. Optimum conditions for the production of large ooids include: 1) the presence of algae, bacteria or organic material; 2) water supersaturated with respect to CaCO_3 ; and 3) shallow (less than 2 meters), warm, turbulent water with normal to increased salinities (Flügel, 1982). These environmental conditions must remain relatively stable as it takes 100 to 1,000 years for Recent ooids to form (Flügel, 1982). Also, if the supply of potential nuclei is too great, burial will occur before ooids can attain a large size. The predominance of cortoids over normal ooids suggests less than optimum conditions for ooid formation. Because cortoids are found in association with high concentrations of detrital grains, it is thought that this high influx of terrigenous detritus is responsible for cortoid formation rather than normal ooids. The normal ooids of the Ste. Genevieve in the Greendale Syncline range in size from 0.4 to 1.1 mm, averaging 0.7 mm, which is above average for Recent ooids but about average for ancient (Flügel, 1982). They show a radial fibrous microstructure. Most are lacking any apparent nucleus but others have nuclei of skeletal debris such as echinoderm and mollusk

fragments. Unidentifiable nuclei probably are micritized skeletal fragments. Some identifiable nuclei show partial micritization.

Intraclasts

Intraclasts represent aggregate grains of any combination of the following: lime-mud, skeletal debris and detrital material. They may form by early cementation on the sea floor, causing the aggregate to act as a single grain or by rip up of the partially cemented (possibly held together by organic and/or mucilaginous material) mud at the sediment water interface. Compound ooids might also be considered as intraclasts, their mode of formation argues for grouping them with ooids. Intraclasts may be composed of carbonate, siliciclastic detritus or mixed carbonate/siliciclastic material. They range in size from 0.5 mm to several centimeters in diameter. There seems to be a bimodal distribution with centimeter-sized intraclasts being shaley and the millimeter-sized intraclasts limey.

Echinoderms (Plates 3 and 4)

Echinoderms are recognized in thin section by their characteristic porous texture and unit extinction. Crinoids, blastoids and echinoids are composed of individual plates which tend to disaggregate after death of the organism. Because their differentiation in thin section is extremely difficult, they are all grouped as echinoderms for point counting purposes. In outcrop,

however, it is apparent that crinoids are among the most abundant fossils in the Ste. Genevieve. Blastoids were also observed.

The echinoderms are susceptible to diagenesis as evidenced by frequent partial micritization, partial replacement by silica and/or dolomite and recrystallization to the more stable low magnesium-calcite.

Bryozoans (Plate 5)

Bryozoans are the second most abundant allochem in the Ste. Genevieve of Washington County. They are predominately fenestrate, and less frequently ramose in form. Both show the characteristic fibrous wall structure. The fenestrate type tend to lie parallel to bedding. Because thin sections were cut perpendicular to bedding, only small parts of the fenestrate bryozoans are visible. This may lead to an under estimation of their abundance.

Bryozoans are frequently partially silicified, and rarely are they replaced by dolomite. Their zooecia are typically filled with iron-poor, equant calcite or less commonly, with mud. Rarely, a bladed isopachous spar precedes the equant calcite mentioned above.

Brachiopods (Plate 1)

Brachiopods are rare in the Ste. Genevieve. In thin section they are characterized by a thin outer wall of fibrous calcite oriented normal to the shell surface and a thicker inner wall of oblique to parallel fibrous calcite. Often the outer wall is

missing. Frequently, brachiopods of the Ste. Genevieve are plicated and either punctate or pseudopunctate. Spines of brachiopods are also common. They are recognized by their concentric-parallel fibrous inner wall and radial-fibrous outer wall layers, hollow central canal and the frequent presence of a pseudo-uniaxial cross.

Pelecypods (Plate 6)

Pelecypods are also rare in the Ste. Genevieve in the Greendale Syncline. They are typically thin-walled with a prismatic wall structure. The majority of Recent pelecypods secrete aragonite shells. Extensive recrystallization of the bivalves observed in the study area suggests that they also secreted aragonite shells. The prismatic wall structure is usually preserved but when it is not, identification must be based solely on shape. Often the bivalves are encased in a micrite envelope.

Peloids (Plate 7)

For point counting purposes, peloids were defined as any micritic grain that is spherical to ellipsoidal in shape. This may include true pellets, totally micritized grains and slightly rounded micritic intraclasts. Pellets tend to be ellipsoidal and less variable in size than intraclasts. Rounded intraclasts can usually be identified by inclusions of debris and/or their more angular nature. Occasionally, however, no inclusions are present and the slightly higher angularity is not sufficient to call them

intraclasts. Micritized grains tend to be spherical or massive without a distinct shape, and they often exhibit an ill-defined remnant structure. Remnant structure alone is not adequate to identify the allochem, so such grains are grouped with peloids.

Foraminifers

The foraminifers observed are of the endothyrid and millioline types. They are very rare in the Ste. Genevieve and never comprise more than two percent of the whole rock. Their distinctive chambers are filled with either equant calcite or mud and their walls are almost always micritized.

Trilobites (Plate 4)

Trilobites are extremely rare and occur only as fragments. They are recognized by a very finely prismatic microstructure, wavy extinction and a typical "shepherd's crook" shape. Observed trilobites are particularly free of diagenetic alteration.

Ostracodes

Ostracodes are similar in abundance to foraminifers. Ostracodes are recognized by their small size, thin carapace and radial-fibrous microstructure. They too are relatively free of alteration.

Gastropods

Gastropods are extremely rare and are identified by their distinctive morphology. The aragonitic shells of gastropods are susceptible to diagenetic alteration. In all observed cases, the shells are recrystallized or dissolved. Occasionally, micrite envelopes are present. The low spired gastropods are either completely filled with mud and skeletal debris or show geopetal structure.

Oncoids (Plate 8)

Oncoids form by the encrustation of blue-green algae around a nucleus, followed by the trapping and agglutination of particles to the surface of the mucliaginous sheath around algal filaments (Tucker, 1981). This is accompanied by extracellular precipitation of CaCO_3 in the mucliaginous sheath without the building of a true skeleton (Flugel, 1982). This produces a spheroidal to lobate grain with concentric laminations that are often convolute, ill-defined and terminated by other laminations.

Oncoids within the Ste. Genevieve of the study area range in size from about one-half centimeter to over five centimeters. Thin sections of the oncolite facies are totally covered by parts of one or two oncoids. Within laminations of the oncoids, all other skeletal grain types found in the Ste. Genevieve, as well as clotted lime mud, are observed. Also found within the oncoids are sponge spicules and worm tubes. These two skeletal types do not occur as

isolated fragments. Worm tubes, however, were occasionally observed as part of intraclasts. The oncoids are frequently silicified, at least partially.

Coral

Corals are relatively rare within the Ste. Genevieve. Outcrop inspection revealed only solitary horn corals. Coral is differentiated from bryozoans by large coralites with varying shapes, radiating septa and variations in thickness of different types of walls. The walls of coral do not exhibit the fibrous microstructure of bryozoans. Internal cavities were most commonly infilled with equant calcite, but also occasionally with mud.

Calcspheres

Calcspheres, as defined for point counting purposes, are small spheres of calcite cement. Their exact origin is unknown, but they have been related to green algae and alteration of other organisms such as radiolarians and foraminifers (Scholle, 1978). Calcspheres in the Ste. Genevieve appear to form from recrystallization of rounded grains such as foraminifers or isolated bryozoan zooecia. This is evidenced by association of calcspheres with identifiable foraminifera and bryozoan fragments. Some may also be of algal origin. They range in size from 0.06 mm to 0.3 mm, averaging about 0.1 mm.

Unidentifiable Skeletal Hash

Unidentifiable skeletal hash is simply skeletal material that is too small and/or altered to accurately identify. Although these particles are frequently recrystallized, they are differentiated from calcite cement by the presence of remnant microstructure and/or a more orangish-red color upon staining, as compared to the more bluish-red (muave) of the cement. If skeletal hash is entirely micritized, there is no way to distinguish it from lime mud. This may cause the percentage of micrite to be over-estimated when point counting.

Detrital Grains

For point counting purposes, any grain below the fine silt range was considered as matrix. Grains above fine silt were always identified and counted as a grain. Within the fine silt range, grains are frequently covered with mud, making identification impossible. Such cases grains were not counted, rather the mud covering them was tabulated as matrix. If identifiable, particles of fine silt size were counted as detrital grains.

Quartz (Plates 9 and 10)

Quartz within the Ste. Genevieve is subangular to subrounded, commonly has corroded grain boundaries, and ranges in size from fine silt to coarse sand. It is predominantly monocrystalline, but polycrystalline grains are common. Monocrystalline grains vary from straight to strongly undulose extinction patterns, but tend to show slight to moderately undulose extinction. They often contain inclusions of muscovite, and less commonly vacuoles and Boehm lamellae are present. Polycrystalline grains typically show irregular to sutured contacts of elongate individuals. The number of individuals within any one aggregate ranges from two to over ten, with five to ten being most common.

Feldspars (Plates 9 and 10)

Plagioclase, microcline and perthite are all present within the Ste. Genevieve of the Greendale Syncline. Plagioclase, by far the predominant feldspar is oligoclase to andesine in composition as determined by the Michle-Levy method. It ranges from medium silt to medium sand in size. It typically shows albite twinning, but untwinned plagioclase is also present. Because of the presence of untwinned plagioclase, and also the possibility of orthoclase being present, the feldspar content may be underestimated. Microcline is identified on the basis of the characteristic cross hatched twinning. Perthite shows subparallel intergrowths of potassium feldspar with plagioclase. All the feldspars generally appear clouded under plane light and show considerable diagenetic alteration.

Rock Fragments (Plates 9 and 11)

Rock fragments are the second most common detrital constituent found within the Ste. Genevieve. They are both metamorphic and sedimentary in origin. Metamorphic rock fragments are strongly foliated and occur in two basic types: 1) those with fine-grained, micaceous individuals (low grade) and 2) those that are coarse-grained, with abundant quartz and feldspar individuals (high grade). Sedimentary rock fragments are differentiated by their lack of foliation and are fine-grained, predominated by mud and silt.

Detrital chert is also recognized in the Ste. Genevieve. In plane light it has a brown to yellow-brown clouded color and is

typically well rounded. Although detrital chert is traditionally considered to be strictly from sedimentary sources (Folk, 1980), recent studies show it can also be derived from metamorphic terrains (Keller, et. al., 1985). A coarser texture is associated with metamorphic chert.

The rock fragments range in size from medium silt to medium sand. High grade metamorphic rock fragments tend to be slightly coarser grained and more well rounded, while low grade fragments tend to be more elongate. All rock fragments tend to show considerable diagenetic alteration. In comparison with other detrital grains, the sedimentary and low grade metamorphic rock fragments were especially susceptible to compaction and occasionally were "squeezed" around more competent grains.

Muscovite (Plate 12)

Muscovite is a relatively common mineral in the Ste. Genevieve. Although never occurring in great abundances, except in some of the mudstones, it is ubiquitous. Muscovite shows a strong preferential alignment parallel to bedding.

Accessory Minerals

Phosphate, zircon, magnetite and biotite are four infrequently occurring minerals within the Ste. Genevieve. They are listed in descending order of relative abundance. Phosphate grains are yellow-brown in plane light and opaque under crossed polars. They

occur as bone fragments or as reworked pebbles. The bone fragments are distinguished by the presence of a distinctive microstructure and generally elongate shape. The pebbles lack microstructure and are typically well rounded. Zircon is extremely highly birefringent with very high relief. It is generally subhedral and of medium to coarse silt size. Magnetite is opaque, has a steel-blue to black color in reflected light and occurs as subrounded grains of coarse silt size. Biotite is recognized by the brown color, pleochroism and strong birefringence of the grains. Often the biotite is altering to chlorite.

Matrix

For the purposes of point counting, anything smaller than fine silt was considered as matrix.

Carbonate (Plate 5)

Carbonate matrix occurs in four forms in the Ste. Genevieve: 1) micrite, 2) dolomicrite, 3) microspar and 4) dolomicrospar. Micrite is simply lime mud. It is generally brown to dark brown in color and translucent in thin section. Dolomicrite looks exactly the same and can be differentiated only through staining. Microspar is minute calcite crystals in the size range of four to ten microns. It is highly birefringent, although the small crystal size makes extinction difficult to see. Dolomicrospar, again, is differentiated on the basis of staining.

Siliciclastic (Plate 13)

Siliciclastic matrix is composed of clay and very fine silt. It has higher birefringence than carbonate matrix and does not stain. X-ray diffraction indicates the predominant clay minerals are illite, chlorite, sericite and possibly kaolinite. Chlorite and sericite replace feldspars and metamorphic rock fragments suggesting a diagenetic origin. Illite, however, is probably detrital. Kaolinite was not recognized petrographically, but it may be detrital and/or diagenetic in origin.

Unknown (Plates 2 and 14)

A third type of matrix is found but it is not readily identifiable through standard petrographic techniques. It is much the same color as detrital chert in plane light, but under crossed nichols no change is observed. It occurs as masses, laths and ill-defined rhombs. Occasionally within the massive form, faint rhombs can also be identified. Birefringence is low and no interference figure is obtainable. It is occasionally seen partially replacing allochems and in close association with silicification, suggesting a diagenetic origin. A "best guess" as to the identity of this material is a mix of some type of silica, possibly semi-crystalline, with dolomite or proto-dolomite. For further discussion, this phase will be called X-type matrix.

Cement

Calcite (plates 6, 7 and 15)

Calcite is by far the predominant cement found within the Ste. Genevieve. It occurs in the following forms: 1) iron-poor equant, 2) iron-poor syntaxial, 3) fringing bladed rim, 4) fringing fibrous rim and 5) replacive. They are listed in order of decreasing relative abundance. Precipitation of equant calcite proceeds such that the crystals coarsen toward the centers of pore spaces. Crystal boundaries are irregularly interlocking. Syntaxial calcite is in optical continuity with the crystalline substrate on which it grew. Echinoderms, having plates of single crystals, serve as the substrate for syntaxial calcite. Because of the large nucleus and absence of competitive crystal growth, syntaxial calcite grows much faster than cement from adjacent nonechinoderm grains (Longman, 1980). This is evidenced by the larger amount of pore space filled by syntaxial cement, which often surrounds several grains to produce a poikilotopic texture. Bladed and fibrous rim calcite are oriented normal to the grain from which they grew. The crystals tend to grow to a uniform length and are thus called isopachous. Fibrous calcite has a length to width ratio of over six to one, whereas bladed calcite is less than that, typically near two to one (Harris et. al., 1985). Calcite seen replacing detrital grains has a finely crystalline equant texture.

Dolomite (Plates 14 and 16)

Dolomite occurs most commonly as a replacive mineral, but also as a pore-filling cement. If replacive, the rhombs range in size from 0.02 mm to 0.5 mm, averaging around 0.1 mm. Pore-filling dolomite often displays a rim of ferroan dolomite and a nonferroan core. Rarely it is seen partially replacing echinoderm fragments in optical continuity with the single calcite crystal of the allochem. Dolomite is frequently found in association with silicification.

Dedolomite (Plate 14)

Dedolomite is found exclusively in association with silicification. It is differentiated from dolomite through staining. Often the dedolomite rhombs exhibit a core of non-replaced dolomite. Also, dedolomite can be rimmed by dolomite. This suggests that, at least in part, silicification, dolomitization and dedolomitization were penecontemporaneous.

Silica (Plates 3 and 14)

Replacive chert, chalcedony and megaquartz are present within the Ste. Genevieve. They usually replace allochems, but occasionally matrix is also replaced. The chert is finely crystalline (on the order of 50 microns) and is the most common silica cement. It occasionally grades into megaquartz of crystal size near 0.03 mm. Chalcedony is radial fibrous in texture and is associated with extensive chertification.

Other

Several other constituents are noted in negligible quantities. They include: 1) iron oxides (hematite/limonite), 2) pyrite, 3) organic material, 4) glauconite and 5) detrital dolomite. Pyrite, organics, and iron oxides are often finely disseminated throughout the rock making it difficult to determine their relative abundance. Hematite also occurs as coatings around grains. Pyrite, as well as being disseminated, is found in masses (Plate 17) and framboids, both associated with organic material. Glauconite appears to be detrital in most cases, but rarely it partially replaces allochems (Plate 15) making, a detrital origin uncertain. Detrital dolomite occurs as rounded polycrystalline grains. Occasionally they serve as nuclei for ooid formation.

Porosity may also be considered a rock constituent. It, too, is present only rarely. Never is any primary porosity preserved. Observed porosity is secondary fracture, dissolution or solution enhanced fracture porosity.

LITHOLOGIES

On the basis of field and laboratory data eight different lithologies were distinguished. They are 1) mudrock, 2) siltstone, 3) sandstone, 4) wackestone, 5) packstone, 6) grainstone, 7) oolite and 8) oncolite. The petrographic criteria used differentiating lithologies were percent and size of individual constituents and their packing (grain versus matrix supported). Table 1 gives average abundances and ranges of all constituents for each facies.

Due to the lithologic variability of the Ste. Genevieve within the Greendale Syncline and to inherent problems with point counting, calculated percentages do not always accurately represent the rock. Because the Ste. Genevieve represents a mixed carbonate/siliciclastic system, classification of individual samples as either carbonate or siliciclastic is often difficult. Whether a rock is a limestone or sandstone may seem straight forward, but this is not always the case in mixed systems such as the Ste. Genevieve. The problem is graphically depicted by the insoluble residue data (Fig. 4), which shows the frequent occurrence of samples near the 50% mark. The fact that diagenetic constituents (e.g. calcite cement) are not included when classifying rocks magnifies the problem. Also, interlaminated lithologies are common producing whole rock percentages of allochems and/or detrital grains such that assigning a sample to a particular lithology is sometimes equivocal. For example, if a limestone is matrix supported but has more than 10% allochems it should be called a

