"MICROFACIES OF THE
MIDDLE ORDOVICIAN NEW MARKET LIMESTONE
IN ROCKBRIDGE COUNTY, VIRGINIA"

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Andrew M. Gombos

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submitted in partial fulfillment of
requirements for the degree of
Bachelor of Science in Geology

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Washington and Lee University

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Frederic L. Schwab
Advisor

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DEDICATED TO

Henry Clifton Sorby

the

"patron saint of petrography"

and

"inventor of thin sections"

TABLE OF CONTENTS

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ABSTRACT

of the New Market Limestone M. Ord.

Two sections were measured and their microfacies defined macroscopically at two locations in Rockbridge County, Virginia. Nineteen microfacies are defined on the basis of detailed petrographic study of one section. Most microfacies are crystalline limestones of Type II (Microcrystalline Allochemical) and III (Microcrystalline), but microfacies of shale, conglomerate (or clastic limestone), and dolomite also occur. Chert (in beds and nodules) and authigenic pyrite grains are intermixed in the carbonate microfacies. Significant sedimentary structures are laminations and cross-lamination.

Intrepretation of the depositional environments of individual microfacies indicates 4 periods of transgression and regression during which the basin changed from a normal, shallow, open type basin to a restricted or semi-restricted, relatively deep basin.

PURPOSE

The purpose of this study is:

(1) To describe the vertical succession of small scale lithofacies, (microfacies), present in a complete, well exposed section of the Middle Ordovician New Market Formation near Lexington, Virginia;

(2) To interpret the environment of deposition of each microfacies on the basis of a detailed petrographic study of mineralogy and texture;

(3) To formulate a basin model with which to explain the complex mixing of such microfacies in time and space.

Because the New Market is the initial deposit of the Chayzan Sea, and because a variety of microfacies can be readily seen in the field, it was a particularly appropriate unit to study with the microfacies approach. It was also hoped that, because the New Market may contain a number of contrasting microfacies, it might be possible to interpret the distribution in time and space of depostional environments produced by the transgression of epeiric seas.

LOCATION

The investigation was conducted in Rockbridge County, in West Central Virginia. Both sections studied are located in the Millboro Quadrangle, mapped by Kozak (1965). (figure 1)

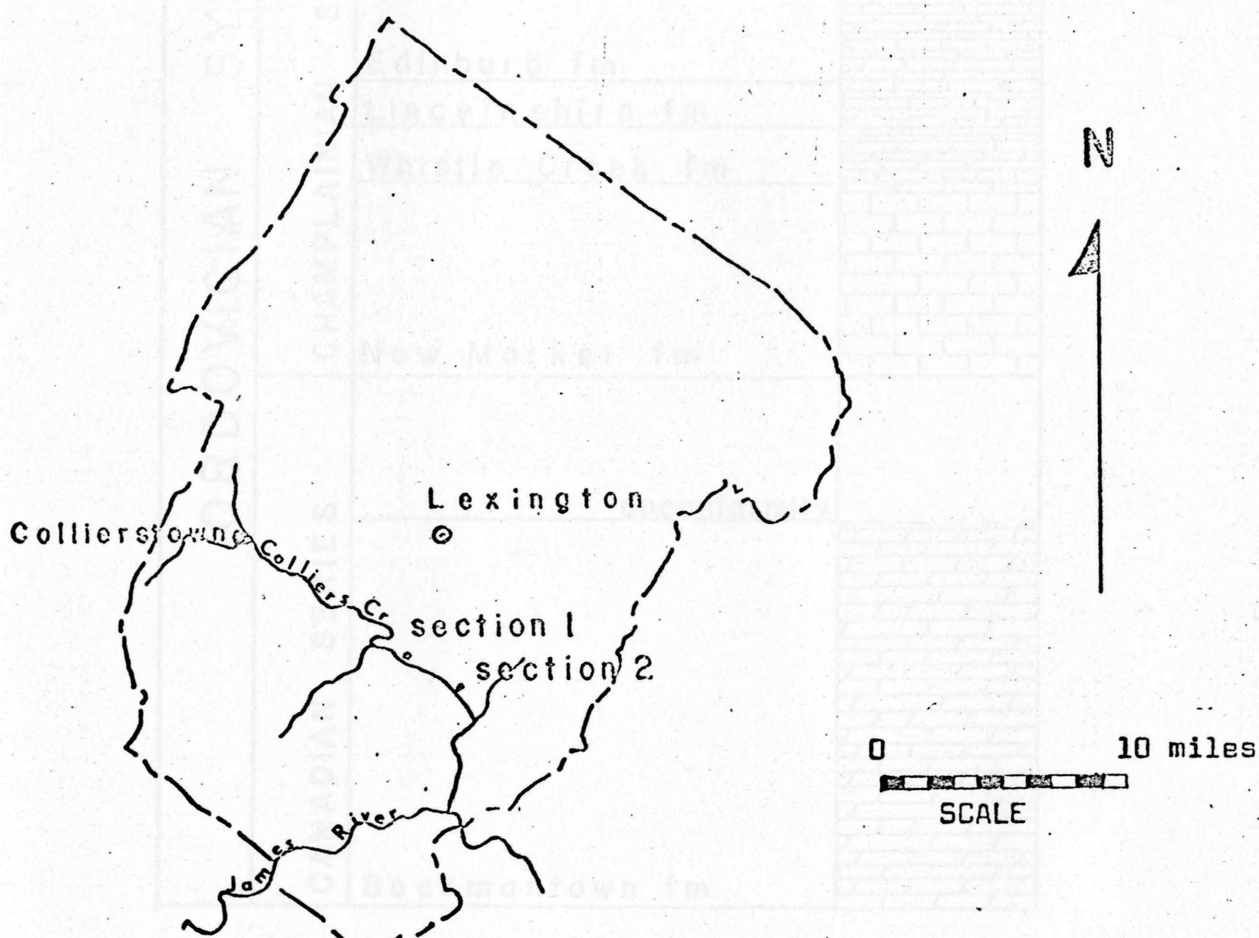
Section number 1, is located along State Highway 251 and Collier's Creek, a few hundred feet east of State Road 644, and 1½ miles east of Collierstown. This is the location of a excellent exposure of the New Market limestone. A detailed description of this section is given in Cooper and Cooper (1946).