CONSTITUENTS		WACKESTONE		PACKSTONE		GRAINSTONE		OOLITE		ONCOLITE		MUDROCK		SILTSTONE		SANDSTONE	
A L L O C H E M S	Ooids	0.1	0-0.6	0.4	0-2.1	3.8	0-15.3	54.6	25.0-81.7	---	---	---	---	0-1.0	0.2	0-2.2	20.8
	Intraclasts	0.2	0-0.9	0.5	0-2.1	0.9	0-3.3	2.2	5.0-12.0	---	---	0-0.3	---	0-0.2	---	0-0.2	1.2
	Echinoderms	9.0	2.6-35.0	26.4	0.6-49.0	30.6	0.6-57.9	4.8	13.4-11.5	---	---	0.9	4.3	3.5	16.9	3.7	9.8
	Bryozoan	11.5	0-18.2	15.7	0-41.0	23.7	0-59.6	6.1	17.8	---	---	0.8	4.2	2.1	11.2	2.7	10.9
	Brachiopods	0.3	0-1.6	1.6	0-2.7	2.4	0-6.0	0.6	2.8	---	---	---	0.6	---	0.3	0.2	1.5
	Pelecypods	0.4	0-1.6	1.6	0-4.5	1.5	0-8.1	0.5	1.5	---	---	---	---	0.1	1.2	0.1	0.6
	Peloids	0.4	0-4.1	0.1	0-0.3	2.0	0-17.5	1.9	6.8	---	---	0.3	6.1	0.1	0.6	0.2	1.8
	Foraminifers	---	---	0.1	0-0.3	0.1	0-1.2	---	0.3	---	---	---	---	---	---	---	---
	Trilobites	---	0-0.3	0.2	0-1.0	0.2	0-0.9	0.1	0.3	---	---	---	0.3	---	---	---	---
	Ostrocodes	---	0-0.3	0.2	0-0.3	---	0-0.3	---	---	---	---	---	---	---	---	---	---
	Gastropods	---	---	0.1	0-0.3	0.1	0-0.6	0.3	1.7	---	---	---	0.3	---	---	---	---
	Oncoids	0.4	0-4.7	---	0-0.3	---	0-0.3	---	0.3	100	---	---	---	---	---	---	---
	Coral	0.1	0-0.6	0.4	0-1.8	0.4	0-2.4	0.2	1.3	---	---	---	---	0.3	---	---	---
	Calcishperes	---	0-0.7	0.3	0-1.3	---	0-0.3	---	---	---	---	0.1	1.5	---	---	---	---
	Skeletal Hash	5.6	13.5	10.2	43.1	2.9	9.8	1.6	3.9	---	---	6.9	21.5	11.4	21.4	7.5	15.0
	TOTAL	27.9	20.0-45.0	57.8	39.7-77.6	68.6	45.4-90.0	72.9	41.2-93.6	100	---	9.0	26.6	17.4	29.8	16.8	30.9
C L A S T I C S	Quartz	2.1	0-6.3	1.9	0-4.4	6.4	0-23.6	4.5	0.9-20.8	---	---	10.2	23.0	26.1	11.8-39.5	36.4	52.7
	Feldspar	---	0-0.3	0.1	0-0.3	0.7	0-4.2	0.3	1.2	---	---	0.4	1.3	1.2	1.6	3.2	5.7
	Rock Frag.s	---	0-0.3	---	0-2.8	15.3	0-3.0	14.8	---	---	---	1.4	7.8	5.0	7.4	9.2	14.5
	Muscovite	---	0-0.3	0.1	0-0.3	---	0-0.3	---	---	---	---	1.5	4.2	1.1	3.2	0.6	1.6
	Accessory	---	---	---	0-0.2	0.9	0-0.1	0.3	---	---	---	0.1	0.9	0.4	1.0	0.2	1.9
	TOTAL	2.1	0-7.2	2.1	0-5.0	10.1	0-32.6	7.8	39.3	---	---	13.6	28.8	35.7	17.2-51.4	49.8	63.4
M A T R I X	Micrite	24.2	0-60.4	17.1	0-40.1	1.9	0-13.7	0.9	3.4	---	---	7.0	45.7	2.4	5.5	0.3	1.9
	Microspar	3.4	0-21.5	1.3	0-3.9	0.8	0-4.8	0.5	2.4	---	---	4.1	82.8	1.1	3.9	---	---
	Dolomite	4.0	0-20.4	0.5	0-2.5	0.6	0-4.6	---	---	---	---	1.6	4.9	2.3	8.2	3.0	11.5
	X-type	3.9	0-12.5	0.7	0-2.9	0.1	0-1.2	---	0.3	---	---	0.2	1.0	0.4	1.0	1.1	8.3
	Siliciclastic	21.5	0-69.9	13.2	0-37.8	2.2	0-10.3	0.1	0.7	---	---	57.8	76.6	24.0	39.6	1.0	25.6
	TOTAL	57.0	32.9-69.9	32.8	14.7-43.1	5.6	17.4	1.5	4.0	---	---	70.7	91.5	32.2	45.1	15.1	32.4
C E M E N T	Equant	0.9	0-4.8	4.6	0-13.8	7.5	2.5-11.5	13.3	24.3	---	---	2.2	6.6	6.3	0.3-11.4	8.9	17.1
	Syntaxial	0.1	0-0.6	0.4	0-1.3	5.9	0-16.9	0.5	2.4	---	---	---	---	0.1	0.6	0.4	3.4
	Bladed	---	---	---	---	---	0-0.3	0.6	2.9	---	---	---	---	---	---	---	---
	Fibrous	---	---	---	---	0.1	0-1.6	1.6	6.4	---	---	---	---	---	---	---	---
	Dolomite	0.1	0-0.6	0.5	0-2.5	0.5	0-3.6	0.2	1.3	---	---	0.9	5.2	2.7	0-7.2	6.3	13.2
	Dedolomite	0.3	0-2.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Chert	9.5	0-32.7	0.3	0-0.9	0.4	0-2.2	0.2	0.7	---	---	0.8	3.6	1.8	0-5.8	1.0	3.6
	Chalcedony	0.4	0-4.5	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	TOTAL	11.3	0-33.7	5.8	0.6-14.4	14.4	7.7-21.1	16.4	30.5	---	---	3.9	9.4	10.9	7.1-12.6	16.6	23.1
Other		1.6	0-3.6	2.0	0-4.7	0.8	0-2.8	0.8	3.0	---	---	2.4	4.7	3.5	0.7-5.2	0.3	6.5

Table 1. Averages (left columns) and ranges (right columns) of individual constituents within each lithology.

wackestone. However, because only thin laminations of lime-grainstone within the host mudrock account for nearly all the allochems, overall the rock must still be considered a mudrock. Additionally, because detrital grains are much more competent than carbonate grains, allochems are subject to extensive pressure solution, which significantly lowers the primary carbonate percentage of the rock. Therefore, the carbonate percentage of the sediment before lithification is questionable. Frequently associated with pressure solution is recrystallization of allochems, leading to unidentifiable carbonate grains interpenetrated by more competent detrital grains. Differentiation of this situation from a true chemically precipitated cement is virtually impossible.

Overlapping of grains or of grains and matrix was the most common problem inherent to the point count method. It became even more common as grain size decreased. Another inherent inaccuracy of point counting is that partially replaced grains are counted as a grain, not the material replacing them. This causes the percentages of replacive minerals (i.e. chert, dolomite, calcite) to be underestimated.

The problems encountered when point counting are included here to clarify the limitations of the information presented below.

Mudrocks (Plates 13, 17, 18 and 19)

Mudrock is the most abundant lithology present within the Ste. Genevieve. Mudrocks are characterized by the predominance of matrix which is composed mostly of siliciclastic detritus. Matrix averages 71% and ranges up to 91.5%. An average of 58% of the matrix is siliciclastic in composition. Carbonate matrix predominates in rare cases where the rocks are actually lime-mudstones. Occasionally, allochem content is greater than 10%, but allochems are largely restricted to coarser-grained interlamination. Cement is also confined to the coarser-grained interlamination, except where it replaces and/or infills rare allochems within the matrix. Dolomite and chert are present as replacive forms, whereas iron-poor, equant calcite, the predominant cement, is pore-filling in nature. Negligible fracture porosity is present.

Rocks in this group are medium to dark gray in color. They exhibit wavy to ripple laminations and thin to very thin bedding. Upon weathering, they become lighter in color and fissile to subfissile. Occasionally within the silty, calcareous, siliciclastic mudrock are thin (less than 1 m) beds of lime-grainstone and/or sandstone. The mudrocks also exhibit varying degrees of bioturbation.

The fine-grained nature of this lithology suggests a low energy environment. However, the wavy laminations and highly bifurcated ripple marks indicate some water movement, suggesting deposition near

wave base. A quiet water setting is further supported by extensive bioturbation and the presence of pyrite and organic material finely disseminated throughout the matrix. Turbulent water energy (i.e., wave action) maintains oxygen content of the water, causing oxidation of organic material. Such aerobic conditions preclude pyrite formation. Also, if wave action is intense enough to act on the upper few centimeters of sediment, most traces of bioturbation are lost. The abundant interlamination and occasional interbeds of coarser-grained material are indicative of fluctuating water energy, which can be related to storm activity. The paucity of recognizable skeletal material may be related to the high siliciclastic input and/or somewhat reducing and suboxic conditions.

Siltstones (Plates 12,13 and 19)

Siltstones have much the same appearance in outcrop as the mudrocks. The siltstones are argillaceous, whereas the mudrocks tend to be quite silty. In fact, there seems to be nearly a complete gradation between mudrocks with silty/sandy interlamination and siltstones with muddy interlamination. The main distinguishing characteristics of the siltstones are slightly thicker bedding and a grain supported fabric. They also tend to be lighter in color and more susceptible to iron staining. The siltstones show wavy to ripple laminations, are occasionally interbedded with lime-grainstone or sandstone and show varying amounts of bioturbation. Using Dott's (1964) classification scheme, these rocks would be called lithic

greywackes.

This lithology is predominated by siliciclastic detritus fine and coarse silt size. Detrital grains average 36% and siliciclastic matrix 24%. Primary carbonate is common in siltstones, with allochems averaging 17% and carbonate matrix 6%. Cement averages 11%. It is found mainly as a pore-filling within the coarser-grained interlamination, but also replacive (chert and dolomite) and intraparticle pore-filling (equant calcite) cements are also recognized. Iron-poor, equant calcite cement predominates. Trace amounts of fracture, dissolution and solution enhanced fracture porosity are seen.

The increase in average grain size of this lithology over the mudrocks indicates a higher energy environment. This is supported by the thicker bedding and more frequent interbeds of sandstone and lime-grainstone. These factors are suggestive of a slightly shallower water environment, probably at or just above wave base.

Sandstones (Plates 10 and 20)

The sandstones of the Ste. Genevieve fall on the triple junction between sublitharenite, litharenite and feldspathic litharenite on Folk's (1980) classification scheme and within the lithic graywacke range of Dott's (1964) classification. Sandstones are differentiated from siltstones by their coarser grain size. At least 50% of the detrital grains fall within the sand-size fraction. They vary in color from medium to dark blue-gray to red to brownish gray. The red

hues are imparted by the presence of hematite and/or limonite. Hematite is predominantly present as grain coatings and may even serve as an early cement, whereas limonite is commonly disseminated throughout or occurs in shapeless masses. Hematite precipitation is believed to be syndepositional, whereas limonite occurs as a late diagenetic phase. Sandstones range from medium to massive bedded, but are mostly thick bedded. They are frequently cross-bedded with high angle (25-35°) sets of 15 cm to 30 cm in thickness. Often sandstones form thin (less than 0.5 m) interbeds within other lithologies, especially siltstones and mudrocks. The sandstones are carbonate cemented and rather fossiliferous. The fossil fragments are abraded and fairly well rounded. Detrital grains are subrounded and typically fine-grained, but range from very fine to coarse sand.

Sandstones are characterized by a predominance of sand-sized detrital grains, which average 50% of the rock. Quartz is the most abundant single constituent. Approximately 5% of the average 36% quartz is polycrystalline. Allochems and cement each average approximately 17%. Unidentifiable skeletal hash is the most abundant allochem, but on the average no single allochem predominates. In some sandstones, though, ooid content reaches 21%. These ooids are actually superficially coated detrital grains and, less commonly, allochems. Cement is mostly interparticle pore-filling, iron-poor, equant calcite. Interparticle, pore-filling, equant dolomite is also common, and in some sandstones it predominates. These two cements could only be differentiated by staining. Matrix content is

relatively high in the sandstones of the Ste. Genevieve, averaging 15%. This high average can be attributed, at least in part, to two factors. First, the majority of the sandstones have a lower matrix content and only a few very argillaceous sandstones raise the average. Secondly, some of the clay is thought to be diagenetic in origin. Only traces of fracture porosity are present in the sandstones.

Coarse grain size and thick, cross-bedded strata are suggest a high energy environment for these sandstones. The presence of early hematite in some of the sandstones indicates oxidizing conditions. The high average clay content is an apparent discrepancy with the high energy environment. However, sandstones with high clay content tend not to be cross-bedded or red in color, suggesting a slightly deeper water, lower energy environment for these finer-grained, more argillaceous sandstones.

Wackestones (Plates 5, 14 and 21)

Wackestones are distinguished from mudrocks by a higher fossil content, although the fossils are still imbedded within a matrix support fabric. Allochems in wackestones are present throughout the rock, whereas in mudrocks they are restricted to coarser-grained interlamination. Wackestones also exhibit a paucity of detrital grains. Beyond these generalizations, the wackestones are quite variable. In outcrop, they can be thick- to thin-bedded to laminated. Their color ranges from grayish black to olive gray to browish black to grayish red, with medium gray being most common. Often this

lithology is associated with extremely abundant chert nodules. Ripple marks are common but not ubiquitous, as are interlaminae of coarser, more highly fossiliferous, grain-supported siltstone, sandstone or lime-grainstone. Primary and secondary characteristics of this lithology are associated with compositional variations. Those wackestones having more carbonate matrix tend to be thicker-bedded and contain more chert. Those with a high siliciclastic matrix content tend to have thinner beds, less chert and are commonly rippled. Color is dependent on the presence or absence of organics, pyrite and/or iron oxides.

Matrix is the primary constituent of the wackestones, comprising an average of 57% of the rock. Carbonate matrix averages 32% whereas siliciclastic matrix only 21.5%. Either matrix type can be almost totally predominant. X-type matrix is more abundant within this lithology than in any other, ranging up to 12.5%. There appears to be an association between the presence of X-type matrix and chertification, which is also more extensive in the wackestones than in any other lithology. Allochems, which are better preserved than those from any other facies within the Ste. Genevieve, average 28% of the wackestones and are predominated by bryozoans and echinoderms. The few detrital grains observed were virtually all monocrystalline quartz. Cement in the wackestones is predominated by chert which averages 9.5% as compared to 11% for all cement. It is non-selectively replacive. Chalcedony is also present in association with extensive chertification. Equant calcite is found as either

intraparticle- or shelter-pore infilling or within grain-supported interlaminae. Syntaxial calcite occurs exclusively in the coarser grained interlaminae. Minor dolomite and dedolomite are found in association with chert nodules. Negligible fracture and solution porosity is present.

The variability of this lithology suggests that the environment of deposition was also highly variable, or there existed more than one environment that was conducive to the formation of wackestones. A low energy environment is suggested by the abundance of matrix material. However, wackestones predominated by siliciclastic matrix are commonly rippled, indicating some water movement. The presence of ripple marks and predominance of siliciclastic matrix may indicate a closer proximity to shore than do the carbonate-matrix-predominated wackestones. Allochems in the latter wackestones are more diverse and less fragmented, giving additional evidence for more open marine conditions farther from shore.

Packstones (Plates 22 and 23)

Packstones are differentiated from wackestones by their grain supported fabric and generally higher allochem content. Their outcrop characteristics are very similar to the wackestones including the variable nature. In general, packstones are thin to medium bedded. Upon weathering they frequently become slightly fissile. Ripple marks are less common in the packstones and when present are associated with higher amounts of siliciclastic matrix. Chert is also less common

than in the wackestones. When present, it is associated with more carbonate-matrix-rich samples. The packstones, in general, exhibit a more diverse faunal assemblage than the wackestones.

Allochems are the primary constituents of packstones, averaging 58%. They provide a grain-supported fabric predominated by echinoderms and bryozoans. Unidentifiable skeletal hash is also common, occurring in higher abundances in packstones rich in siliciclastic matrix. Carbonate matrix is more common than siliciclastic matrix, but either can predominate in a given sample. Detrital grains are minimal in this lithology, most of which are monocrystalline quartz. Cement is mostly iron-poor, equant calcite. Dolomite, syntaxial calcite and chert are also present. Chert is replacive whereas the other cement types infill porosity. Fracture and dissolution porosity are present in trace amounts.

The lower matrix content of this lithologies indicates high water energies resulting in the winnowing of fines. Like the wackestone facies, there appear to be two distinct depositional environments responsible for the formation of the packstone facies. The one closer to shore produced a rippled packstone enriched in siliciclastic matrix and unidentifiable skeletal hash. The other, farther from shore, produced a packstone predominated by carbonate matrix with a diverse faunal assemblage and a paucity of ripple marks.

Grainstone (Plates 1, 4, 20, and 24)

Although not the most common lithology in the Ste. Genevieve, the grainstones are very prominent in outcrop. They are differentiated from packstones by their generally higher allochem content and paucity of matrix. The majority are medium gray, thick- to massive-bedded bioclastic grainstones. They exhibit large-scale, low-angle, planar cross-bedding. Cross-bed sets are on the order of several meters thick with a dip of approximately 10. Allochems are fragmented and very well rounded. Detrital grains are scarce. A second type of grainstone, although still predominated by bioclastic debris, is more variable in color, tending to have a red hue and higher concentrations of detrital grains. These grainstones are medium- to thick-bedded with small-scale, high-angle cross bedding like that described in the sandstones.

Allochems are, by far, the predominant constituents of this lithology, averaging 69%. Echinoderms and bryozoans are most abundant. Total allochem content can reach as high as 90%. Detrital grain content is variable, ranging from 0% to 33%. Quartz and rock fragments (mostly intraclasts) are the most common detrital constituents. Matrix is scarce, averaging less than 6%, but in grainstones with high concentrations of detrital grains it can reach an abundance of more than 17%. Cement averages of 14% of the grainstones. Calcite cements are all pore-filling and include the following types: 1) iron-poor, equant; 2) syntaxial overgrowths; 3) fibrous rim; and 4) bladed rim. Chert is present as a grain-selective

replacement. Dolomite can be either replacive or pore-filling. No porosity was observed in this lithology.

Based on the paucity of matrix, the abundance of coarse, well rounded allochems and the presence of cross-bedding, grainstones were deposited in a very high energy environment. Grainstones richer in detrital grains and siliciclastic matrix, more red in color, and having small-scale, high-angle cross-bedding probably represent deposition more proximal to shore. Carbonate-rich grainstones with large-scale, low-angle cross-bedding probably were deposited farther from shore. The large-scale cross-bedding may be indicative of a migrating carbonate sand body. Lack of nonfragmented skeletal material or any preserved trace fossils, for both grainstone types, gives further evidence of a highly mobile substrate within a high energy zone.

Oolites (Plates 2 and 25)

Oolites, grain supported, carbonate-predominated rocks with allochems comprised of at least 50% ooids, are relatively scarce within the Ste. Genevieve of the Greendale Syncline. Those that are present are typically thick-bedded, grayish red to brownish gray in color and predominated by cortoids. Nuclei are most commonly detrital grains or, less often, skeletal fragments. Detrital grains without oolitic coatings are also common. Occasionally, high-angle, small-scale cross-bedding like that found in the sandstones is observed. Less commonly oolites are predominated by normal ooids,

lack a red hue (being dark to medium gray), thick-bedded and tend to have few detrital grains. Both oolite types are commonly found as thin interbeds (less than one meter) within other lithologies.

Oolites contain an average of 73% allochems, 75% of which are ooids. Non-coated allochems are generally small, abraded, well-rounded skeletal fragments. Detrital grains vary from non-existent to over 39%. Oolites with high detrital grain content are predominated by cortoids, whereas oolites with low concentrations of detrital grains are predominated by normal ooids. Matrix is extremely rare in the oolites, averaging only 1.5%. Micrite and microspar constitute virtually all of the matrix and probably originated from diagenetic alteration of allochems rather than settling of lime mud. Cement averages 16% with iron-poor, equant calcite predominating. Other calcite cements include fibrous rim, syntaxial overgrowth and bladed rim cements. Fibrous rim calcite cement is more common in this lithology than any other. Dolomite and chert are present in trace amounts. No porosity was observed in the grainstones.

For ooids to form shallow (subtidal, above wave base to intertidal), turbulent water is required. However, two distinct oolite types are present in the Ste. Genevieve indicating differing depositional environments. Oolites predominated by cortoids have high concentrations of detrital grains and red hues and indicate deposition close to shore. Oolites predominated by normal ooids and lacking red

hues and detrital grains are suggestive of deposition farther from shore.

Oncolites (Plates 8)

The oncolite lithology is the least abundant within the Ste. Genevieve of the Greendale Syncline. In all three measured sections it occurs at or very near the base of the formation. The oncolites are medium-bedded and dark olive gray in color. Black chert nodules are almost as common in this lithology as they are in the wackestones. Based on point count analysis, the oncolites are comprised of nearly 100% oncoidss. The boundaries between oncoids are microstylolitic, having concentrations of insoluble material (i.e., clays, silt and organic material).

For oncoids to form, there needs to be sufficient water movement to at least periodically roll the grain over. Otherwise, laminations would form only on one side of the nucleus. However, oncoids would be destroyed by anything greater than the most gentle agitation (Brock and Moore, 1981). Flugel (1982) considers oncoids to represent a morphological and ecological adaptation of encrusting organisms to soft bottoms and/or low energy environments. Within the oncoid laminations, very few detrital grains or siliciclastic matrix are present. This suggests the oncolite lithology was formed far enough from shore not to be influenced by detrital input.

STRATIGRAPHIC RELATIONSHIPS

Based on environmental interpretations of each lithology, an overall shallowing sequence is recognized (Fig. 3). Wackestones and oncolites are found almost exclusively near the base of the formation. Packstones are also common in this part of the section. These lithologies contain very few detrital components suggesting deposition offshore. Although slightly different depositional environments are indicated, the presence of high matrix content suggests sedimentation took place in relatively low energy environments. Wackestones and packstones in the middle and top of the formation have significantly higher siliciclastic concentrations. These are thought to have been deposited closer to shore. The top of the formation in all studied sections is characterized by high concentrations of detrital grains. Detrital input was frequently sufficient to choke out carbonate production. Alternating carbonate and sandstone units attest to the high, but variable, detrital influx (Fig. 3). The carbonates present near the top of the section are packstones, grainstones and oolites with high concentrations of detrital grains and hematitic iron. The iron is either disseminated throughout or present as coatings around grains. Oolites are predominated by cortoids. The occasional sandstones present toward the center and base of the formation are finer-grained, more argillaceous and less fossiliferous and iron-rich than those near the top. These are interpreted as being deposited in a more quiet water setting farther from shore. The most typical

lithologies of the Ste. Genevieve of Washington County, Virginia, are mudrocks and siltstones. These are present throughout the studied sections, but become less common at the base and top (Fig. 3). Interrupting the thinly bedded, often interlaminated mudrocks and siltstones are three thick- to massive- and cross-bedded lime-grainstones (or oolite), except in the Hayters Gap section where only two are present (Fig. 3). The lithologic units adjacent to the grainstones are most commonly fine-grained sandstones, siltstones or packstones (Fig. 3). Juxtaposed to these are mudrocks or wackestones. The grainstones and oolites represent deposition in the highest energy conditions, the mudrocks and wackestones the lowest and the fine-grained sandstones, siltstones and packstones moderate. Thus, gradational shifts in energy is seen when moving either up or down section from the cross-bedded grainstones.

Laterally few distinct correlations of lithologic units can be made. The uppermost unit, although varying slightly in composition and thickness is distinctive. It is a red calcarenaceous, oolitic, cross-bedded sandstone or very sandy oolite. The upper boundary of this unit marks the contact between the Ste. Genevieve and Girkin Limestones (Plate 26). The base of all three studied sections is marked by the presence of chert-rich oncolites and wackestones (Fig. 3). However, the exact placement of the contact between the base of the Ste. Genevieve and the top of the Hillsdale Limestones is equivocal as no distinct break in lithology or marker bed is present. A subtle change in lithology from the more massive- to thick-bedded

oncolites and wackestones of the Ste. Genevieve to the more thin-bedded, argillaceous limestones of the uppermost Hillsdale allowed for placement of this contact (Plate 27). The lowest common occurrence of the Ste. Genevieve guide fossil, the crinoid Platycrinus penicillus (Plate 28), was also noted immediately above the contact. The base of the Muddy Hollow section was covered.

The only other correlations that can be made are between the thick- to massive- and cross-bedded lime-grainstone units (Fig. 3). In the Muddy Hollow and Greendale sections three such grainstone units are recognized. In the Hayters Gap section only two are present and are correlated with the upper and lower grainstones of the other two sections. At the approximate stratigraphic position where the middle grainstones would be expected only a thin (2m) grainstone unit is present which is bound by covered intervals (Fig. 3). This grainstone unit and covered intervals are in turn bound by siltstones as is the middle grainstone of the Greendale section (Fig. 3). Although the middle grainstone unit of the Muddy Hollow section is not enveloped by siltstones, the limestone lithologies present indicate a similar depositional environment. There are two possible explanations why only two prominent thick- to massive- and cross-bedded lime-grainstones are present in the Hayters Gap section. First, it is possible that part of the middle grainstone unit of this section is covered, but generally these grainstones stand out in relief while the less consolidated siltstones and mudrocks weather. The more probable reason is that local variabilities (subsidence, detrital input, etc.)

were such that conditions were not conducive to the deposition of lime-grainstone in the Hayters Gap section whereas they were in the other two sections. In the Muddy Hollow section the lower lime-grainstone is actually an oolite (Fig. 3). This is interpreted as a facies change due to slightly shallower water depths.

Below the lower prominent grainstone unit in all three sections, lithologies representative of deposition in more open marine conditions are present. The lithologies found between the lower and middle and middle and upper (lower and upper for the Hayters Gap section) grainstone units are indicative of deposition in a semi-restricted environment below wave base. Immediately above the upper grainstone units the same environment is suggested by the lithologies present. These lithologies grade into lithologies indicative of a beach environment at the top of all three sections. Other than these general correlation of lithologic "packages" below, between and above the prominent grainstone units, no correlations can be made of specific units in these parts of the sections.

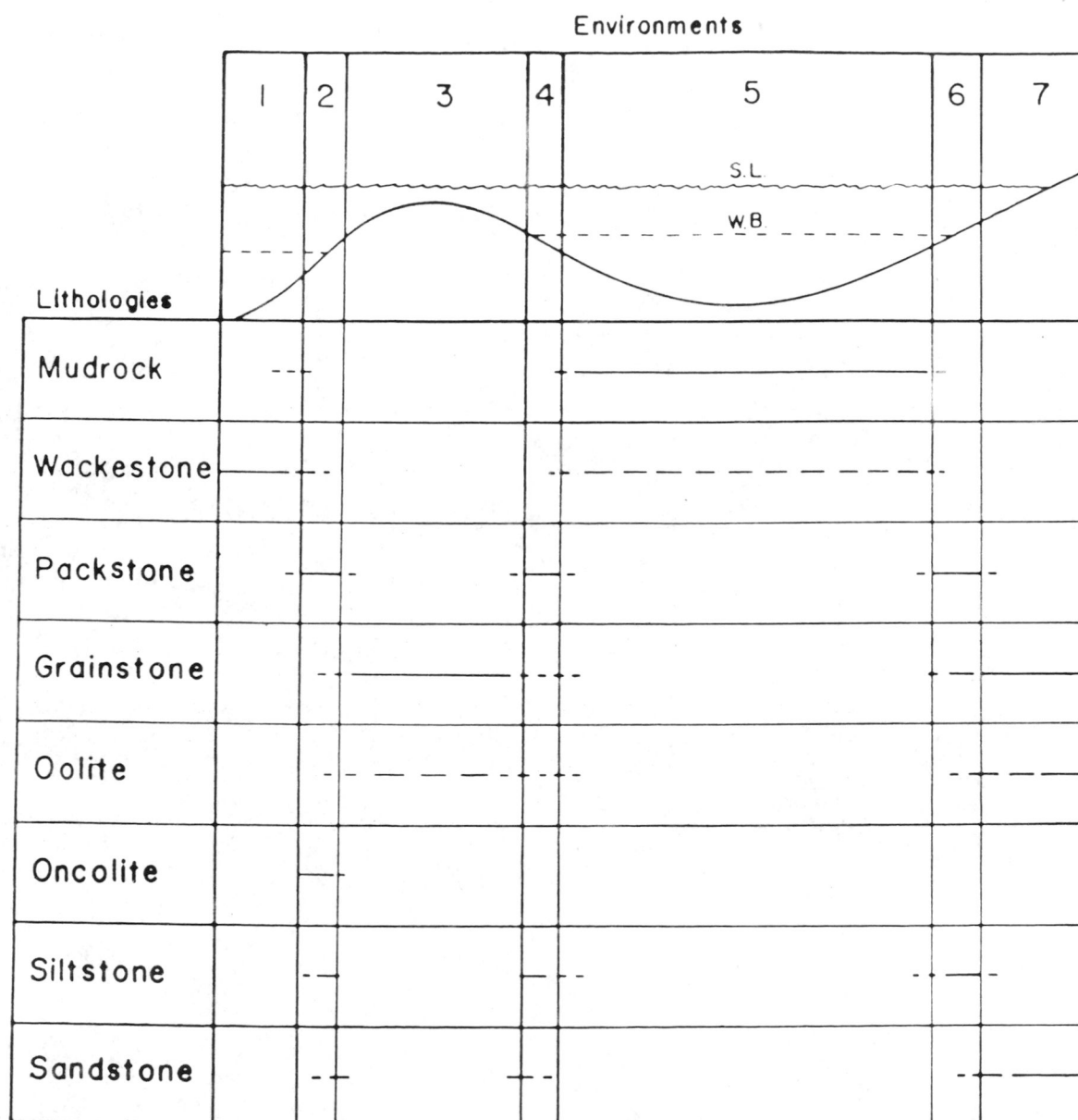


Figure 5. Proposed depositional model for the Ste. Genevieve Limestone, Washington County, Virginia. S.L. = mean sea level. W.B. = normal wave base.

1 = open marine

3 = carbonate sand shoal

5 = back-shoal, semi-restricted

7 = beach

2, 4 & 6 = transitional zones

DEPOSITIONAL MODEL

Eight lithologies have been identified in the Ste. Genevieve of Washington County, Virginia, each representing distinct environmental conditions. Based on the environmental conditions suggested by each lithology and their stratigraphic relationships, the following depositional model is proposed. The proposed model is a gently sloping homoclinal ramp interrupted by carbonate sand shoals (Fig. 5). The shoals represent the highest energy environment of the Ste. Genevieve. They serve to absorb wave energy protecting the area behind the shoal. The environment having the second highest energy is exemplified by a beach. Between the beach and shoal is a somewhat restricted, very low energy zone with transitional moderate energy environments along its nearshore and offshore edges. A gradational shift from high to low energy environments is encountered when going basinward from the shoal.

The carbonate sand shoals are apparently discontinuous. This is evidenced by small (approximately 5m across), lens shaped, fining upward sequences (i.e., channel fills) situated in stratigraphic proximity to the cross-bedded grainstones (i.e., shoal). Other, larger channels dissect beach sediments. These larger channels are on the order of 15m to 20m across, are trough cross-bedded and are thought to represent point sources of clastic input. Two were recognized in the Hayters Gap section (outcrop 2) and one in the

Greendale section (outcrop 1). None were seen in the Muddy Hollow section (outcrop 3). The shoals, in addition to protecting the back-shoal areas from intense wave action, also serve as a barrier to the offshore movement of terrigenous detritus. Almost all siliciclastic dominated rocks, which represent back-shoal environments, are found toward the top of the sections. Detrital clastics deposited in front of the shoal probably were derived from longshore drift and/or were transported through tidal channels which dissect the shoals.

The proposed model can be divided into seven distinct depositional environments (Fig. 5). The first is a subtidal, low energy environment below wave base. It is marked by the presence of wackestones and is transitional to the high energy, shallow subtidal to intertidal carbonate sand shoal (environment 3). The shoal environment, represented by thick- to massive- and cross-bedded lime-grainstones, grades into the back-shoal, subtidal environment which lay slightly below wave base. Mudrocks characterize this environment. This, in turn, grades into the high energy beach environment (7). Iron-rich, cross-bedded, calcarenaceous sandstones and sandy lime-grainstones and oolites represent this environment. Environments 2, 4 and 6 of Figure 5 are the transitional zones between the four main depositional environments. These moderate energy environments are characterized by packstones and siltstones with frequent wash-over from adjacent high energy zones. Oncolites are also found in the transitional zone between environments 1 and 3. The

majority of the oolites and sandstones are thought to indicate a beach environment. They are both medium- to thick-bedded, tending to be red in color (iron-rich) and exhibit small-scale, high-angle cross-bedding. Some sandstones that are very fine-grained, argillaceous and lack both red hue and cross-bedding are thought to have been deposited in moderate energy environments on either side of the shoal. These fine sands were winnowed by intensive wave action across the shoals and settled where turbulent energy decreased. The oolites representative of the beach zone are comprised predominantly of cortoids and often contain large amounts of uncoated detrital grains. Other oolites composed mainly of normal ooids and lacking a red hue are thought to have formed on the crest of the shoal when conditions were conducive to ooid formation. Most of the time this was not the case and the skeletal fragments of the shoal remained uncoated. Bioclastic grainstones are most representative of the shoal environment. However, all grainstones were not deposited at this site. Those that have higher concentrations of detrital grains, a reddish hue and small-scale, high-angle cross-bedding are believed to have been deposited in the beach zone. The wackestones are most characteristic of deposition occurring basinward of the shoal, however, they are also fairly common in the low energy zone between the shoal and beach where the mudrocks were also deposited..

The presence of carbonate sand shoals during the Mississippian is not exclusive to the Ste. Genevieve of the Greendale Syncline. Ruppel (1984), working on the Chappel Formation of the Eastern Palo Duro

Basin, interpreted echinoderm-bryozoan grainstone facies as being deposited as a wave-dominated carbonate shoal. Keller and Becker (1980), in a study of the Salem Limestone of Gibson County, Indiana, described a "broad, amoeboid sand bank with superimposed bars trending nearly perpendicular to the main sand body." This study is suggestive of a wide sand flat with tidally influenced bars and channels. The presence of channels in the Ste. Genevieve has already been recognized. The carbonate grainstones interpreted as wash-over from storm activity may represent, at least in part, superimposed tidal bars trending perpendicular to the main bar, as suggested by Keller and Becker (1980). However, no conclusive evidence for either interpretation was observed in the studied sections. Stevenson (1976) recognized the presence of an oolitic/skeletal carbonate sand body within the Salem Limestone of Wayne County, Illinois. Cluff (1984), working on the Salem - St. Louis - Ste. Genevieve Limestones of the Illinois Basin, also interpreted the presence of carbonate sand shoals within these rocks, confirming Stevenson's findings. All of these investigations describe lithologies and sedimentary structures similar to those found in the Ste. Genevieve of Washington County, Virginia. Interpretation of these characteristics as indicative of a homoclinal ramp superimposed by carbonate sand bars is consistent with the findings herein.

The overall sequence represented by the Ste. Genevieve is regressive. The deepest water facies are found at the base of the section. This is consistent with the findings of deWitt and McGrew

(1979), who place the maximum transgression of epiherc seas in the Central Appalachian Basin during deposition of the Hillsdale Limestone. Danahy (personal communication) believes the deepest water facies (maximum transgression) to be near the top of the Hillsdale interval. A general shallowing upward sequence for the Ste. Genevieve is consistent with the interpretation of the overlying Girkin Limestone as a shallow sub-tidal to intertidal deposit (Bergren, 1985). The regressive nature of the Ste. Genevieve is further supported by the general increase of insoluble residue (Fig. 4) up section. Although the overall sequence is regressive, small-scale sea-level fluctuations are evidenced by the stratigraphic relationships of the observed facies (Fig. 3).

DIAGENESIS

The diagenetic overprint of the Ste. Genevieve Limestone in the Greendale Syncline is varied and extensive. Some diagenetic features are ubiquitous, whereas others are restricted to certain lithologies.

Below is a list of observed diagenetic features:

- 1) Iron oxides (hematite/limonite)
- 2) Allochem micritization
- 3) Pyritization
- 4) Fibrous calcite cement
- 5) Compaction/Pressure solution features
- 6) Bladed calcite cement
- 7) Equant calcite cement
- 8) Syntaxial calcite cement
- 9) Neomorphism of unstable constituents
- 10) Stylolitization
- 11) Fracturing
- 12) Silicification
- 13) Dolomitization
- 14) X-type matrix
- 15) Dedolomite
- 16) Calcite fracture infilling
- 17) Sericitization
- 18) Vacuolization
- 19) Chloritization

- 20) Authigenic clay cement
- 21) Corrosion of quartz boundaries
- 22) Replacement of detrital grains by calcite and/or dolomite
- 23) Neomorphism of micrite to microspar

Of these, pyritization, compaction/pressure solution, equant calcite cement, allochem recrystallization, silicification, dolomitization and X-type matrix seem to be independent of depositional environment. The remaining diagenetic features are restricted to certain facies.

A general chronological sequence is proposed for the observed diagenetic features (Fig. 6). Following is a discussion of the early, middle and late stages of diagenesis. However, the precise timing of many processes cannot be determined. Such cases are discussed under the heading "Undetermined".

DIAGENETIC FEATURES	DIAGENETIC ENVIRONMENTS			
	MARINE	METEORIC	DEEP BURIAL	VADOSE
Hematite	— — —			
Micritization	— — —			
Fibrous Calcite	— — — — —			
Pyrite	— — — — —			
Coarse Dolomite	— — — — —			
Compaction/ Pressure Solution		— — — — —		
Neomorphism of Calcite		— — — — —		
Bladed Calcite		— — — — —		
Equant Calcite		— — — — —		
Syntaxial Calcite		— — — — —		
Quartz Corrosion			— — — — —	
Detrital Grain Replacement			— — — — —	
Stylolitization			— — — — —	
Fracturing			— — — — —	
Fine Dolomite			— — — — —	
Silicification			— — — — —	
X-type Matrix			— — — — —	
Fracture Infilling				— — — — —
Limonite				— — — — —
Sericitization	?			
Vacuolization	?			
Chloritization	?			
Authigenic Clay	?			
Neomorphism of Micrite	?			

TIME →

Figure 6. Proposed timing and diagenetic environments for individual diagenetic features.

Early-Stage Diagenesis

For purposes of this discussion, early diagenesis includes all features that occurred before the presence of fresh water within the pore system of the Ste. Genevieve. This includes hematite precipitation, micritization of allochems, pyritization, fringing fibrous calcite formation and an early stage of dolomitization.

Hematite is found only in rocks deposited in the beach environment. The hematite is dark red-brown to black and is either amorphous or cryptocrystalline. It occurs as a thin coating around grains or disseminated throughout the matrix. A diagenetic origin is indicated by the cryptocrystalline habit and the absence of hematite coatings at grain contacts (Tucker, 1981). Early formation of the hematite is postulated because it requires an oxidizing environment for precipitation and because it is engulfed by later calcite cements.

Micritization of allochems has been attributed to two different processes, both of which take place penecontemporaneously with deposition. The first is a result of algae, fungi or bacteria boring into carbonate particles with subsequent death of the boring organism and micrite infilling of the vacated tube (Bathurst, 1971). The second is simple recrystallization of the allochem to a grain of cryptocrystalline carbonate (Purdy, 1963). Both mechanisms can produce grains of unidentifiable origin (i.e. peloids). Grains micritized by endolithic algae (or other organisms) may tend to have a darker color due to incorporated organic material. When micritization

by this method is incomplete, a micrite envelope will form, whereas recrystallization tends to be patchy. In the Ste. Genevieve micrite envelopes with varying degrees of penetration into the allochem are common (Plate 3) as is total micritization of grains (Plate 7). The formation of the micrite envelopes is believed to be a result of boring organisms. Total grain micritization may be more a function of recrystallization, however, this is equivocal. Allochem micritization is common in all but the low energy lithologies (mudrocks, wackestones and siltstones) where it is less abundant.

The formation of pyrite as masses, framboids and finely disseminated particles throughout the matrix (Plate 17) probably occurred shortly after deposition. Its occurrence and the nature of its occurrence are associated with concentrations of organic material. For example, when pyrite is disseminated, so are the organics. This association is consistent with early pyritization. Conditions conducive to the formation of pyrite include negative Eh and high sulfide activity. Sulphate dissolved in seawater is reduced by bacteria, providing the necessary sulphide. Decomposition of the associated organic material by bacteria consumes oxygen in the environment, creating reducing conditions. If water movement is slow, a microenvironment adjacent to organic material will form that is conducive to pyritization. Water movement through the sediment becomes very slow with only minimal burial or in restricted environments. If burial proceeds too far, all of the sulphate and organic material will be reduced and conditions may return to those

where Eh is positive and sulphide is low. Therefore, pyrite formation must have taken place early in the diagenetic history. Pyrite within the Ste. Genevieve is common in all lithologies. In the lower energy lithologies (representing more restricted conditions) the pyrite is finely disseminated throughout the matrix whereas in higher energy lithologies it is found in localized patches. In all lithologies pyrite also occurs as either masses or framboids associated with organic material. No explanation was found to explain why occasionally framboids formed rather than shapeless masses.

Many workers (Longman, M.W., 1980; Kendal, 1985; Harris et. al, 1985 and others) have demonstrated a marine phreatic origin for fringing fibrous rim calcite. Whether this cement was initially aragonite and subsequently neomorphosed to calcite or originally precipitated as calcite is not clear (see Kendal, 1985). In either case, the same diagenetic environment is suggested. This cement is rare in the Ste. Genevieve of the Greendale Syncline. It is found rarely in the grainstones and oolites indicative of the shoal environment (Plate 29).

The last feature of early diagenesis (as defined above) is the formation of a coarsely crystalline, grain-selective and/or pore-filling dolomite (Plate 16), which probably formed in a marine-freshwater mixing zone. The size (0.07 - 0.3 mm) and high crystallinity of this dolomite indicate slow crystallization at low salinities and temperatures (Folk, 1980). The dolomite, although predominantly replacive, also fills pore space. Often the cores of

pores partially filled by dolomite are occluded by later calcite cement. Also, coarsely crystalline dolomite is found most commonly within or immediately underlying the grainstones and sandstones of the shoal and beach environments. The mudrocks and wackestones never contain coarsely crystalline dolomite, and packstones only occasionally contain it. Periodically the carbonate sand shoals and beaches were subaerially exposed causing the formation of a freshwater lens or wedge. In two samples, meniscus and pendant cements were observed in oolites suggesting subaerial exposure. Also, when passing from the marine to meteoric environment (where later cements were precipitated), an intervening mixing zone must exist. For these reasons the mixing zone of marine and fresh water seems most likely for the formation of the coarsely crystalline dolomite.

Middle-Stage Diagenesis

The middle stage of diagenesis of the Ste. Genevieve was predominated by calcite cementation. Allochem recrystallization and compaction/pressure solution also took place during this stage of diagenesis, which developed in the presence of freshwater during shallow burial.