Section number 2 is located along State Highway 251 and Buffalo Creek, a few hundred feet east of Effinger School. The New Market limestone is exposed in the creek and along its north bank. The outcrop is badly weathered by the creek and thus not well suited for a detailed study of its microfacies. Section number 2 is presented along with Section number 1 in figure 4 for comparison of horizontal variations.

STRATIGRAPHY

The New Market Formation is Middle Ordovician and is the lowest formation in the Champlainian Series in the Valley of Virginia, (figure 2). The New Market is a massively bedded, aphanitic to fine-grained, medium-gray to dove-gray limestone which in many places contains crystals of clear calcite about 1 mm in diameter giving a "birdseye" appearance to the rock (plate 1a). Black chert nodules are present locally, (Kozak, 1965). The type section of the New Market limestone at New Market, in Shenandoah County, Virginia, is 86 feet thick. At Section number 1 of this report it is 90 feet thick, but it may exceed 100 feet locally,

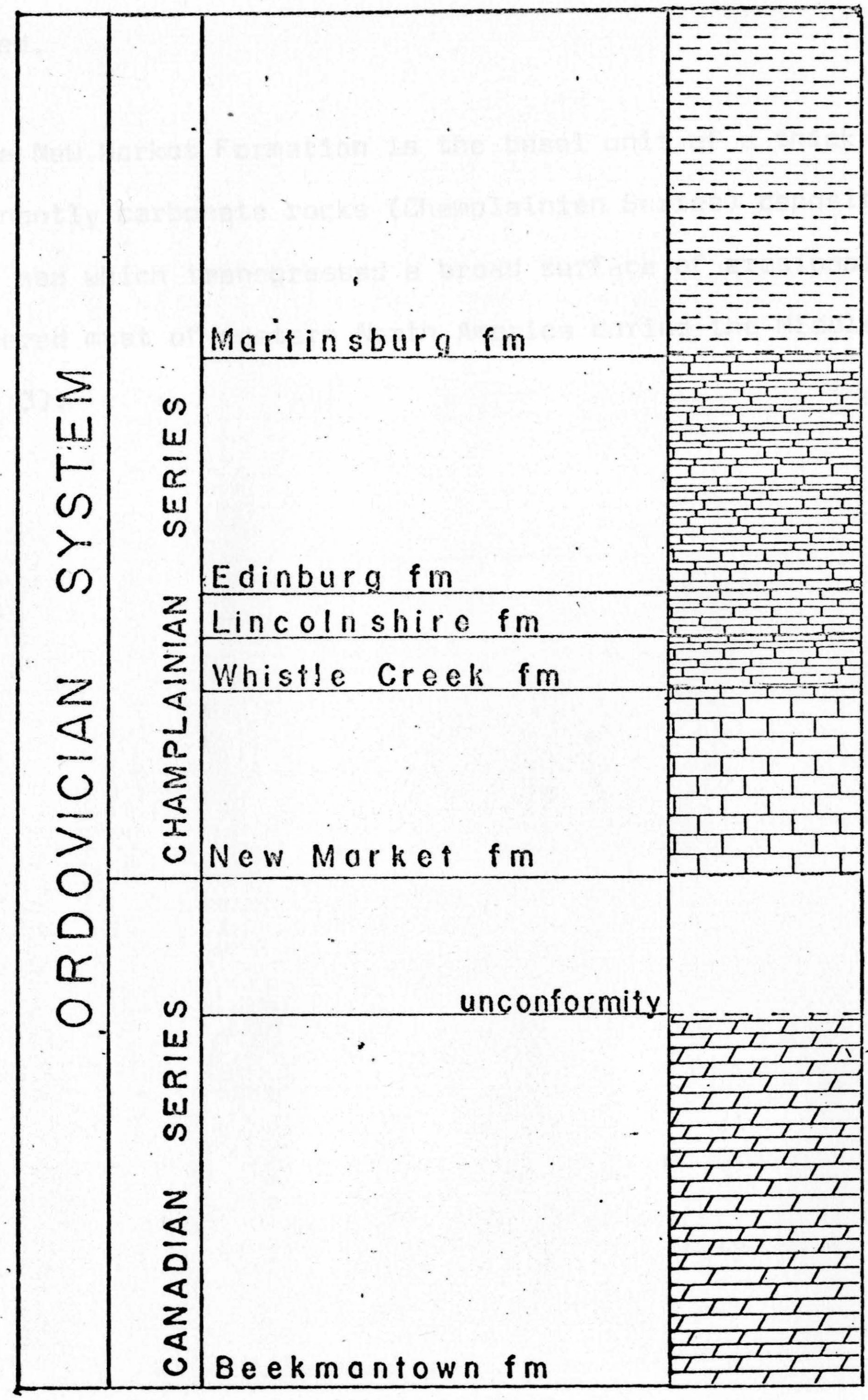
AREA of INVESTIGATION



Rockbridge County

Virginia

FIGURE 1



(FIG. 2) The stratigraphic relationships of the formations in the Valley of Virginia. (After Spencer, 1966).

depending on the relief of the Beekmantown surface upon which it was deposited.

The New Market Formation is the basal unit of a thick succession of dominantly carbonate rocks (Champlainian Series) deposited by the epeiric sea which transgressed a broad surface of erosional unconformity and covered most of eastern North America during the Middle Ordovician (figure 3).