Probably the first event during this stage of diagenesis was the neomorphism of unstable carbonate constituents (i.e., aragonite or high-magnesium calcite) to low-magnesium calcite. Aragonitic constituents may have included gastropods, pelecypods and, fringing fibrous calcite and lime mud. High-Mg calcite may have been contributed by echinoderms, bryozoans, corals, foraminifers, micrite and fringing fibrous calcite. Two mechanisms are thought to have taken place: 1) inversion and 2) dissolution/reprecipitation. Inversion from one polymorph to another would maintain gross chemical composition and at least some of the original microstructure. Dissolution of a constituent, leaving an open cavity that is subsequently filled by equant calcite, would leave no trace of the original microstructure. Neomorphism was observed commonly in all lithologies. The metastable calcium carbonate polymorphs, aragonite and high-magnesium calcite, may remain unaltered in a marine environment for substantial periods of time, but in the presence of freshwater alteration is rapid (Lippmann, 1973).

With only minimal burial, compaction and pressure solution commences. Compaction/pressure solution features were observed in all

facies. Pressure solution, however, is limited to grain supported fabrics. With increased quantities of matrix, pressure solution lessens. Observed compactional features include alignment of elongate and platy grains parallel to bedding (Plate 12), the formation of pseudomatrix by "squeezing" of labile grains (i.e., low grade metamorphic rock fragments and intraclasts) around more competent grains, and grain failure. Types of observed grain failure are: 1) simple fracturing of grains, 2) spalling of ooid cortices and 3) collapse of micrite envelopes subsequent to leaching of the original grain. Pressure solution produces microstylolitic or sutured boundaries between equally competent grains (Plate 4) or interpenetration of more competent grains into solution susceptible grains (Plate 25). Penetration of siliciclastic grains into carbonate grains is most prevalent. Pressure solution of this sort can be a major source of calcium carbonate for the subsequent precipitation of cement. Compaction and pressure solution must necessarily predate pervasive carbonate cementation. Cementation would solidify the sediments dispersing overburden stress away from point contacts, which would alleviate pressure solution.

The calcite cement which was precipitated during the middle stage of diagenesis is of three forms: 1) equant, 2) syntaxial overgrowth and 3) fringing bladed rim. All of these cements are iron-poor as indicated by staining. Equant calcite (Plate 6) is by far the most prevalent, occurring in all lithologies. It fills inter- and intraparticle pores. The mudrocks did not contain any of these

cements except as pore filling within the coarser grained interlaminae and within rare intraskeletal porosity. Syntaxial overgrowth of echinoderm fragments (Plate 15) is the second-most common cement observed. In some samples with abundant echinoderms, this is the predominant cement. Never are echinoderm fragments observed to be directly coated by either bladed or equant calcite. Fringing bladed calcite (Plate 6) most commonly coats bryozoans, ooids and bivalves, but frequently is lacking. Syntaxial calcite is only found in the grainstones, packstones, oolites and, rarely, in the sandstones. Fringing bladed rim calcite is restricted to the grainstones and packstones. These three cements are reported to form in the meteoric phreatic environment (Bathurst, 1971; Longman, 1980; Flugel, 1982; and Harris, et. al, 1985). Calcium carbonate for cementation probably had a dual source: 1) from pressure solution and 2) from calcium carbonate liberated by dissolution in a zone of undersaturated meteoric water. This, however, cannot be demonstrated in these rocks.

Late-Stage Diagenesis

Late stage diagenesis includes those features that post-date meteoric cementation. Features included herein are corrosion of quartz boundaries, stylolitization, fracturing, silicification, dolomitization, formation of X-type matrix, dedolomite, quartz and calcite infilling of fractures and limonite precipitation.

Corrosion of quartz grain boundaries and partial replacement of other detrital grains by calcite (Plate 11) probably began early in the late stage of diagenesis, or even late in the middle stage. With increased burial, calcite precipitation is favored, whereas silica solubility increases (Thomas, 1983). The earliest possible timing of calcite replacement of detrital grains would be contemporaneous with cementation. Even if replacement did begin this early, it probably continued through late diagenesis as conditions became more favorable. Whenever quartz or other detrital grains (i.e., feldspars and rock fragments) are exposed to cement, some degree of replacement is noted, the least being finely pitted grain boundaries or corrosion and the maximum being total replacement. Oversize pores and "ghost grains" indicate total grain replacement. All lithologies with detrital grains adjacent to cement exhibit this type of replacement. With increasing matrix content there is a paucity of replacement and corrosion of detrital grains.

After meteoric cementation virtually occluded porosity, pressure solution at point contacts ceased as overburden stress was distributed more evenly and, if stress was sufficient, dissolution occurred along

surfaces perpendicular to the stress. This can cause reduction in rock volume, reducing sequences by up to 40% (Tucker, 1981) through the formation of stylolites (Plate 30). Also, if stress is sufficient, cementation makes the rock act brittle causing fractures (Plate 29, 30). Both of these features are present in all lithologies. Stylolitization may be either horizontal (parallel to bedding) or vertical (perpendicular to bedding). Horizontal stylolites were probably a result of overburden pressure, whereas vertical stylolites resulted from tectonically induced stresses. Later, small hair-line fractures parallel to bedding resulted from the release of overburden pressure.

A second stage of dolomitization occurred late in the diagenetic history of the Ste. Genevieve. Associated with this dolomite are chert/chalcedony/microquartz, dedolomite and X-type matrix. The dolomite is carbonate-matrix-selective (or micritic-grain-selective) and is, therefore, more common in the mudrocks, wackestones, packstones and oncolites. It is, however, still present in the remaining lithologies where carbonate-matrix or micritic allochems are present. Evidence for formation of this dolomite in subsurface waters after deep burial is threefold. First the finely crystalline nature (i.e. dolomicrite to dolomicrospar) and poor crystallinity indicates rapid crystallization at elevated temperatures and salinities (Folk, 1980). Second, the association of this dolomite with silicification suggests a late stage of diagenesis. Because silicification replaces all pre-existing carbonate constituents, it necessarily post-dates

meteoric cementation. Also, authigenic quartz is found infilling fractures which have already been demonstrated to be of late diagenetic origin. Finally, this dolomite is not restricted to any lithology or stratigraphic positioning suggesting this dolomitization was not influenced by meteoric water. Dedolomite and X-type matrix are exclusively associated with silicification, and, therefore, are also presumably of late diagenetic origin. These features also are found in all lithologies.

Two remaining diagenetic features, calcite infilling of fractures and the formation of limonite formed very late. In fact, they may represent alteration in the vadose zone. The calcium carbonate that infills fractures may have come from that liberated by stylolitization or from dissolution within the meteoric vadose environment (or both). All that is certain is that this calcite must post-date the fracture it fills. Limonite is finely disseminated throughout the matrix and stains grains. It most likely is a weathering product, although no conclusive evidence in support of this was found. However, two factors seem to suggest this origin. First, limonite is a common weathering product in many limestones. The pervasive occurrence of limonite throughout the subaerially exposed Ste. Genevieve in all lithologies may suggest weathering. Second, coarsely crystalline dolomite often has a rim of ferroan dolomite and a core of iron free dolomite. This rim may be a result of the incorporation of iron into the crystal lattice after precipitation of the dolomite. If so, this precludes an early timing for the formation of limonite.

Undetermined

Sufficient evidence was not present to postulate an environment or timing of formation for the following diagenetic features:

1) sericitization, chloritization and vacuolization of feldspars and low grade metamorphic rock fragments; 2) authigenic clay cement; and 3) neomorphism of micrite to microspar.

The feldspars within the Ste. Genevieve show considerable alteration. However, whether this alteration occurred before, during or after deposition is questionable. Three forms of alteration were commonly observed in the feldspars. Sericitization and chloritization were most frequently noted. Sericitization is the alteration or replacement of the feldspars by a fine grained white mica (Plate 10). In addition to the feldspars, chloritization also affects low grade metamorphic rock fragments). Microcline and perthite seem less susceptible to either sericitization or chloritization than plagioclase. Vacuolization is most common in plagioclase feldspars, but is also seen in potassium feldspar. Vacuolization is a dissolution process producing abundant small vacuoles which can be filled with fluids, organic material or other clay-sized particles. In feldspars, sericitization, chloritization and vacuolization occur preferentially along cleavage planes. This type of alteration is found in all lithologies where the susceptible grains are present.

The formation of authigenic clay as a cementing agent occurred on a very limited scale within the Ste. Genevieve. It was only recognizable under SEM, and, the exact nature of these clays is

questionable. They apparently were filling pore-spaces, but it could not be determined if these pores were inter- or intraparticle. Also, the substrate from which the clays grew was not always identifiable. Because of these unknowns, it is impossible to determine if the observed clays are actually pore-filling cement or alteration of detrital grains as described above. If actually present, clay cement seems to be restricted to the sandstone facies.

The last diagenetic feature for which timing was undetermined is the neomorphism of micrite to microspar. Almost all the microspar of the Ste. Genevieve probably formed from aggradational neomorphism of micrite. Several lines of evidence exist for this interpretation. Often, allochems are found "floating" in a matrix of microspar suggesting the presence of an original micrite matrix. Secondly, a gradational boundary between the microspar and micrite, found as isolated patches within the microspar, is common. The fact that microspar is restricted to low energy facies with abundant micrite also suggests a neomorphic origin.

DISCUSSION

During the Upper Mississippian a predominantly limestone sequence was deposited in the Central Appalachian Basin. This sequence includes the following formations: Little Valley Limestone, Hillsdale Limestone, Ste. Genevieve Limestone, Girkin Limestone, Fido Sandstone and Cove Creek Limestone. This carbonate sequence is situated between the Maccrady Shale and Price Formation below and the Pennington Formation above (Fig. 2). However, these carbonates contain considerable terrigenous-clastic deposits as evidenced by the siliciclastic dominated lithologies in the Ste. Genevieve, as well as the Little Valley Limestone (DiRenzo, 1986), the Hillsdale Limestone (Danahy, personal communication) and the Girkin and Cove Creek Limestones (Bergren, 1985). The source of detrital material was presumably from the highlands to the east associated with the Acadian orogeny and possibly a secondary source from the Canadian Shield to the north (deWitt and McGrew, 1979). Sandstone compositions of the Ste. Genevieve suggest a primary metamorphic source, perhaps derived from a collision orogen provenance described by Dickenson and Suczek (1979). However, there are also indications of a secondary sedimentary provenance or, at least, a mixed metamorphic/sedimentary terrain. The collision orogen provenance is consistent with an easterly source and can also account for a sedimentary source in the form of thrust sheets. The Virginia-Carolina River (deWitt and

McGrew, 1979) is believed to be the major source of terrigenous-clastic debris. Throughout the Late Devonian and Early Mississippian, clastic input slowed as the ancestral Appalachians were subdued. By latest Early Mississippian time, the Appalachian Basin was experiencing a major transgression in response to a eustatic rise in sea level (Vail, et. al., 1977b) which reached its peak during deposition of the uppermost Hillsdale (deWitt and McGrew, 1979). Following Hillsdale deposition, the seas again retreated. However, carbonate production continued until the clastics of the Pennington Formation capped the limestone package of the Upper Mississippian. The retreat of the sea and the return to a clastic depositional regime was in response to gentle upwarping and rejuvenation of the source area to the east (deWitt and McGrew, 1979).

The above scenario of an advance and retreat of the sea in response to regional (or global) events (tectonic and/or climatic) is representative of a second-order cycle of Miall (1984). Smaller-scale fluctuations are evident within the Ste. Genevieve and other formations of the Upper Mississippian limestone sequence (Bergren, 1985). These fluctuations are in response to local events such as rates of basin subsidence, local tectonics (i.e., uplift, faulting) and/or facies migration (i.e., delta or barrier complex). Within the Ste. Genevieve, at least two of the third- or fourth-order fluctuations are suggested by the recurrence of the bioclastic grainstones of the shoal environment. The Greendale Syncline represents the thickest accumulation of Mississippian strata in the

Appalachian Basin. None of the limestones of the Upper Mississippian are representative of deep water (slope to abyssal depths) accumulations (Bergren, 1985; DiRenzo, 1986; Danahy, personal communication). Therefore, considerable subsidence is required to account for the unusually thick sequence. Varying rates of subsidence are likely to have caused the small-scale sea level fluctuations noted during deposition of the Ste. Genevieve and other Upper Mississippian formations.

The small-scale fluctuations described above are believed to have influenced the distribution of facies as well as early diagenesis of the Ste. Genevieve. Local sea level fluctuations caused migration of the skeletal sand bar and, consequently, the associated depositional environments and resultant lithologies. During low stands of sea level, the skeletal sand shoals were exposed subaerially, forming a freshwater lens and consequent meteoric-marine mixing zone. This fluctuating mixing zone resulted in an early episode of dolomitization, and possible minor vadose cementation. However, it wasn't until a regional retreat of the seas brought meteoric waters into the pores of Ste. Genevieve sediments that the majority of cementation/diagenesis occurred.

CONCLUSIONS

1) The Ste. Genevieve Limestone of Washington County, Virginia, is a mixed carbonate/siliciclastic unit. Lithologies vary from detritus-free limestones to rocks with virtually equal parts of primary carbonate and siliciclastic detritus to clean sandstones.

2) Eight lithologies are recognized within the Ste. Genevieve and include: 1) mudrock, 2) siltstone, 3) sandstone, 4) wackestone, 5) packstone, 6) grainstone, 7) oolite and 8) oncolite. Local variation of these lithologies is so great that little correlation can be made between the studied sections.

3) The observed lithologies were deposited on a gently sloping homoclinal ramp with superimposed carbonate-sand bars.

4) Diagenesis is extensive and varied within the Ste. Genevieve. It began penecontemporaneously with deposition and continued through deep burial and subsequent uplift and exposure. The most ubiquitous features are calcite cementation and those related to compaction/pressure solution and silicification.

5) Global and local tectonism affected both deposition and diagenesis. Eustatic sea-level drop during Ste. Genevieve deposition is evidenced by the overall regressive arrangement of the observed lithologies. The drop in sea level also brought freshwater into the pore system of the Ste. Genevieve, resulting in the development of a meteoric phreatic environment where the majority of cementation took place. Local fluctuations are also recognized and are responsible for recurrence of lithologies and an early episode of dolomitization.

In the following plates photomicrographs were taken of thin sections stained with a combined solution of Alizarine Red S and potassium ferricyanide. Such a staining solution produces the following colors:

- iron-free calcite - red
- iron-poor calcite - muave
- iron-rich calcite - purple
- iron-free dolomite - unstained
- ferroan dolomite - light blue
- ankerite - dark blue

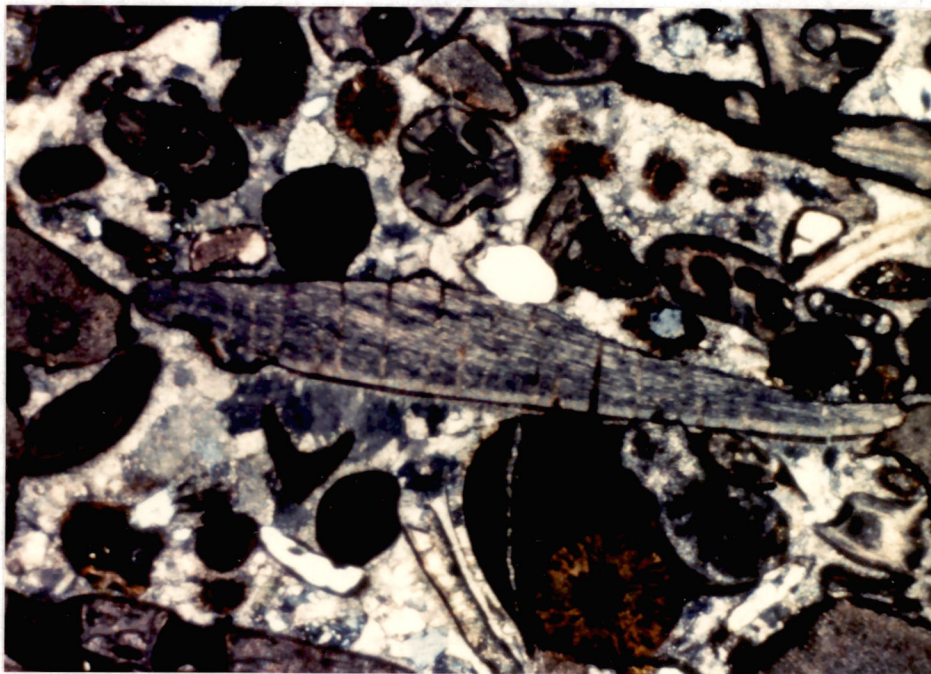


Plate 1. Photomicrograph of a typical grainstone from the beach environment. Note the punctate brachiopod in center and abundance of superficially coated grains (cortoids).

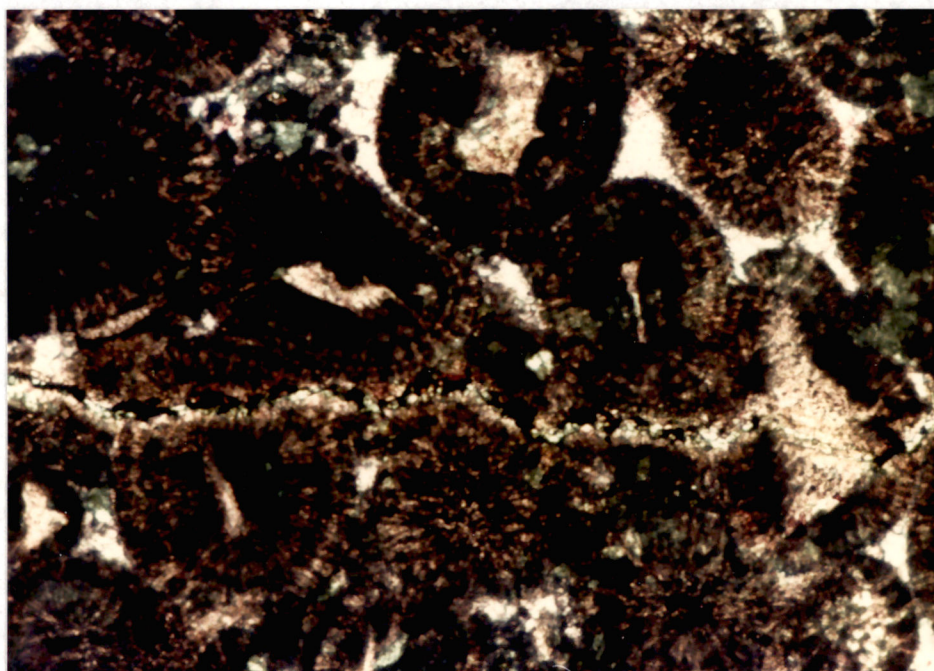


Plate 2. Photomicrograph of a typical oolite of the shoal environment predominated by normal ooids. Note partial replacement of ooids by X-type matrix (right center).

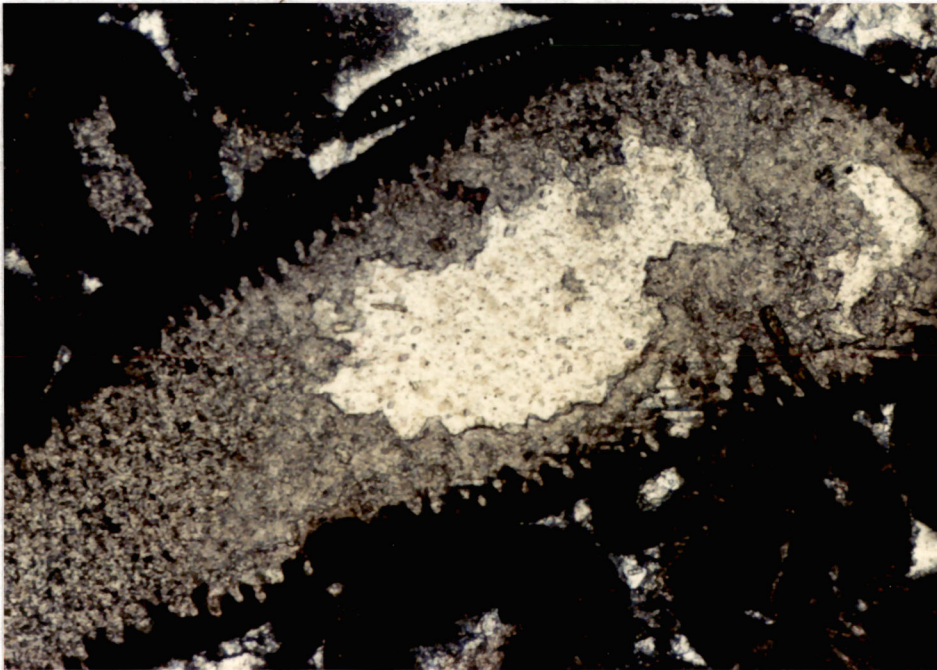


Plate 3. Photomicrograph of a partially silicified echinoderm fragment with a micrite envelope.

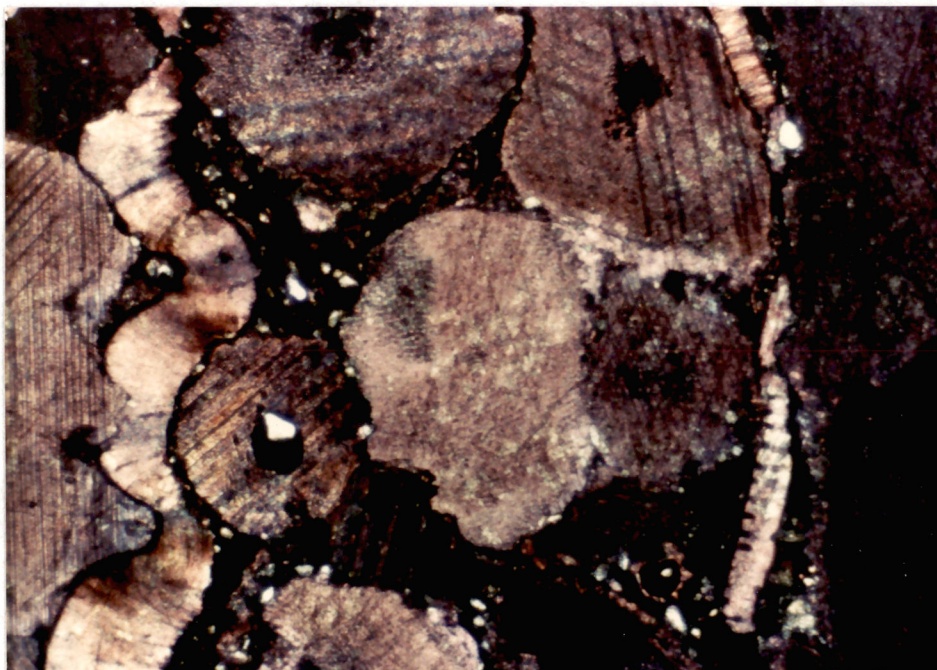


Plate 4. Photomicrograph of a typical grainstone from the shoal environment, characterized by a predominance of echinoderm fragments (crinoids) and a lack of detrital grains. Note recrystallization of allochems and also the trilobite fragment.

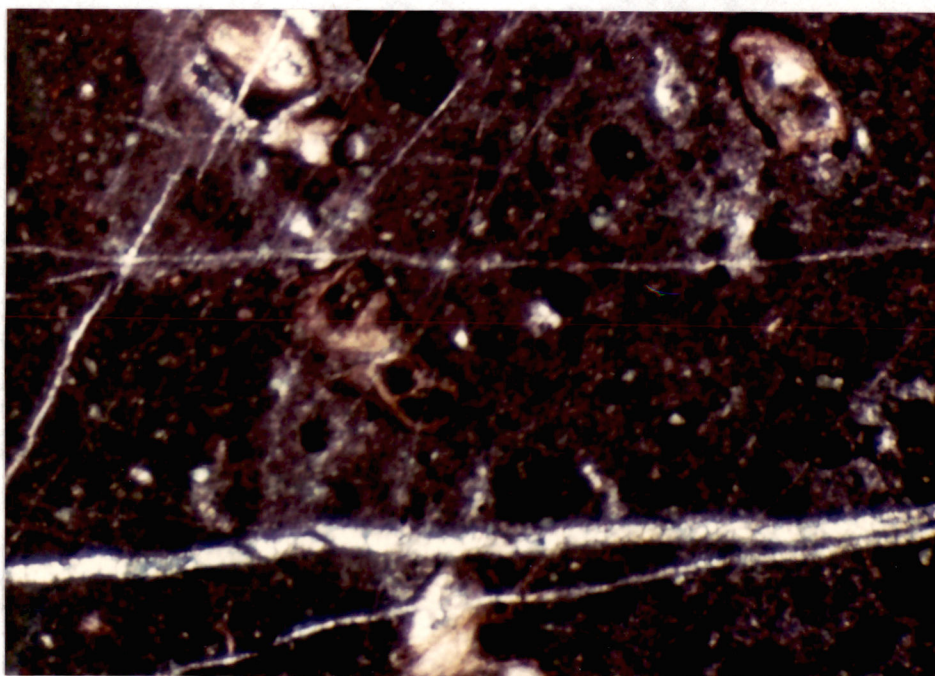


Plate 5. Photomicrograph of a typical lime-wackestone indicative of an offshore, open marine environment below wave base. These rocks are characterized by a micritic matrix and the predominance of fenestrate bryozoans.

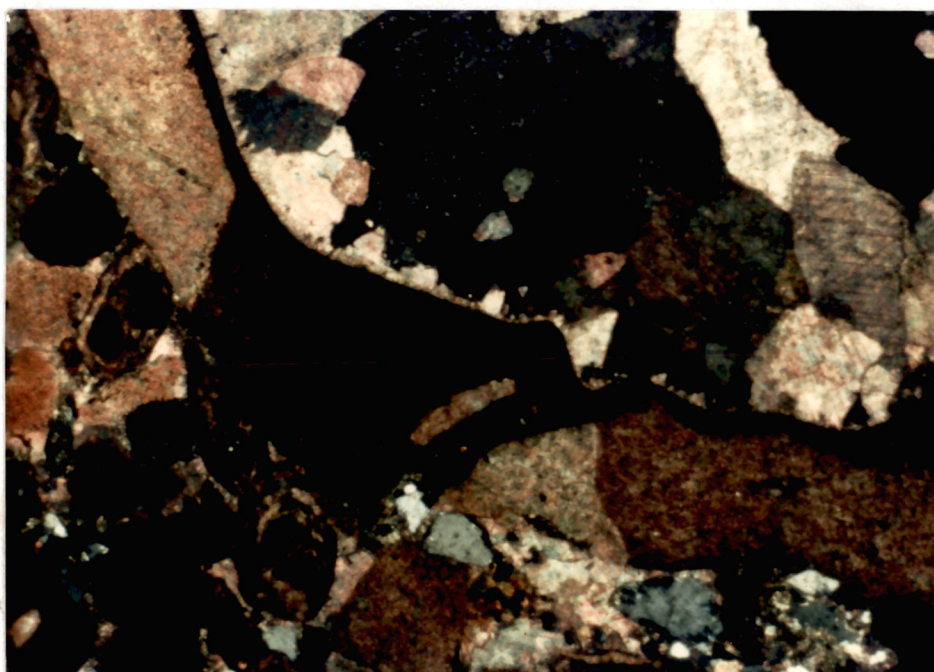


Plate 6. Photomicrograph of a pelecypod (identified by morphology) infilled by bladed and equant calcite cements.

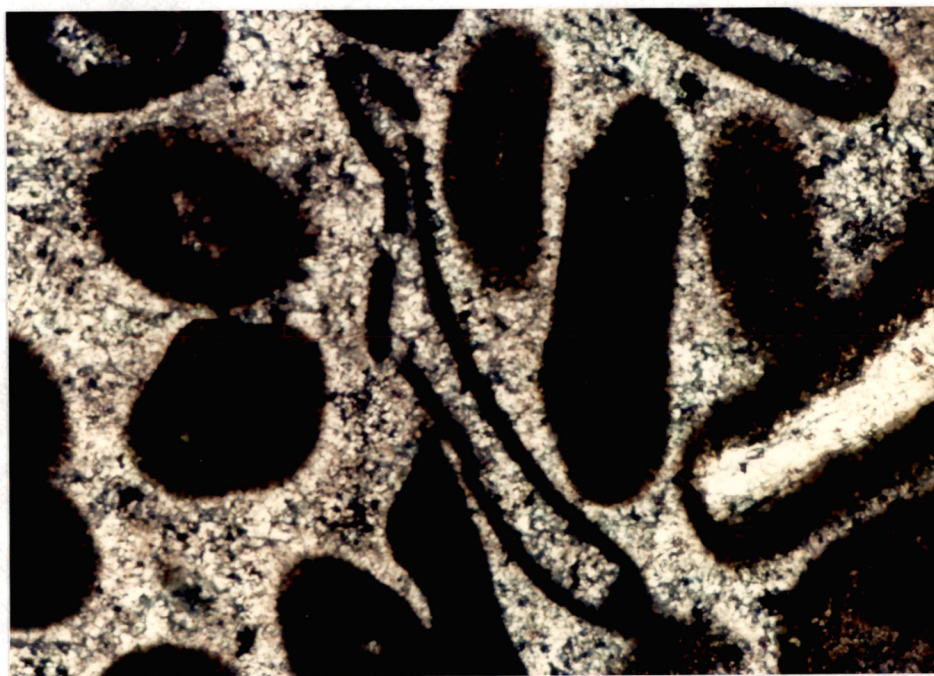


Plate 7. Photomicrograph of a cluster of totally micritized grains (probably of oolitic origin). Note fractured micrite envelope and fringing fibrous calcite rim cement.

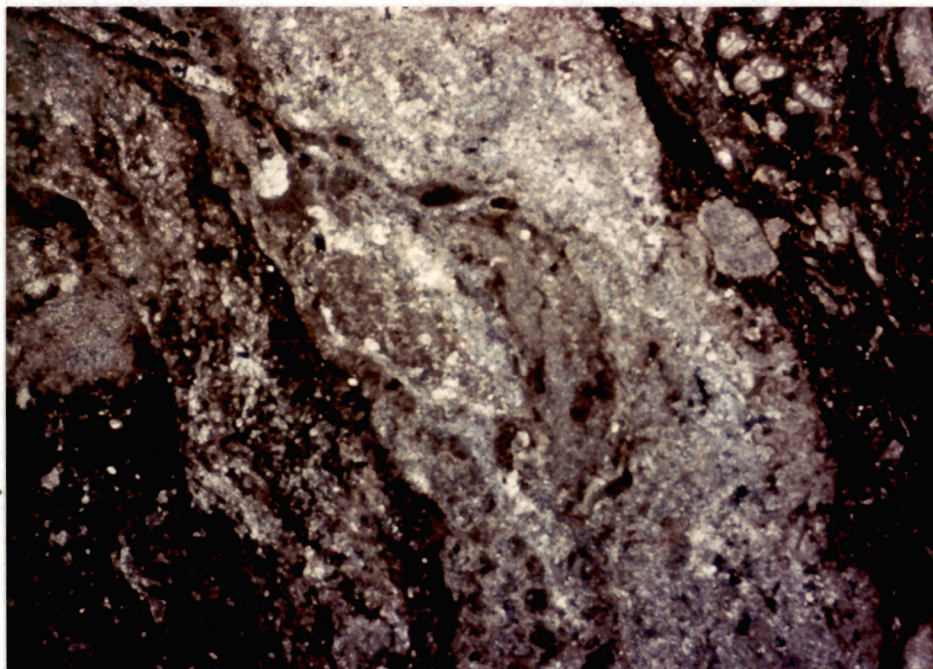


Plate 8. Photomicrograph of a portion of a partially silicified oncolite.

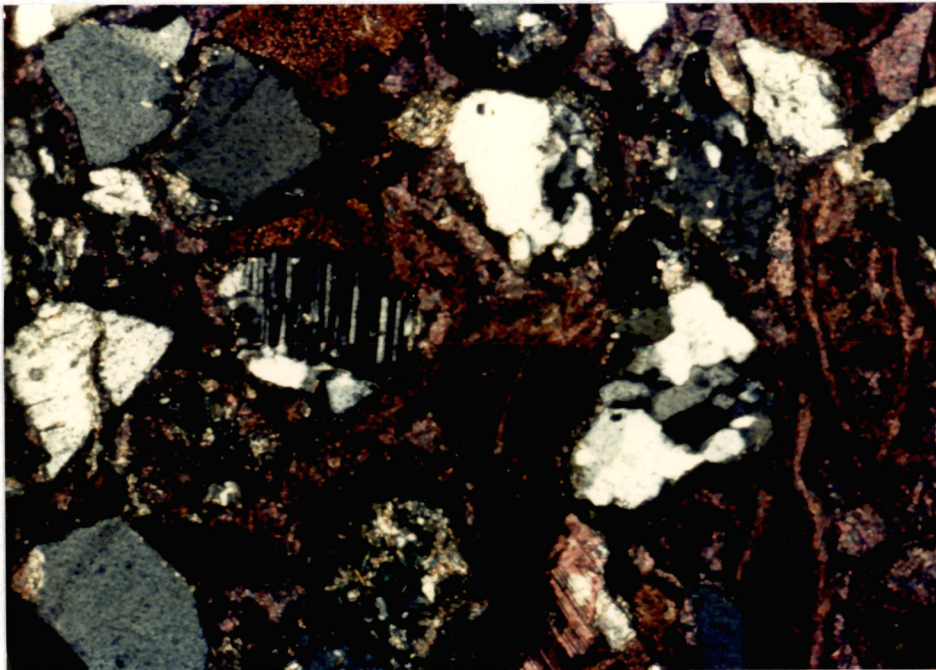


Plate 9. Photomicrograph of a typical sandstone from the beach environment composed of mono- and polycrystalline quartz, plagioclase (twinned) and rock fragments (sedimentary seen here).

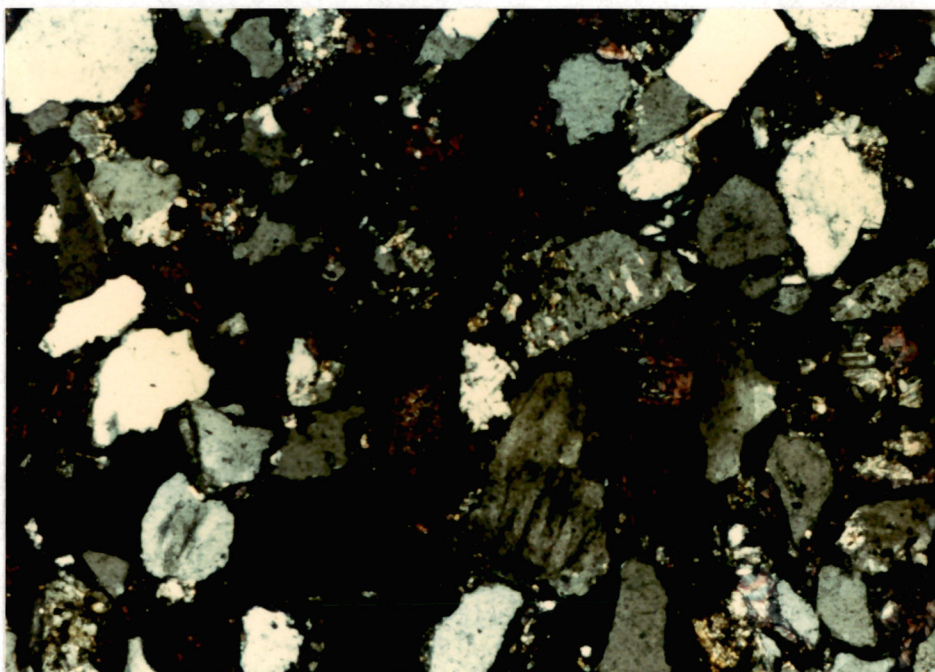


Plate 10. Photomicrograph of a typical sandstone from the beach environment. Note partially sericitized, untwinned plagioclase feldspar.



Plate 11. Photomicrograph of a "squeezed" micaceous metamorphic rock fragment around corroded and partially replaced (by calcite) quartz grains.



Plate 12. Photomicrograph of an argillaceous siltstone which has undergone compaction as evidenced by the strong alignment of the elongate muscovite grains.

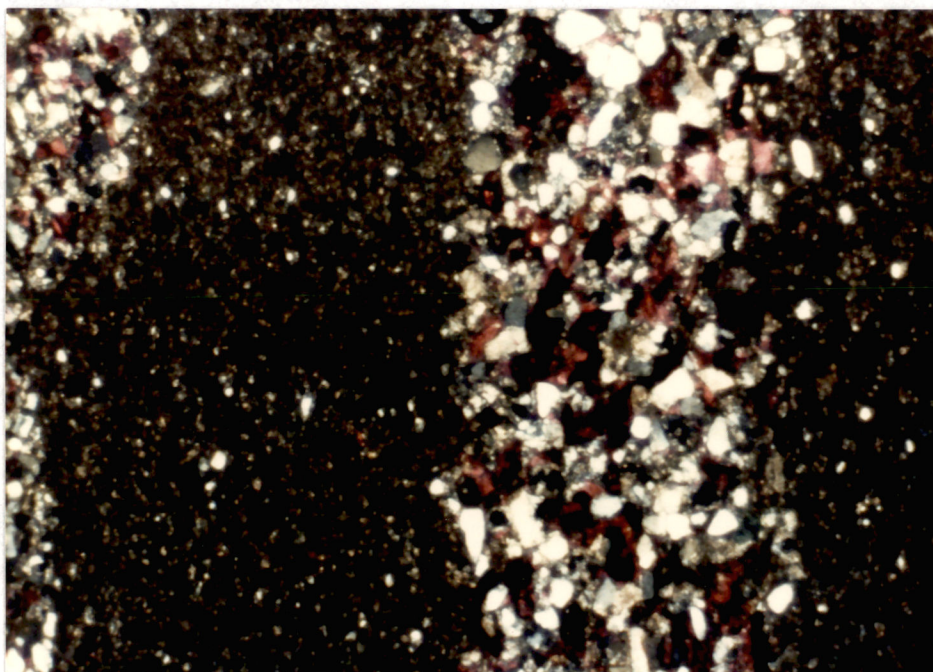


Plate 13. Photomicrograph of interlaminated
siliciclastic mudrock and
calcareneaceous siltstone.

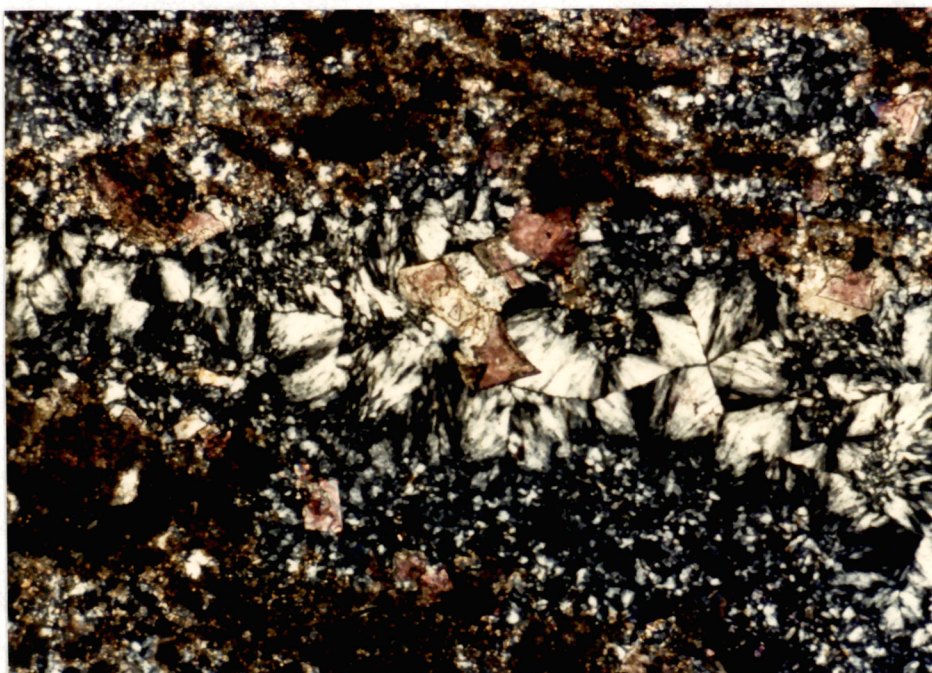


Plate 14. Photomicrograph of a "chert" nodule within a lime-wackestone. Rim of nodule is of chert/microquartz and core is of chalcedony. Note partial replacement of nodule by dolomite and dedolomite. Brown, non-descript material acting as matrix was not identified (X-type matrix).