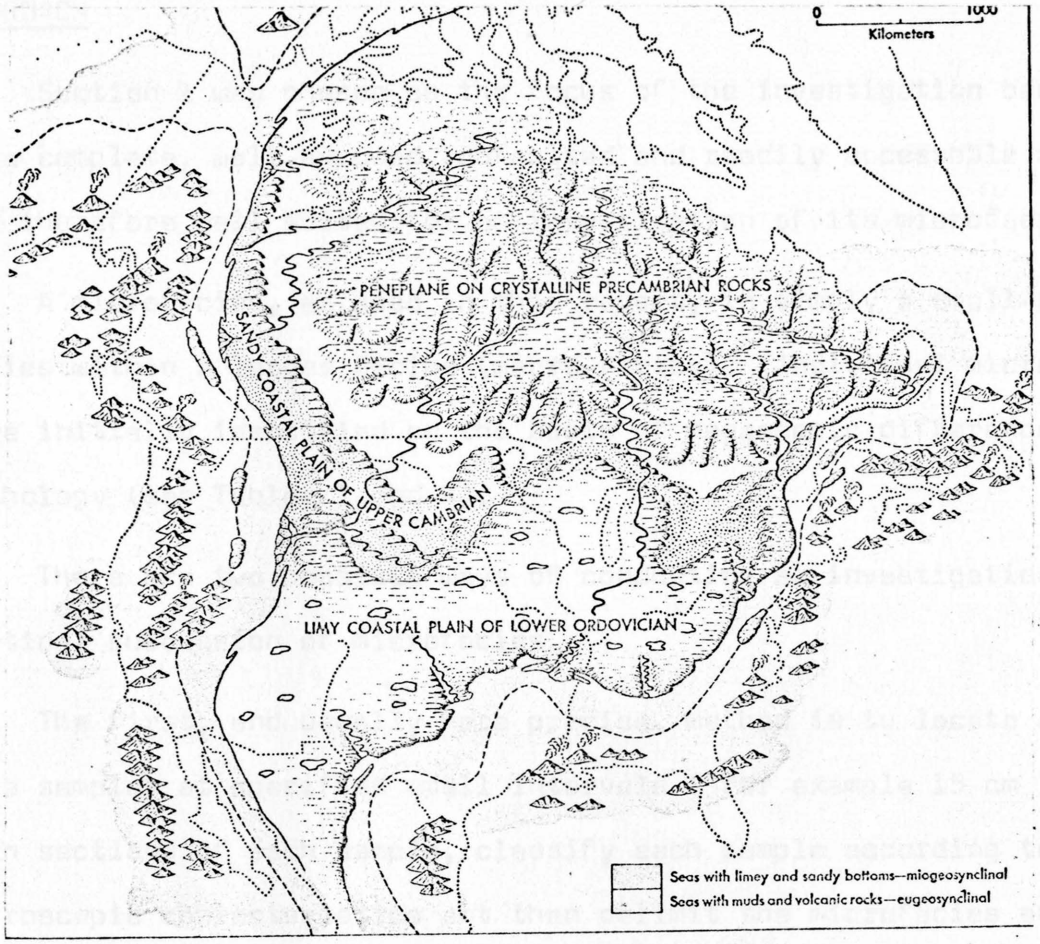


FIGURE 6-14 *Paleogeographic map of North America during the Middle (Chazyan) Ordovician Period. After transgressing the continent in Early Ordovician times, the seas retreated and then partially readvanced during the middle part of the period. During the Late Ordovician Period the continent was once more inundated. The continental margins are bordered by the tectonically active geosynclines which persisted through the Paleozoic Era in the east, and until the end of the Mesozoic Era in the west. (From M. Kay and E. Colbert, 1965.)*

FIGURE 3

(From Laporte 1968)

APPROACH

Section 1 was chosen as the focus of the investigation because it is a complete, well exposed, unfaulted and readily accessable section and therefore well suited for an investigation of its microfacies.

A microfacies, as used in this report, is simply a small-scale facies within a larger facies (macro-facies). Individual microfacies were initially identified on the basis of megascopic differences in lithology (see Tables 1 and 4).

There are two possible ways of conducting an investigation of the vertical succession of microfacies.

The first, and usually more precise, method is to locate a section, take samples at specified small intervals (for example 15 cm), make thin sections of each sample, classify each sample according to its microscopic characteristics ant then delimit the microfacies on the basis of this microscopic information. The next step is to go back into the field and see what megascopic characteristics, if any, of the rocks are useful in identifying the microscopically defined microfacies, (Carrozi, 1967, 1968), (Chilinger, et. al. 1967).

The second method involves first locating a section and initially delimiting the microfacies in the field on the basis of the megascopic characteristics of the rocks. Samples are then taken from these megascopically defined microfacies; the samples are thin sectioned and their microscopic characteristics are noted. Finally, the microscopic characteristics of the samples are added to the definition of the megascopically defined microfacies. It is difficult to pick up "new" microfacies on the basis of microscopic characteristics by this method because of the limited number of thin sections made.

The second of the above mentioned methods was the one employed for the purposes of this study. The first method, with its greater number of thin sections required, is prohibitively expensive for the beginning student. The second method, requiring a minimum number of thin sections is well within the means of the beginning student and serves as an adequate introduction to the petrographic study of microfacies.

The procedure used in the examination of Section number 1 is as follows: an initial survey was made of the section and the Beekmantown and Whistle Creek formational contacts were located. Next, the provisional boundries of the microfacies were delimited on the basis of obvious megascopic differences in lithology. Some of these boundries were later changed upon closer examination of the megascopic differences. The vertical limit of each microfacies was marked out directly on the outcrop with a blue carpenter's crayon, and the thickness of each microfacies was noted.

Samples were then taken from each microfacies. Samples were chosen which represented the typical lithotype of each microfacies; occasional samples were taken from the contacts of one microfacies with another. The location from which each sample was taken was marked with red spray paint, and its position noted on a photograph of the section.

In the lab, thin sections were cut from each sample. The samples were oriented in the field so that the cutting of the thin sections, perpendicular to bedding, would be faciliated.

Megascopic characteristics of the microfacies were noted in the field. Microscopic examination was done with a polarizing microscope.

At Section number 2, the megascopic characteristics and thickness of each megascopically defined microfacies were noted in the field. No thin sections were made from Section number 2

DESCRIPTION OF MICROFACIES

Nineteen microfacies were defined at Section 1 on the basis of the textural and compositional parameters discussed above. Figure 4 and Tables 1, 2, & 3 summarize the major microfacies and their vertical distribution in the New Market.