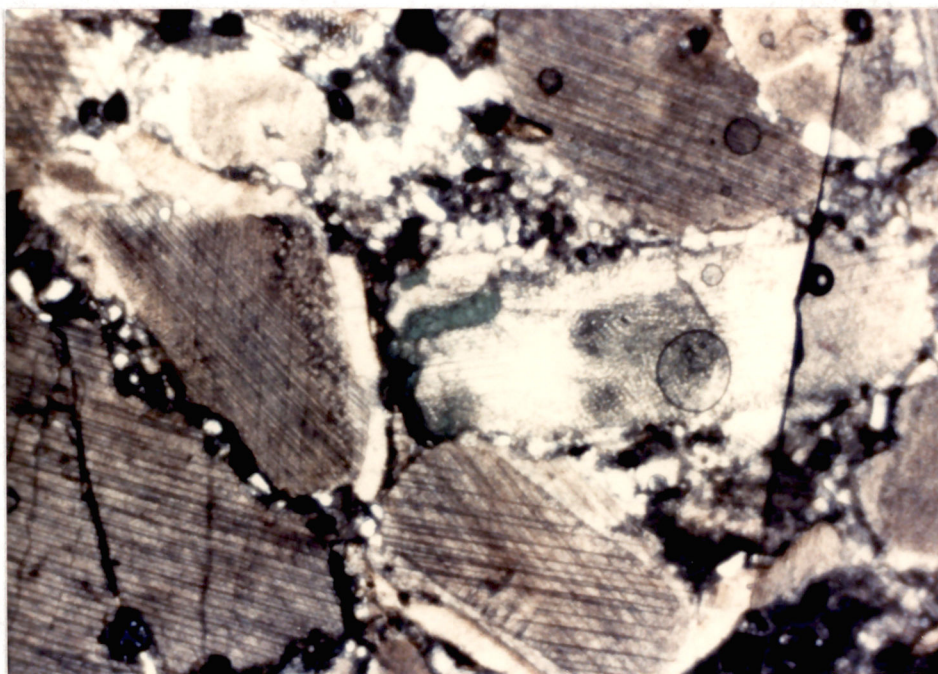


Plate 15. Photomicrograph of a shoal grainstone. Note partial replacement of echinoderm fragment by glauconite (center) and syntaxial calcite overgrowths of echinoderm fragments acting as cement.

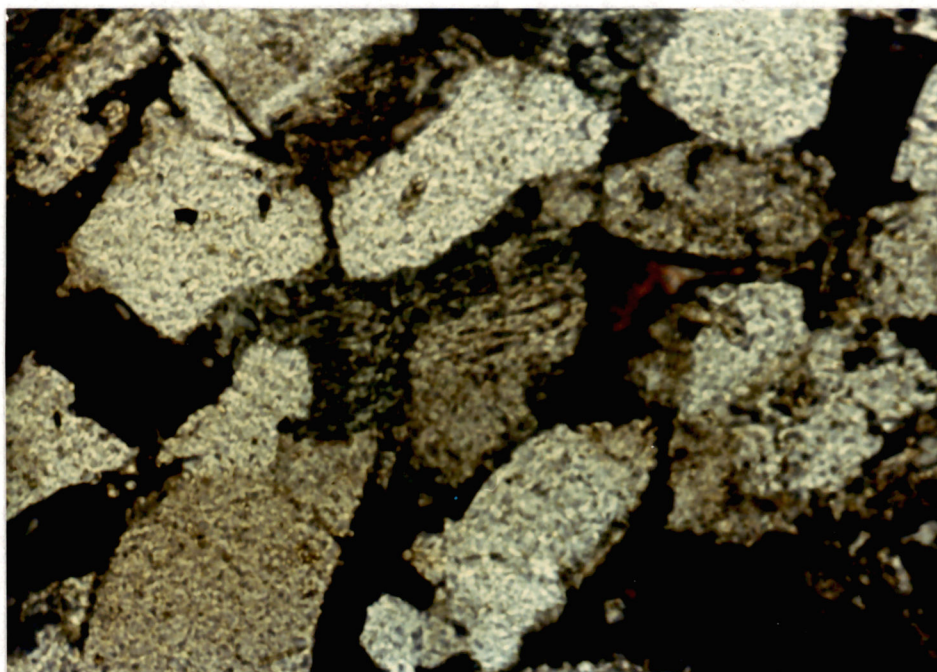


Plate 16. Photomicrograph of a sandstone indicative of more open marine conditions (from sands winnowed from the shoal). Note the pore-filling dolomite cement.

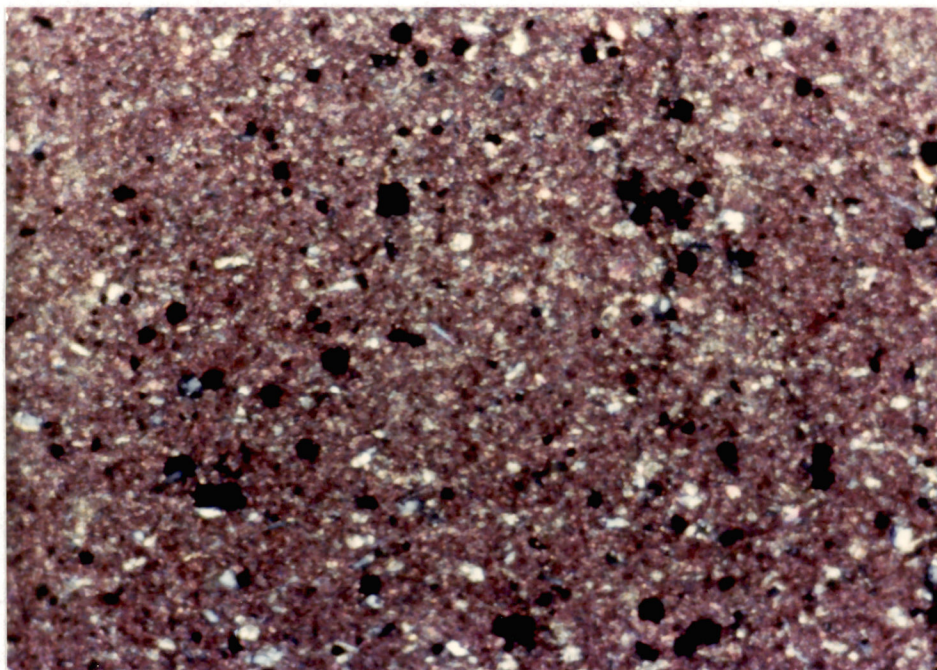


Plate 17. Photomicrograph of a mixed carbonate/
siliciclastic mudrock with abundant
opaque masses of pyrite.



Plate 18. Outcrop view of a mudrock with darker (more iron stained) interlamination of siltstone.



Plate 19. Bedding plane view of a typical mudrock showing highly bifurcated ripple marks (also typical of siltstones).



Plate 20. Outcrop view of a beach sandstone showing typical high-angle, small-scale cross-bedding which is also common in the beach grainstones and cortoid predominated oolites.



Plate 21. Highly chert-rich unit of lime-wackestone found near the base of all studied sections.

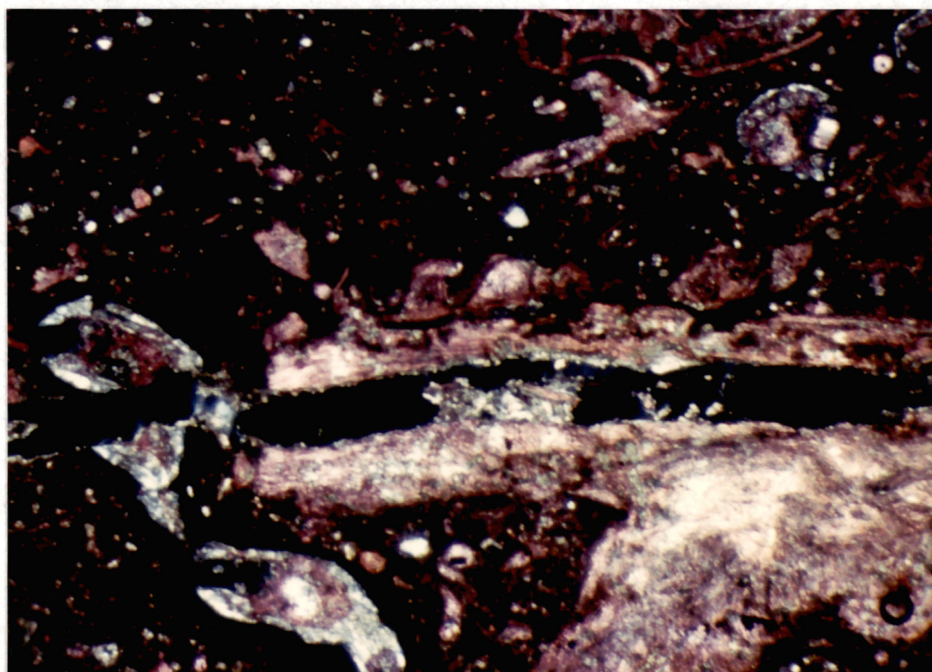


Plate 22. Photomicrograph of a typical Lime-packstone. Note partial silicification of allochems along the fracture.

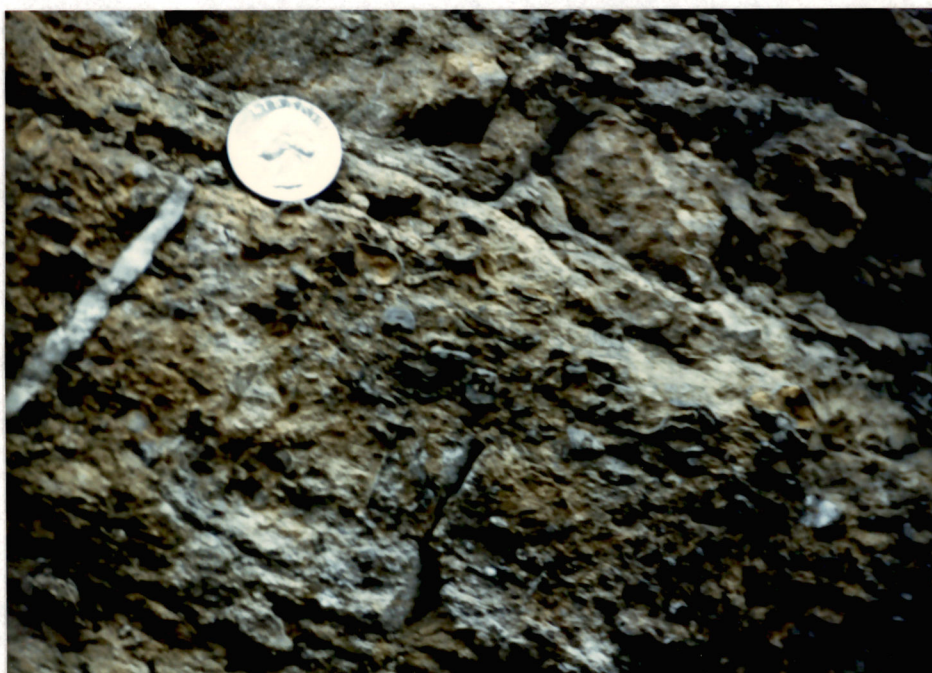


Plate 23. Outcrop view of a typical lime-packstone.



Plate 24. Large-scale, low-angle cross-bedding typical of shoal grainstones (pine in middle is about 2m in height).

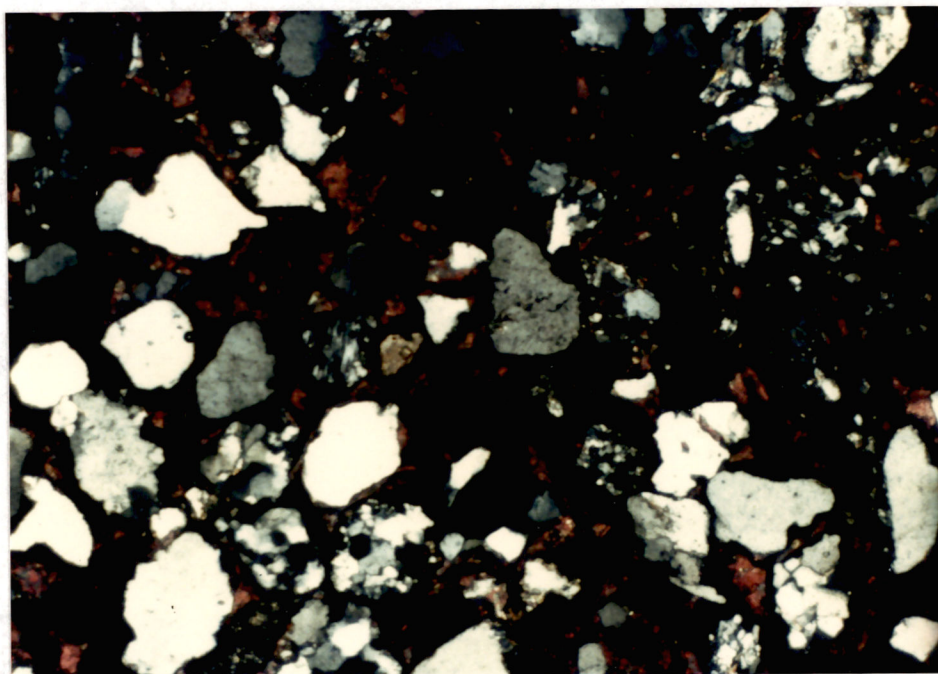


Plate 25. Photomicrograph of a very sandy, iron-rich, cortoid-predominated oolite indicative of a beach type environment. Note interpenetration of detrital grains into the less competent carbonate constituents.



Plate 26. The upper contact with the light grey, thin- to medium-bedded lime-mudstone of the lowermost Girkin Limestone is located at the top of a red calcarenaceous, oolitic, cross-bedded sandstone or very sandy oolite.



Plate 27. The Ste. Genevieve contact with the Hillsdale Limestone below is situated between the massive to thick-bedded limestones of the Ste. Genevieve and the thin-bedded, argillaceous limestones of the Hillsdale.



Plate 28. The ste. Genevieve guide fossil, the crinoid Platycrinus penicillus (circled).

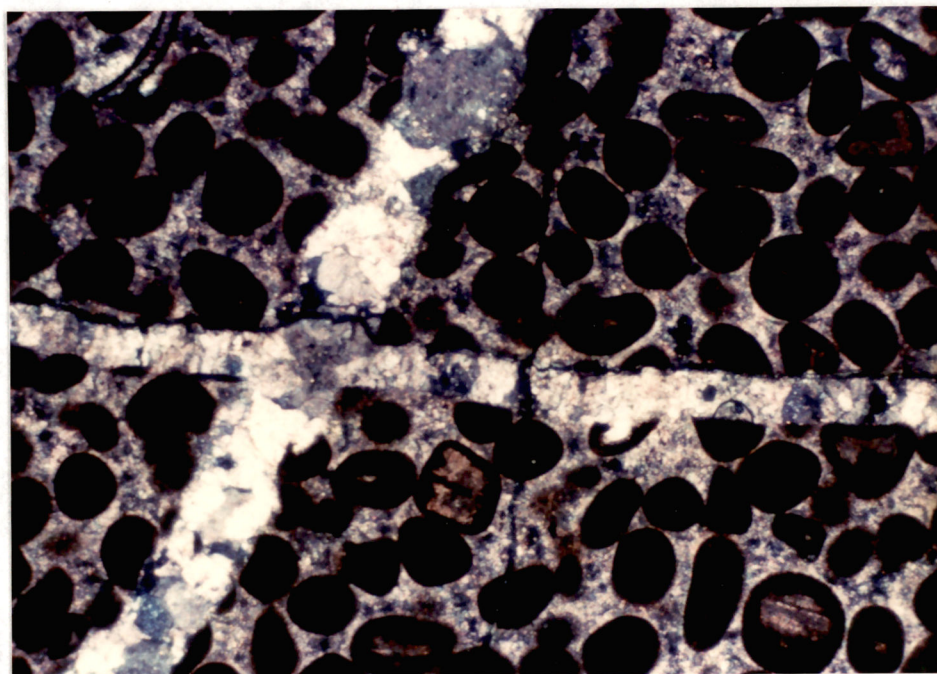


Plate 29. Photomicrograph of a shoal oolite with fringing fibrous calcite rim cement and subsequently formed fractures.

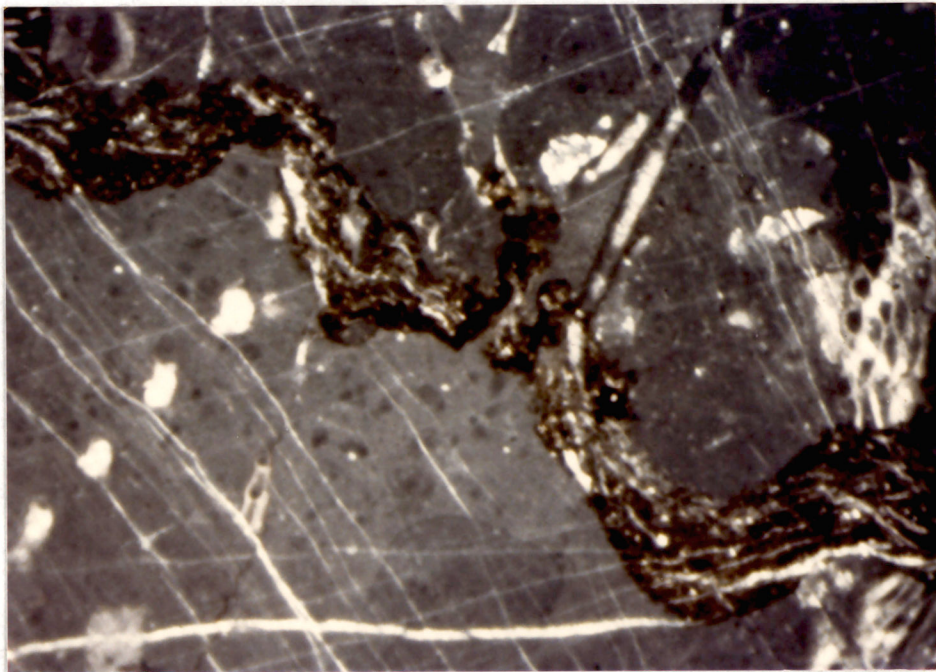


Plate 30. Photomicrograph of a lime-wackestone exhibiting strombolitization and subsequent fracturing.

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APPENDIX A

Measured Sections

Three outcrops were included in this study of the Ste. Genevieve Limestone, Washington County, Virginia. The top of all three studied sections are in contact with the Girkin Limestone. The base of sections 1 and 2 are in contact with the Hillsdale Limestone, whereas the base of section 3 is covered.

Location:

- 1) Greendale Section - U.S. Highway 19 (Alt. 58)
approximately 8km northwest of Abingdon, VA;
- 2) Hayters Gap Section - VA state route 80
approximately 9km northeast of Abingdon, VA;
- 3) Muddy Hollow Section - VA state route 798
approximately 10km north of Bristol, VA.