The majority of the microfacies (fourteen) are thinly-bedded to massively bedded crystalline limestone units which vary in thickness from one to twelve feet. Most of these limestones show thin-bedding, many have laminations, and many contain pyrite cubes (ranging in size from less than 1/10 cm to 1 cm). Other microfacies include clastic limestone (microfacies 5), shaly limestone (microfacies 13), chert (microfacies 17 and 19), shale (microfacies 8, 11, & 16) and dolomite (microfacies 7).

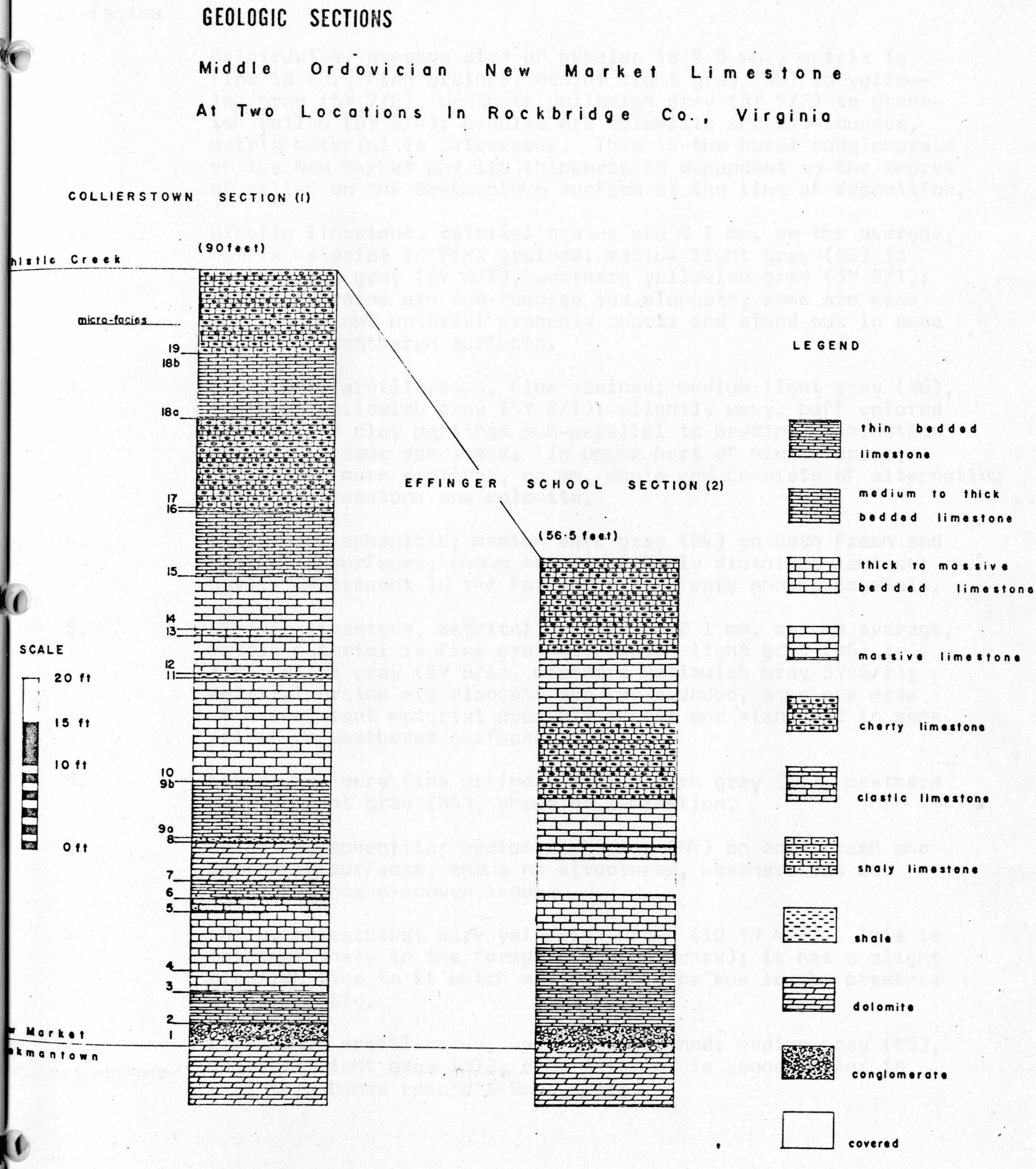

GEOLOGIC SECTIONS
Middle Ordovician New Market Limestone
At Two Locations In Rockbridge Co., Virginia
COLLIERSTOWN SECTION (I)
(90feet)
histic Creek
micro-facies
19
18b
18a
17
16
15
14
13
12
11
10
9b
9a
8
7
6
5
4
3
2
1
w Market
kmantown
SCALE
20 ft
15 ft
10 ft
0ft
EFFINGER SCHOOL SECTION (2)
(56·5 feet)
LEGEND
thin bedded limestone
medium to thick bedded limestone
thick to massive bedded limestone
massive limestone
cherty limestone
clastic limestone
shaly limestone
shale
dolomite
conglomerate
covered

FIGURE 4

Table I. Megascopic characteristics of the micro-facies of the New Market limestone as seen at Section 1. (See Appendix for terminology).