APPENDIX A
Measured Sections

Outcrop 1
(Greendale Section)

<u>Unit</u>	<u>Interval Thickness (m)</u>	<u>Cumulative Thickness (m)</u>
43. Grayish-red, massive, ooid-rich, fossiliferous, calcarenaceous, medium-grained sandstone.	6.1	0 - 6.1
42. Brownish-gray, medium-bedded, fossiliferous, coarse-grained siltstone.	2.4	6.1 - 8.3
41. Medium-dark gray, thin-bedded, ripple-laminated, silty, calcareous siliciclastic-mudrock.	5.2	8.3 - 13.5
40. Grayish-red, medium-bedded, intra-clast-rich, slightly sandy lime-packstone.	6.1	13.5 - 19.6
39. Medium olive-gray, medium-bedded, ripple-laminated, silty, calcareous siliciclastic-mudrock.	4.6	19.6 - 25.2
38. Light grayish-brown to dusky-red, thick- to medium-bedded, cross-bedded, fossiliferous, calcarenaceous sandstone with lime grain stone interbeds at top (< 1m thick).	15.3	25.2 - 40.5
37. Medium gray, medium-bedded, rippled, sandy, bioclastic packstone/grainstone. Lose mud up section and becomes cross-bedded.	15.3	40.5 - 55.8
36. Medium olive-gray, thin-bedded, weathers to subfissile, very silty, sandy, calcareous siliciclastic-mudrock.	12.2	55.8 - 68.0
35. Medium gray, medium-bedded, very sandy, ooid rich, bioclastic grainstone.	4.6	68.0 - 72.6
34. Medium-dark gray, thin to medium-bedded, ripple-laminated, very silty/sandy, calcareous siliciclastic-mudrock. Becomes more silty/sandy upsection.	18.9	72.6 - 91.5
33. Unfossiliferous, calcareous, medium-grained sandstone.	8.5	91.5 - 99.0

<u>Unit</u>	<u>Interval Thickness (m)</u>	<u>Cumulative Thickness (m)</u>
32. Medium gray, medium-bedded, unfossiliferous, calcareous medium-grained sandstone.	8.5	99.0 - 107.5
31. Dark gray, thin-bedded, mottled-laminated, silty, calcareous siliciclastic-mudrock.	7.6	107.5 - 115.1
30. Medium-dark gray, medium-bedded, slightly fossiliferous, calcareous, fine-grained sandstone.	3.1	115.1 - 118.2
29. Medium-dark gray, thin- to medium-bedded, cross-rippled, very silty, calcareous siliciclastic-mudrock.	8.8	118.2 - 127.0
28. Medium-dark gray, very fossiliferous, intraclast-rich, coarse-grained calcareous sandstone (channel fill).	3.4	127.0 - 130.4
27. Medium gray, medium-bedded, cross-bedded, slightly fossiliferous, calcareous, fine-grained sandstone.	10.7	130.4 - 141.1
26. Medium-dark gray, thin- to medium-bedded, ripple-laminated, slightly silty, calcareous siliciclastic-mudrock.	42.7	141.1 - 183.8
25. Dark gray, thin-bedded, ripple-laminated, slightly silty, argillaceous lime-wackestone.	6.7	183.8 - 190.5
24. Medium-light gray, massive bioclastic grainstone.	0.9	190.5 - 191.4
23. Medium-dark gray, thin-bedded, cross-ripple laminated, very argillaceous, calcareous siltstone.	12.2	191.4 - 203.6
22. Medium-light gray, thick-bedded, ooid bearing bioclastic grainstone with common shale intraclasts.	12.2	203.6 - 215.8
21. Medium-dark gray, very thin-bedded, ripple-laminated, weathers to subfissile, silty, calcareous siliciclastic-mudrock.	4.6	215.8 - 220.2
20. Medium-light gray, massive, slightly sandy, ooid bearing bioclastic grainstone.	2.1	220.2 - 222.3

<u>Unit</u>	<u>Interval Thickness(m)</u>	<u>Cumulative Thickness(m)</u>
19. Medium-dark gray, very thin-bedded, ripple-laminated weathers to subfissile, silty calcarenaceous siliciclastic-mudrock.	19.2	222.3 - 241.5
18. Medium brownish- to olive-gray, thin-bedded, weathers to subfissile, slightly silty, argillaceous lime-packstone.	12.5	241.5 - 254.0
17. Medium gray, very thin-bedded, ripple-laminated, slightly fossiliferous siliciclastic-mudrock.	16.5	254.0 - 270.5
16. Medium-dark gray, medium- to thick-bedded, interbedded, argillaceous siltstones and argillaceous, fine-grained sandstones. Both calcareous and fossiliferous.	25.0	270.5 - 295.5
15. Medium-dark gray, massive bioclastic grainstone.	2.1	295.5 - 297.6
14. Dark gray, thin-bedded, ripple-laminated, calcarenaceous, silty siliciclastic-mudrock.	1.8	297.6 - 299.4
13. Medium-dark gray, thick- to massive-bedded, bioclastic grainstone.	13.1	299.4 - 312.5
12. Variable colored, thin-bedded siltstone at base grading into thick-bedded, very fine-grained sandstone at top. Calcareous and slightly fossiliferous.	18.9	312.5 - 331.4
11. Medium gray, thick- to massive-bedded, large scale, low angle cross-bedding, bioclastic grainstone. Thin (<0.5cm) lenses/wedges of greenish-gray shale.	33.6	331.4 - 365.0
10. Medium-dark gray, thick- to massive-bedded, argillaceous, fossiliferous, calcarenaceous, fine-grained sandstone. Black chert nodules common at top. Fault separates chert bearing section from that below.	12.2	365.0 - 377.2
9. Medium-light gray, massive bryozoan/echinoderm grainstone.	3.1	377.2 - 380.3

<u>Unit</u>	<u>Interval Thickness (m)</u>	<u>Cumulative Thickness(m)</u>
8. Olive gray, thin-bedded, silty, argillaceous bryozoan/echinoderm wackestone.	4.3	380.3 - 384.6
7. Olive gray, thin-bedded, silty, fossiliferous, calcarenaceous siliciclastic-mudrock.	7.6	384.6 - 392.2
6. Medium-dark gray, very thin-bedded, weathers to subfissile, silty, argillaceous bryozoan wackestone.	15.3	392.2 - 407.5
5. Grayish-black, thick- to massive-bedded, fossiliferous, calcarenaceous, argillaceous siltstone.	10.4	407.5 - 417.9
4. Medium brownish-gray, thick-bedded oolite.	4.0	417.9 - 421.9
3. Medium gray, medium-bedded, chert-rich, bryozoan wackestone.	11.6	421.9 - 433.5
2. Medium-dark, olive-gray, thick-bedded, chert-rich oncolite.	13.7	433.5 - 447.2
1. Dark gray, thick-bedded oolite.	2.1	447.2 - 449.3

Outcrop 2
(Hayters Gap Section)

<u>Unit</u>	<u>Interval Thickness (m)</u>	<u>Cumulative Thickness (m)</u>
47. Grayish-red, thick-bedded, cross-bedded, very sandy, slightly, fossiliferous, oolitic grainstone.	3.1	0 - 3.1
46. Brownish-gray, massive- to thick-bedded, cross-bedded, fossiliferous, silty, fine-grained sandstone.	10.7	3.1 - 13.8
45. Brownish-gray, thick- to massive-bedded, very sandy, bryozoan, echinoderm bearing, ooid grainstone.	10.7	13.8 - 24.5
44. Brownish-gray, trough cross-bedded (channel), fossiliferous, calcareous sandstone with shale partings.	6.1	24.5 - 30.6
43. Medium gray, thick-bedded, cross-bedded, slightly sandy, ooid, bryozoan bearing, intraclast rich, echinoderm grainstone.	4.3	30.6 - 34.9
42. Medium gray, thin-bedded, ripple-laminated, fossiliferous, very silty, calcareous, siliciclastic-mudrock.	42.4	34.9 - 77.3
41. Medium gray, massive, intraclast rich, slightly vuggy, brachiopod, echinoderm bearing, bryozoan grainstone.	0.9	77.3 - 78.2
40. Medium-dark gray, massive, fossiliferous, calcarenaceous, fine-grained sandstone.	1.8	78.2 - 80.0
39. Medium gray, massive, slightly sandy, intraclast bearing, bryozoan rich, echinoderm grainstone.	0.9	80.0 - 80.9
38. Medium-dark olive-gray, thin-bedded, ripple-laminated, very silty, calcareous, siliciclastic-mudrock.	18.9	80.9 - 99.8
37. Very dark yellowish-brown, massive, intraclast rich, very sandy, bryozoan/echinoderm grainstone.	1.5	99.8 - 101.3
36. Medium gray, thin-bedded, ripple-laminated, silty, calcareous, siliciclastic-mudrock.	8.5	101.3 - 109.8

<u>Unit</u>	<u>Interval Thickness (m)</u>	<u>Cumulative Thickness (m)</u>
35. Dark gray, medium-bedded, mottled-laminated, slightly fossiliferous, calcarenaceous, fine-grained sandstone.	9.2	109.8 - 119.0
34. Medium-dark gray, medium-bedded, cross-bedded, very sandy, bryozoan/echinoderm grainstone.	9.2	119.0 - 128.2
33. Medium gray, thin-bedded, cross-rippled, argillaceous, calcareous, coarse-grained siltstone.	2.4	128.2 - 130.6
32. Medium-dark gray, medium- to thick-bedded, cross-bedded, sandy, bryozoan/echinoderm grainstone.	5.2	130.6 - 135.8
31. Medium gray, thin-bedded, cross-rippled, argillaceous, calcareous, coarse-grained siltstone.	35.1	135.8 - 170.9
30. Covered interval.	7.6	170.9 - 178.5
29. Medium-dark bluish-gray, thin- to medium-bedded, argillaceous, calcarenaceous, fine-grained sandstone (units 28 and 29 are gradational).	7.6	178.5 - 186.1
28. Medium-dark gray, thin-bedded, ripple-laminated, silty, calcareous, siliciclastic-mudrock with wispy laminations of siltstone.	18.3	186.1 - 204.4
27. Medium gray, thin-bedded, mottled, argillaceous, silty, echinoderm bearing, bryozoan wackestone.	4.6	204.4 - 209.0
26. Medium-dark gray, thin-bedded, ripple-laminated, silty, calcareous, siliciclastic-mudrock with wispy laminations of siltstone.	12.2	209.0 - 221.2
25. Medium gray, very thin-bedded, burrowed, argillaceous, calcareous siltstone with wispy laminations of siliciclastic-mudrock.	22.9	221.2 - 244.1
24. Medium-light gray, massive, stylolitized, echinoderm bearing, bryozoan wackestone.	3.1	244.1 - 247.2
23. Dark olive-gray, massive, brachiopod, intraclast, bryozoan bearing, poorly washed, echinoderm grainstone.	7.9	247.2 - 255.1
22. Covered interval.	3.7	255.1 - 258.8

<u>Unit</u>	<u>Interval Thickness (m)</u>	<u>Cumulative Thickness (m)</u>
21. Medium olive-gray, massive, ooid, intraclast, bryozoan bearing, echinoderm grainstone.	2.1	258.8 - 260.9
20. Covered interval.	6.1	260.9 - 267.0
19. Medium gray, massive, skeletal grainstone.	1.5	267.0 - 268.5
18. Dark gray, thin-bedded, ripple-laminated, silty, calcareous siliciclastic-mudrock. Weathers to fissile. Thin (5cm) interbeds of sandstone.	18.3	268.5 - 286.8
17. Medium-dark gray, thick-bedded, slightly mottled, very argillaceous, calcareous, fine-grained sandstone.	3.1	286.8 - 289.9
16. Medium-dark gray, thin-bedded, ripple-laminated, slightly fossiliferous, silty, calcareous, siliciclastic-mudrock.	29.0	289.9 - 318.9
15. Medium olive-gray, thin-bedded, wavy-laminated, fossiliferous, argillaceous, calcareous siltstone.	23.5	318.9 - 342.4
14. Covered interval.	8.5	342.4 - 350.9
13. Medium gray, massive, echinoderm/bryozoan grainstone.	1.5	350.9 - 352.4
12. Covered interval.	1.5	352.4 - 353.9
11. Medium olive-gray, thin- to medium-bedded, fossiliferous, argillaceous, calcareous siltstone.	12.2	353.9 - 366.1
10. Medium-dark gray, medium-bedded, rippled, siliciclastic-mudrock interlaminated with wispy skeletal grainstone.	1.5	366.1 - 367.6
9. Medium-dark gray, ripple-laminated, burrowed, silty, calcareous siliciclastic-mudrock.	7.6	367.6 - 375.2
8. Dark olive-gray, thin-bedded, slightly cherty, burrowed, very argillaceous, calcareous siltstone.	13.4	375.2 - 388.6
7. Medium-dark gray, thick- to massive-bedded, cross-bedded, bryozoan-rich, echinoderm grainstone.	18.3	388.6 - 406.9

<u>Unit</u>	<u>Interval Thickness (m)</u>	<u>Cumulative Thickness (m)</u>
6. Dark brownish-gray, medium-bedded, fossiliferous, very argillaceous, calcareous siltstone.	16.8	406.9 - 423.7
5. Dark brownish-gray, medium-bedded, bryozoan/echinoderm packstone.	7.6	423.7 - 431.3
4. Dark olive-gray, medium-bedded, fossiliferous, argillaceous, calcareous siltstone with sparse chert nodules.	10.7	431.3 - 442.0
3. Dark olive-gray, thick-bedded oncolite with abundant black chert nodules,	3.7	442.0 - 445.7
2. Dark olive-gray, thick-bedded, chert rich, peloidal/skeletal packstone/wackestone (increase in mud up section).	7.6	445.7 - 452.3
1. Dark olive-gray, thick-bedded oncolite with abundant black chert nodules.	8.8	452.3 - 461.1

Outcrop 3
(Muddy Hollow Section)

<u>Unit</u>	<u>Interval Thickness (m)</u>	<u>Cumulative Thickness (m)</u>
32. Medium olive-gray, thick-bedded, stylolitized, sandy oolite. Grades to pale brown at top.	6.1	0 - 6.1
31. Brownish-gray, thick-bedded, ooid bearing, calcarenaceous sandstone.	3.1	6.1 - 9.2
30. Pale grayish-red, thick-bedded, silty, bryozoan packstone.	3.4	9.2 - 12.4
29. Dark olive-gray, thick-bedded, very silty, lime-wackestone.	5.8	12.4 - 18.2
28. Brownish-gray, thick- to massive-bedded, ooid bearing, slightly fossiliferous, calcarenaceous sandstone.	3.1	18.2 - 21.3
27. Medium olive-gray, medium-bedded, sandy, bioclastic grainstone. Becomes reddish at top.	4.9	21.3 - 25.2
26. Medium-dark gray, thin-bedded, ripple-laminated, silty calcarenaceous siliciclastic-mudrock.	73.2	25.2 - 98.4
25. Covered interval.	6.1	98.4 - 104.5
24.. Dark gray, medium-bedded, ooid bearing bioclastic grainstone with common shaley intraclasts.	4.6	104.5 - 110.1
23. Covered Interval.	7.0	110.1 - 117.1
22. Medium gray bioclastic grainstone.	0.6	117.1 - 117.7
21. Covered interval.	4.6	117.7 - 122.3
20. Medium-dark gray, thin-bedded, mottle-laminated, slightly fossiliferous, calcareous siliciclastic-mudrock.	8.5	122.3 - 130.8
19. Covered interval.	9.8	130.8 - 139.6
18. Dark gray, thin-bedded, mottle-laminated, silty, argillaceous lime-mudstone.	12.2	139.6 - 151.8
17. Medium-dark olive-gray, thin-bedded, ripple-laminated, silty, calcarenaceous siliciclastic-mudrock.	33.6	151.8 - 185.4
16. Medium-dark gray, thick- to massive-bedded, bioclastic grainstone (large scale cross-bedding?).	10.4	185.4 - 195.8
15. Medium-dark gray, thick-bedded, fossiliferous, fine- to medium-grained, calcarenaceous sandstone.	10.7	195.8 - 206.5

<u>Unit</u>	<u>Interval Thickness (m)</u>	<u>Cumulative Thickness (m)</u>
14. Medium-dark gray, thick-bedded, very sandy, echinoderm rich, lime-packstone.	6.1	206.5 - 212.6
13. Covered interval.	4.6	212.6 - 215.2
12. Medium-light gray bioclastic grainstone.	0.9	215.2 - 216.1
11. Grayish-black, medium-bedded, highly silicified, lime-wackestone.	10.7	216.1 - 226.8
10. Covered interval.	4.6	226.8 - 231.2
9. Light to medium gray, thick-bedded, bioclastic grainstone with abundant stylolites.	11.6	231.2 - 242.8
8. Medium to dark gray, medium- to thin-bedded, echinoderm/bryozoan wackestone/packstone (becomes more fossiliferous up section).	10.7	242.8 - 253.5
7. Dark gray, thick-bedded, bioclastic grainstone. Becomes more oolitic up section. Abundant chert nodules.	9.2	253.5 - 262.7
6. Medium greenish-gray, ripple-laminated, very fine-grained, calcarenaceous sandstone with thin (2cm) interbeds of blue-gray coarse-grained sandstone.	7.6	262.5 - 270.3
5. Dark olive- to medium gray, chert rich, bryozoan/echinoderm packstone/wackestone.	12.2	270.3 - 282.5
4. Dark gray, medium-bedded, slightly fossiliferous, chert bearing, calcarenaceous, fine-grained sandstone.	10.7	282.5 - 293.2
3. Brownish-black echinoderm grainstone.	1.5	293.2 - 294.7
2. Brownish-black, thick-bedded, chert rich oncolite.	4.6	294.7 - 299.3
1. Brownish-gray, thick-bedded, bryozoan/echinoderm wackestone.	6.1	299.3 - 305.4

APPENDIX B

Point Count Data

Below is a list of abbreviations used in this appendix.

OOID = ooid	INTR = intraclast
ECHI = echinoderm	BRYO = bryozoan
BRAC = brachiopod	PELE = pelecypod
PELO = peloid	FORA = foraminifera
TRIL = trilolite	OSTR = ostracode
GAST = gastropod	ONCO = oncoid
CALC = calcisphere	HASH = unidentifiable
QUTZ = quartz	skeletal hash
ROFS = rock fragments	FELD = feldspar
MUSC = muscovite	ACCE = accessory minerals
MICI = micrite	MICR = microspar
X-TY = X-type matrix	CLAY = clay
SILT = silt	SYNT = syntaxial calcite
EQUA = equant calcite	BLAD = blade calcite
FIBR = fibrous calcite	FDOL = finely
CDOL = coarsely	crystalline dolomite
crystalline dolomite	CHER = chert
CHAL = chalcedony	MQTZ = microquartz
OTHE = other	PORE = porosity

Outcrop 1 Greendale Section

	OOD	INTR	ECHI	BRYO	BRAC	PELE	PELO	FORA	TRIL	OSTR	GAST	ONCO	CALC	NASH	OUTZ	ROFS	FELD	MUSC	ACCE
SG-78	63.9	-	0.3	-	-	1.0	4.3	-	-	-	-	-	-	-	-	-	-	-	-
SG-77	-	-	5.3	7.5	0.3	0.3	4.1	-	-	-	-	4.7	-	9.1	1.9	-	-	-	-
SG-76	-	-	-	-	-	-	-	-	-	-	-	99.9	-	-	-	-	-	-	-
SG-75	-	-	6.9	10.8	0.3	0.3	0.3	-	-	-	-	-	-	11.1	1.6	-	-	-	-
SG-74	49.2	5.0	13.4	8.5	2.8	1.2	1.6	-	0.3	-	1.7	-	-	3.4	-	-	-	-	-
SG-73	-	-	0.6	4.1	-	-	-	-	-	-	-	-	1.3	43.1	4.4	-	0.3	0.3	-
SG-71	-	-	10.6	27.8	-	1.3	-	-	-	-	-	-	-	5.3	3.4	-	-	-	-
SG-69	-	-	4.0	10.2	-	0.3	-	-	-	-	-	-	-	7.9	5.6	-	-	-	-
SG-65	-	-	5.9	0.6	-	-	-	-	-	-	-	-	-	8.6	27.0	7.7	-	1.2	-
SG-62	0.6	-	47.9	20.9	2.2	0.3	0.6	-	-	-	-	-	-	5.6	0.3	-	-	-	0.3
SG-59	0.3	0.6	48.0	20.1	2.3	2.3	0.3	-	-	-	0.3	-	-	-	1.9	0.3	-	-	-
SG-57	-	-	-	-	-	-	-	-	-	-	-	-	-	4.1	34.3	6.4	-	-	-
SG-54	-	-	-	-	-	-	-	-	-	-	-	-	-	2.6	46.3	5.4	-	0.6	-
SG-52	-	-	1.5	1.5	-	-	-	-	-	-	-	-	-	5.4	31.0	8.6	-	0.9	-
SG-50	1.3	0.3	49.7	14.2	2.6	1.3	0.6	-	-	-	-	-	-	3.0	7.6	0.3	0.3	-	-
SG-49	-	-	16.9	5.1	0.3	1.2	0.3	-	-	-	-	-	-	6.0	11.8	2.7	1.5	0.6	0.6
SG-46	-	-	3.3	1.5	-	-	-	-	-	-	-	-	-	12.2	3.3	2.7	0.9	0.9	-
SG-43	-	-	-	-	-	-	-	-	-	-	-	-	-	4.8	6.6	0.3	-	0.6	-
SG-41	-	-	38.0	14.8	1.2	0.3	-	-	-	0.3	-	-	-	4.3	0.3	-	-	-	-
SG-39	-	-	0.3	2.7	0.6	-	-	-	-	-	-	-	1.5	21.3	3.3	0.3	-	-	0.3
SG-36	-	-	1.9	0.6	0.3	-	-	-	-	-	-	-	-	6.1	6.1	1.2	-	1.0	-
SG-33	-	-	2.9	-	-	-	-	-	-	-	-	-	-	6.6	7.5	0.3	0.3	1.4	-
SG-31	-	-	-	-	-	-	-	-	-	-	-	-	-	2.2	2.2	-	-	1.9	-
SG-29	-	-	0.9	-	-	-	-	-	-	-	-	-	-	4.1	10.7	0.6	0.6	2.3	-
SG-26	-	-	0.6	-	-	-	-	-	-	-	-	-	-	3.9	11.4	-	0.6	4.2	0.3
SG-24	-	-	2.3	-	-	-	-	-	-	-	-	-	-	8.2	52.7	7.3	2.9	-	0.3
SG-23	1.2	1.2	5.2	10.4	0.9	-	1.8	-	-	-	-	-	-	7.0	25.0	22.0	3.4	-	-
SG-20	-	-	2.7	-	-	-	0.3	-	-	-	-	-	-	5.8	44.0	8.8	3.4	0.9	0.6
SG-16	-	-	-	-	-	-	-	-	-	-	-	-	-	6.0	18.2	3.8	0.6	3.4	0.9
SG-14	6.3	0.3	12.2	18.2	0.9	0.3	3.6	-	-	-	-	-	-	3.3	23.6	4.8	4.2	-	-
SG-13	0.6	-	1.6	1.3	-	-	0.6	-	-	-	-	-	-	8.5	21.6	3.9	1.0	1.0	0.3
SG-12	2.1	2.1	14.2	11.4	2.4	4.5	0.3	-	-	0.3	-	-	-	2.4	0.6	-	-	-	-
SG-11	1.0	1.6	13.4	21.6	0.7	0.7	1.6	0.3	0.3	-	-	-	-	9.8	20.3	5.9	1.6	-	0.3
SG-8	-	-	0.3	6.2	2.6	-	-	-	-	-	-	-	-	12.1	41.8	8.8	4.5	0.6	0.3
SG-7	12.8	0.3	11.3	27.2	1.9	0.6	0.9	-	0.6	-	0.6	-	-	5.3	14.0	0.3	0.3	-	-
SG-5	0.3	0.9	8.5	15.4	-	0.3	-	-	-	-	-	-	-	1.2	6.6	-	0.3	-	0.3
SG-2	-	-	5.1	11.2	-	-	-	-	-	-	-	-	-	4.8	26.3	2.3	1.0	1.3	-
SG-1	20.8	-	3.8	1.3	-	-	-	-	-	-	-	-	-	5.0	33.3	14.5	5.7	0.3	0.3