Number of micro-facies	
1.	Calcirudite, average size of pebbles is @ 5 mm., matrix is fine to very fine grained; medium light gray (N6) to yellowish gray (5Y 7/2), weathers yellowish gray (5Y 7/2) to greenish yellow (5Y 8/4); pebbles are dolomitic and sub-rounded, matrix material is calcareous. This is the basal conglomerate of the New Market and its thickness is dependent on the degree of relief on the Beekmantown surface at the time of deposition.
2.	Clastic limestone, detrital grains are @ 1 mm. on the average, matrix material is fine grained; medium light gray (N6) to light olive gray (5Y 6/1), weathers yellowish gray (5Y 8/1); detrital grains are sub-rounded and elongate, some are made of a resistant material probably quartz and stand out in some relief on weathered surfaces.
3.	Limestone, argillaceous, fine grained; medium light gray (N6), weathers yellowish gray (5Y 8/1); slightly wavy, buff colored (10 YR 7/4) clay partings sub-parallel to bedding, lamination visible in some specimens. In upper part of micro-facies, lamination more distinct, on mm. scale and consists of alternating bands of limestone and dolomite.
4.	Limestone, aphanitic; medium dark gray (N4) on both fresh and weathered surfaces; shows traces of badly disturbed laminae; pyrite is present in the form of a few, very small, crystals.
5.	Clastic limestone, detrital grains are @ 1 mm. on the average, matrix material is fine grained; medium light gray (N6) to light olive gray (5Y 6/1), weathers yellowish gray 5Y 8/1); detrital grains are elongate and sub-rounded, some are made of a resistant material probably quartz and stand out in some relief on weathered surfaces.
6.	Limestone, very fine grained; medium dark gray (N4), weathers medium light gray (N6), shows no lamination.
7.	Dolomite, aphanitic; medium dark gray (N4) on both fresh and weathered surfaces, shows no structures, weathers out as roughly concavo-convex lenses.
8.	Shale, calcareous; dark yellowish brown (10 YR 4/2). This is thickest shale in the formation (@ 6 inches); it has a slight greenish tine to it which may possibly be due to the presence of glauconite.
9a.	Limestone, argillaceous; very fine grained; medium gray (N5), weathers light gray (N7), clay material is concentrated in very thin bands spaced 1-5mm. apart.

9b. Limestone, aphanitic; dark gray (N3) on both fresh and weathered surfaces; contains birdseyes and breaks with concoidal fractures.

10. Limestone, very fine grained; argillaceous; dark gray (N3) to medium dark gray (N4), weathers light olive gray (5Y 6/1); clay material concentrated in continuous, wavy bands which vary in width from .1 to 2 mm., a fresh surface exhibits a mottled appearence.

11. Shale, calcareous, grayish black (N2).

12. Limestone, fossiliferous, matrix material is very fine grained, fossils average between 3-5 mm.; medium dark gray (N4), weathers light olive gray (5Y 6/1), fossils consisting of brachiopod and gastropod fragments are concentrated in layers of varying thicknesses, separateed by fine grained non-fossiliferous layers; pyrite is quite common and occurs as flakes less that .1 mm., and as cubic crystels up to 5 mm.

13. Limestone, shaly, fine grained; medium light gray (N6), weathers light gray (N7). Shows badly disturbed laminae; veins of pure white calcite up to 6-8 mm. thick fill fractures which run parallel to the bedding. Slickensides are evident on some specimens.

14. Limestone, very fine grained, argillaceous; dark gray (N3) to medium dark gray (N4), weathers medium dark gray (N4), clay material concentrated in wavy bands which average about 1 mm. in width; a fresh surface exhibits a mottled appearence.

15. Limestone, argillaceous, aphanitic; medium dark gray (N4), weathers medium light gray (N6) to light gray (N7); lower part of micro-facies characterized by slightly wavy bands of clay material, these become less frequent upwards.

16. Shale, calcareous, grayish black (N2).

17. Limestone, cherty; aphanitic; medium dark gray (N4), weathers medium light gray (N6); shows disturbed laminae; chert is sparse, occurs as nodules averaging about 1-2 inches.

18a. Limestone, aphanitic; medium gray (N5) on both fresh and weathered surfaces; shows possible cross-lamination.

18b. Limestone, fossiliferous, fossils and cement are both composed of very fine grained to aphanitic limestone; fossils are not obvious at first glance, upon close examination they are seen to be very abundant, consisting of brachiopod and gastropod fragments. Styolites are present also.

19. Limestone, cherty, aphanitic; medium gray (N5) fresh and weathered surfaces; chert present as very long stringers.

Table 2. Summary of the microscopic characteristics of the micro-facies of the New Market formation.

Number of micro-facies	
1.	This facies is a calcirudite (conglomerate) consisting of @ 30-35% dolomite pebbles, most likely from the underlying Beekmantown formation, and 70-65% micrite cement.
2.	Intrasparudite; 14% intraclasts composed of micrite, probably reworked from the micrite cement of micro-facies 1. 86% sparite.
3.	Dismicrite; 60% micrite, 40% sparite.
4.	Fossiliferous micrite; 5% broken brachiopod fragments whose shell composition is sparite, 95% micrite matrix.
5.	Calcirudite; This facies consists of @ 30-35% small pebbles most of which are insoluble in HCl--probably chert. Pebbles average @ 1 mm. Matrix is sparite. 1-2% red iron oxide material.
6.	Dismicrite; 80% micrite, some of this material is disturbed, i.e. broken or lifted out of it bedding plane, probably by burrowing organisms. 18% sparite--filling burrows. 2% pyrite.
7.	Microcrystalline dolomite; 100% dolomite.
8.	Shale, (no thin section made of this micro-facies)
9a.	Dismicrite; possibly intraclast bearing, about 3% or rock consists of distinct chunks of micrite, these may have been broken off by burrowers which most likely caused many of the laminae to be disturbed yet still recognizable as distinct laminae. Micrite, 60%; sparite, 34%--as pore filler; 3% hemititic mud in thin reddish bands parallel to laminae, and pyrite flakes.
9b.	Micrite; 92% micrite, 8% sparite--occurs as birdseyes.
10.	Micrite; 94% micrite, 6% sparite--fills fractures.
11.	Shale, (no thin section made of this micro-facies).
12.	Biomicrudite; 10% fossils--mostly brachiopod fragments, some show evidence of being transported, i.e. they are slightly rounded. 60% micrite; 27% sparite; 3% pyrite--occurs as crystals.
13.	Dismicrite; 70% micrite, 30% sparite occuring as vein filler.
14.	Biomicrudite; 13% fossils, broken, unrounded, composed of sparite. 87% micrite.
15.	Biomicrite; 20% fossils, brachiopods and gastropods some broken and some whole. 78% micrite. 2% pyrite and clay.

16. Shale, (no thin section made of this micro-facies).

17. Cherty micrite; 70% micrite, 25% chert, 5% sparite pore filler.

18a. Micrite; 80% micrite, 20% sparite, occurs as pore and vein filler.

18b. Biomicrudite; 25% fossils, brachiopods and gastropods, these are the larges fossils found in the formation many being on the order of several millimeters in size. Several of the larger fossils are filled with fossil bearing micrite and some gastropods are partially filled with sparite. Most fossils are unbroken. 75% micrite.

19. Cherty micrite; 20% chert, 80% micrite--shows micro-scale cross lamination. A few fossils in upper parts of micro-facies.

Table 3. The main limestone types of each microfacies of Section 1.

Microfacies	Limestone type
1.	Conglomerate
2.	Sparry Allochemical
3.	Microcrystalline
4.	Microcrystalline
5.	Clastic Limestone
6.	Microcrystalline
7.	Dolomite
8.	Shale
9a.	Microcrystalline
9b.	Microcrystalline
10.	Microcrystalline
11.	Shale
12.	Microcrystalline Allochemical
13.	Microcrystalline
14.	Microcrystalline Allochemical
15.	Microcrystalline Allochemical
16.	Shale
17.	Microcrystalline
18a.	Microcrystalline
18b.	Microcrystalline Allochemical
19.	Microcrystalline

Sparry Allochemical rocks (Type I limestone)

Microcrystalline Allochemical rocks (Type II limestone)

Microcrystalline rocks (Type III limestone)

Table 4. Megascopic characteristics of the micro-facies of the New Market limestone as seen at Section 2.