	MICI	MICK	X-TY	CLAY	SILT	SYNT	EQUA	BLAD	FIBR	FDOL	CDOL	CHER	CHAL	MOZZ	OTHE	PORE
-	-	-	-	-	-	-	24.3	-	6.2	-	-	-	-	-	-	-
60.4	2.8	-	-	-	2.2	-	-	-	-	-	-	-	-	-	1.3	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	-
33.8	5.6	5.9	0.3	4.3	-	-	-	-	-	2.6	-	12.8	-	-	2.0	1.3
3.4	0.3	0.3	-	-	0.6	9.3	-	-	-	-	-	0.3	-	-	0.3	-
-	-	-	18.7	19.1	-	-	-	-	-	2.5	-	0.6	-	-	4.7	-
-	-	-	24.7	13.1	-	1.6	-	-	-	6.9	-	0.3	-	-	3.6	1.3
-	-	5.9	24.7	11.9	-	0.3	-	-	-	11.2	-	16.8	0.3	-	0.6	-
-	0.3	3.6	9.2	8.6	-	6.5	-	-	-	10.4	5.9	3.6	-	-	0.9	-
0.9	0.3	-	-	3.1	12.1	4.9	-	-	-	-	-	-	-	-	0.6	-
-	1.0	-	-	1.3	16.9	3.6	-	-	-	-	-	0.6	-	-	-	-
-	-	0.3	14.6	12.7	-	3.8	-	-	-	8.2	4.8	2.5	-	-	2.5	0.9
-	-	0.3	10.5	8.8	-	3.4	-	-	-	7.1	4.8	2.0	-	-	5.1	1.1
-	-	0.3	14.0	11.6	-	6.8	-	-	-	6.8	5.9	0.6	-	-	5.1	-
0.6	-	0.3	-	0.3	9.9	4.3	-	-	-	1.3	0.3	1.0	-	-	0.3	-
3.0	2.1	0.6	21.4	12.1	0.6	5.1	-	-	-	0.9	1.8	0.6	-	-	3.9	0.6
5.5	3.9	0.9	21.3	9.1	-	10.0	-	-	-	4.6	-	0.6	-	-	4.9	0.6
-	-	-	70.2	7.6	-	2.2	-	-	-	3.8	0.6	0.3	-	-	1.9	0.9
17.9	1.5	0.6	9.3	6.2	-	0.3	-	-	-	-	-	0.9	-	-	2.5	1.8
6.7	1.2	0.6	37.1	12.5	-	-	-	-	-	1.2	-	3.6	-	-	4.2	-
3.8	1.6	1.0	51.3	17.0	-	0.6	-	-	-	1.6	-	2.2	-	-	0.6	0.3
1.7	6.0	-	41.0	27.2	-	0.6	-	-	-	1.4	0.6	-	-	-	8.0	0.6
-	42.8	-	0.3	5.9	-	-	-	-	-	2.5	-	-	-	-	2.2	-
3.4	-	0.3	44.3	16.8	-	3.4	-	-	-	4.9	0.3	1.7	-	-	1.2	-
1.3	-	-	43.3	22.1	-	4.2	-	-	-	3.3	-	0.6	-	-	1.0	1.0
-	-	-	3.0	0.3	-	10.2	-	-	-	-	10.2	1.6	-	-	1.6	-
-	0.9	-	0.6	-	0.6	17.1	-	-	-	2.1	0.6	-	-	-	1.2	-
-	-	0.6	9.5	-	0.3	9.5	-	-	-	-	10.1	0.6	-	-	1.8	1.2
9.0	-	-	31.3	21.6	-	0.9	-	-	-	0.9	0.9	-	-	-	1.2	0.9
1.5	0.3	0.6	-	0.3	3.3	10.4	-	-	-	1.8	-	1.5	-	-	2.2	-
3.6	1.3	0.3	29.1	10.5	-	11.4	-	-	-	0.3	0.6	0.6	-	-	1.3	0.3
40.1	0.9	-	6.3	1.8	0.6	13.8	-	-	-	-	-	-	-	-	2.1	-
0.3	1.3	-	-	2.9	1.3	11.5	-	-	-	1.0	1.0	0.3	-	-	1.6	-
0.3	-	0.3	2.6	2.0	0.3	9.1	-	-	-	1.0	-	0.3	-	-	6.5	-
0.9	0.9	-	0.3	4.7	3.1	10.6	-	-	-	-	-	-	-	-	1.1	-
51.8	3.0	-	1.2	4.5	-	1.2	-	-	-	-	-	0.3	-	-	7.4	-
4.5	2.2	0.6	18.6	12.5	-	1.5	-	-	-	1.0	2.6	1.0	-	-	1.0	-
-	0.9	0.6	-	-	1.6	8.8	-	-	-	0.3	0.9	0.3	-	-	1.4	-

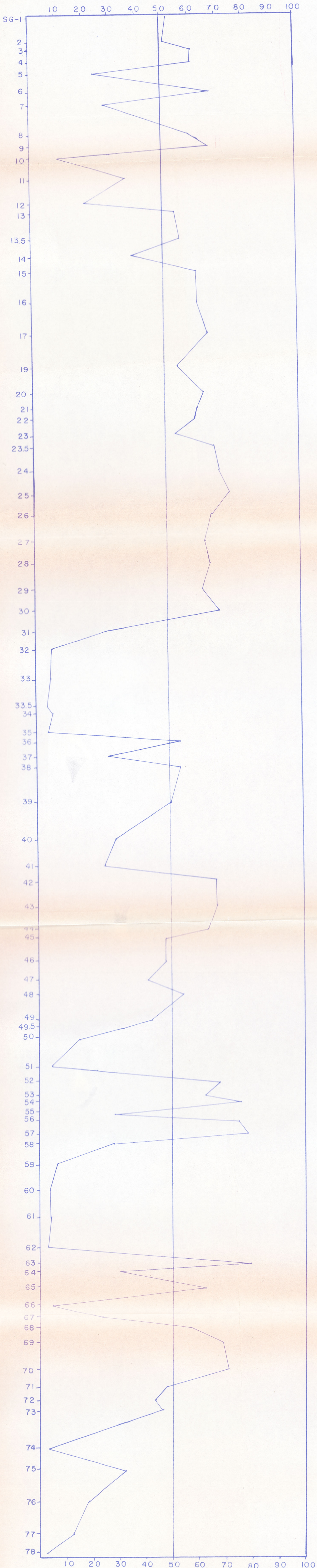
Outcrop 2 Hayters Gap Section

	UNIT	INT	FEET	PROD	BRAC	FEET	FEET	FOPA	TRIL	OSTR	GAST	UNCO	CALL	HASH	UNIT	RUFF	FEET	MISC	ACCI
A-4	-	-	-	-	-	-	-	-	-	-	-	99.9	-	-	-	-	-	-	-
A-6	-	-	-	-	-	-	-	-	-	-	-	99.9	-	-	-	-	-	-	-
A-7	-	-	8.7	18.2	0.3	-	-	-	-	-	-	-	-	0.7	-	-	-	-	-
A-9	-	0.3	10.3	41.0	2.7	2.7	-	0.3	-	0.3	-	-	-	-	4.0	-	-	-	-
A-9	-	-	15.0	2.8	-	-	-	-	-	-	-	-	-	1.1	-	-	-	-	-
A-10	-	-	55.0	22.0	6.0	2.0	-	-	-	-	-	-	-	-	0.3	-	-	-	-
A-11	0.6	-	7.9	24.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HC-3	-	-	1.2	1.9	-	-	-	-	-	-	-	-	-	12.1	7.6	8.4	0.6	-	-
HC-5	1.0	-	3.7	1.4	-	-	-	-	-	-	-	-	-	21.4	28.2	3.1	0.7	-	-
HC-9	-	-	2.3	0.6	-	-	-	-	-	-	-	-	-	12.4	21.8	4.6	1.0	1.0	-
HC-11	-	-	1.3	3.6	-	-	-	-	0.3	-	-	-	-	-	9.9	2.0	0.3	0.3	-
HC-13	-	-	1.0	-	-	-	-	-	-	-	-	-	-	12.3	11.7	0.9	-	1.0	-
HC-14	-	-	1.2	0.3	-	-	-	-	-	-	-	-	-	7.2	19.6	4.6	0.9	-	-
HC-16	-	-	1.5	0.3	-	-	-	-	-	-	-	-	-	21.5	13.4	2.3	0.6	-	-
HC-18	8.1	2.2	20.6	24.0	5.0	1.9	2.8	-	0.3	-	-	-	-	2.8	-	-	-	-	-
HC-19	0.6	0.9	15.1	13.0	0.9	-	0.3	-	-	-	-	-	-	2.1	-	-	-	-	-
HC-21	-	-	-	-	-	-	-	-	-	-	-	-	-	14.7	10.5	7.5	1.5	0.6	0.3
HC-23	-	-	8.7	8.0	0.3	0.3	-	-	-	-	-	-	-	2.7	2.7	0.3	-	-	-
HC-25	-	-	0.3	-	-	-	-	-	-	-	-	-	-	4.5	23.0	2.8	0.6	2.6	-
HC-27	1.5	-	2.7	2.1	-	-	-	-	-	-	-	-	-	15.0	39.0	12.0	4.5	-	-
HC-29	0.3	-	1.0	0.3	-	-	-	-	-	-	-	-	-	10.3	13.5	9.4	1.6	1.6	0.6
HC-33	-	-	0.6	-	-	-	-	-	-	-	-	-	-	7.8	10.5	8.5	0.3	2.3	-
HC-36	5.0	-	16.1	11.5	1.5	0.3	3.1	1.2	0.6	-	-	-	-	6.2	19.3	8.6	4.0	-	0.3
HC-38	-	-	1.2	0.3	-	-	-	-	-	-	-	-	-	12.0	39.5	9.5	1.8	0.3	0.3
HC-40	-	-	-	-	-	-	-	-	-	-	-	-	-	7.5	5.5	1.0	0.3	3.6	-
HC-42	5.7	0.9	23.8	36.1	1.5	0.6	0.6	-	-	-	-	-	-	3.6	-	3.9	-	-	-
HC-46	-	-	0.3	1.6	0.3	-	-	-	-	-	-	-	-	4.9	10.2	0.9	-	2.3	-
HC-49	-	-	-	-	-	-	-	-	-	-	-	-	-	4.5	11.3	0.3	-	-	-
HC-51	15.3	3.3	12.0	16.8	1.8	8.1	1.2	-	0.3	-	0.6	-	-	2.4	1.5	15.3	-	-	0.3
HC-52	6.7	0.9	9.8	6.1	1.5	-	-	-	-	-	-	-	-	9.8	26.7	7.3	3.7	-	0.3
HC-53	25.0	3.9	9.0	17.8	0.9	1.5	0.6	-	-	-	-	-	-	3.9	11.1	4.8	1.2	-	0.3
HC-55	3.6	0.6	2.6	3.6	-	0.3	-	-	-	-	-	-	-	11.4	10.5	8.1	3.5	1.0	0.6
HC-57	31.7	1.3	3.3	3.6	-	-	-	0.3	-	-	-	-	-	1.0	20.8	17.5	1.0	-	-

	MISC	MISC	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7.7	-	-	47.2	22.2	-	3.7	-	-	-	-	-	-	-	-	-	-	-	-	-
1.6	-	2.2	44.8	5.6	-	9.3	-	-	1.9	0.6	1.9	-	-	-	-	-	-	-	-
-	-	-	-	-	-	4.3	4.0	-	-	1.3	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	8.3	-	-	-	0.7	-	-	-	-	-	-	-	-	-
3.4	-	0.6	40.6	15.3	-	0.9	-	-	0.3	2.5	0.6	-	-	-	-	-	-	-	-
4.1	0.3	-	15.3	12.2	-	0.3	-	-	0.7	1.0	1.8	-	-	-	-	-	-	-	-
2.3	1.0	1.0	19.9	16.3	-	2.6	-	-	1.3	2.8	1.3	-	-	-	-	-	-	-	-
12.2	-	-	42.0	13.2	-	1.3	-	-	1.3	-	1.7	-	-	-	-	-	-	-	-
9.4	-	0.6	31.4	22.6	-	-	-	-	1.6	3.7	1.0	-	-	-	-	-	-	-	-
4.4	-	0.6	34.8	13.8	-	0.9	-	-	1.8	-	2.5	-	-	-	-	-	-	-	-
3.7	-	0.9	33.5	9.5	-	1.5	-	-	1.4	-	2.5	-	-	-	-	-	-	-	-
13.7	2.6	-	0.9	-	-	10.6	-	-	0.3	0.3	-	-	-	-	-	-	-	-	-
48.8	0.9	7.3	0.6	-	0.6	4.8	-	-	0.9	-	1.8	-	-	-	-	-	-	-	-
0.9	-	0.3	18.0	9.0	-	4.2	-	-	0.6	7.2	2.1	-	-	-	-	-	-	-	-
35.3	0.3	4.3	27.0	7.3	-	-	-	-	0.3	-	1.0	-	-	-	-	-	-	-	-
0.3	-	-	46.1	9.4	-	3.9	-	-	-	5.2	0.3	-	-	-	-	-	-	-	-
-	-	-	3.3	2.4	-	5.4	-	-	0.3	7.5	2.1	-	-	-	-	-	-	-	-
0.3	-	0.3	5.1	1.2	-	9.0	-	-	0.3	11.5	0.6	-	-	-	-	-	-	-	-
0.3	-	-	30.2	7.8	-	6.5	-	-	-	1.9	-	-	-	-	-	-	-	-	-
0.3	-	-	2.6	1.5	1.5	10.9	-	-	-	0.9	2.2	-	-	-	-	-	-	-	-
-	-	0.3	16.6	4.3	-	5.2	-	-	-	4.9	1.5	-	-	-	-	-	-	-	-
6.2	-	-	57.1	16.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.5	0.3	-	-	-	-	6.6	5.7	-	1.8	3.6	-	-	-	-	-	-	-	-	-
8.2	-	-	49.3	13.2	0.3	5.9	-	-	-	-	0.6	-	-	-	-	-	-	-	-
6.2	-	-	55.2	17.2	-	1.9	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2	4.8	-	-	0.3	1.5	9.6	-	-	-	0.9	-	-	-	-	-	-	-	-	-
-	-	-	-	0.9	3.4	10.3	-	-	-	4.6	1.2	-	-	-	-	-	-	-	-
1.5	2.4	-	-	-	2.4	10.5	2.1	-	-	-	0.3	-	-	-	-	-	-	-	-
1.9	-	0.3	19.2	5.5	-	4.5	-	-	-	-	1.6	-	-	-	-	-	-	-	-
-	-	-	-	0.7	0.3	13.5	-	-	-	1.3	0.7	-	-	-	-	-	-	-	-

OUTCROP I
(Greendale)

Percent Insoluble Residue



(Figure 4)

10 m

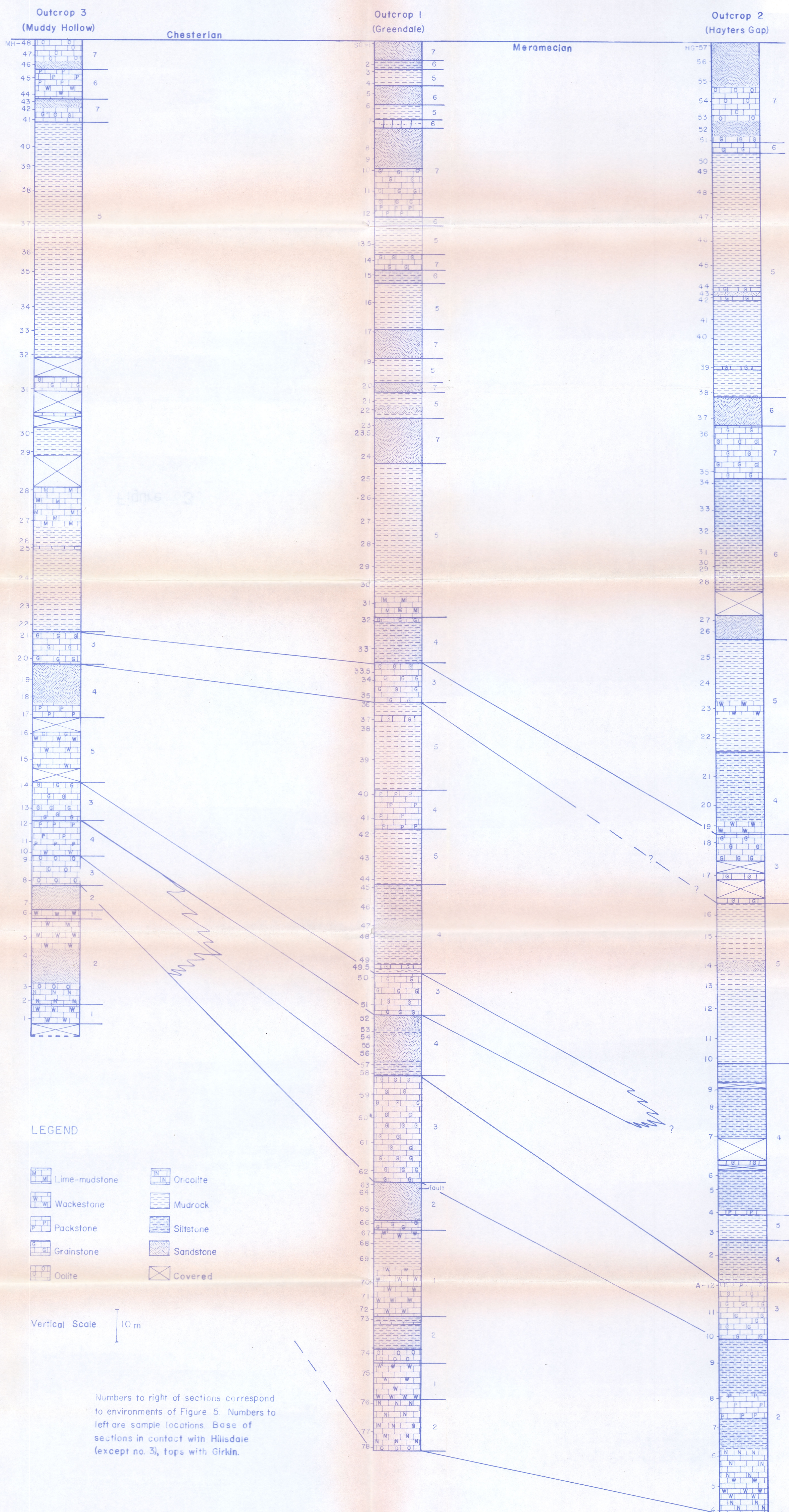


Figure 3. Correlation of lithologies across measured outcrops, Ste. Genevieve, Washington County, Virginia.