Number of micro-facies	
1.	Calcirudite; average size of pebbles is @ 5 mm., matrix is fine to very fine grained; medium dark gray (N4), weathers light gray (N7). Pebbles are dolomitic for the most part though a few are composed of a dark, resistant mineral which stands out in some relief and is not affected by 10% HCl. This is the basal conglomerate of the New Market and its thickness varies with the degree of relief present, at the time of deposition, on the old Beekmantown surface.
2.	Limestone; laminated, medium to fine grained; medium dark gray (N4), weathers light gray (N7). Pyrite present as a few scattered flakes. Laminae are most common near base of micro-facies, here they consist of alternating light and dark layers, (possibly varve like deposits) which are for the most part disturbed, possibly by burrowing organisms.
3.	Limestone; fine grained; medium light gray (N6) on both fresh and weathered surfaces. Birdseyes are very common.
	Covered interval
4.	Limestone; fine to medium grained; medium dark gray (N4), weathers medium gray (N5). Birdseyes are present, but are not as common as in micro-facies 3.
5.	Clastic limestone; detrital grains are chert and limestone, average size @ ½ inch, largest observed pebble is 1 inch, pebbles are elongate and sub-rounded. Matrix is medium to fine grained limestone; medium dark gray (N4), weathers very light gray (N8). A few widely spaced, wavy clay layers about 1 mm. thick are present.
6.	Limestone; cherty, medium to fine grained; medium dark gray (N4), weathers light gray (N7). Chert increases toward top of micro-facies where it occurs as laterally discontinous beds about 1-2 inches thick on the average. Wavy clay bands are more abundant than in micro-facies 5.
7.	Limestone; aphanitic; medium gray (N5), weathers light gray (N7). Birdseyes common. Chert very sparse.
8.	Limestone, cherty; medium to fine grained. Chert common, occurs as large irregularly shaped nodules.

INTERPRETATION OF MICROFACIES

CARBONATES

The following general interpretations of depositional environments are made based on the composition and texture of the carbonates. As summarized in Table 3 most of the limestone microfacies are either Microcrystalline Allochemical rocks (Type II) or Microcrystalline rocks (Type III) (Refer to Appendix). Type II limestones (4 microfacies) indicate weak, short-lived currents or a rapid rate of precipitation of microcrystalline ooze. Type III limestones (10 microfacies) imply both a rapid rate of precipitation of microcrystalline ooze, together with a lack of persistent strong currents. The fact that the limestone microfacies are largely of Type III indicates that they formed either in very shallow, sheltered lagoonal areas, or on broad, submerged shelves of little relief and moderate depth where wave action is cut off by the very width of the shelf. Some Type III limestones may also form in deeper offshore areas (Folk, 1959).

The above interpretations are necessarily general and infer a composite of possible depositional environments, rather than specific environments, because our knowldege of carbonate deposition at this time is relatively limited. However, the presence of lithologies other than limestone, in particular dolomite, chert, pyrite and shale are useful in specifying depositional conditions more accurtaely.

DOLOMITE

Dolomite occurs as a microfacies (number 7) in Section I near Collierstown.

The origin of dolomite is still uncertain because of the fact that it is only known to be forming today in a very few places. Therefore the principle of uniformitarianism is of little help in determing how this rock type was formed in the past.

Dunbar and Rodgers (1957) list two main geologic occurrences of dolomite which reflect two main modes of origin: (1) as widespread beds, tongues, members or formations, normally inter-bedded or inter-tongued with limestones, or (2) as irregular masses, normally cross-cutting the bedding of limestone formations and related instead to fracture systems, commonly the same fracture systems that seem to have guided ore deposition.

(1) The first type of occurence is stratigraphically controlled; its relations with other rocks and formations are the normal stratigraphic relations of unconformity, vertical alteration, facies change and so forth. This type of dolomite is called S-dolomite.

There are two theories about the origin of S-dolomite. The primary precipitation theory holds that dolomite was precipitated directly from sea water. The other theory, called the penecontemporaneous replacement theory, holds that pre-existing calcitic deposits were altered to dolomite on the sea floor or after burial, (Dunbar and Rodgers, 1957). Of these two theories, the replacement theory has the strongest support among American geologists.

(2) The second type of dolomite is tectonically controlled; its relations with other rocks are like those of structurally guided hydro-thermal replacement deposits of ore minerals. This type of dolomite is called T-dolomite.

(3) Dunbar and Rodgers also suggest a third occurence of dolomite; that is as a blanket or bodies in limestone related neither to primary

bedding nor later fractures, but to the present or an ancient land surface--in other words, that it has been produced during the subaerial weathering of the limestone. This type of dolomite is called W-dolomite. Two modes of origin have been proposed for this type of dolomite: (1) slightly magnesian limestone may be leached of its $CaCO_3$ during weathering to produce a rock of about the composition of dolomite, or (2) magnesium-bearing surficial waters may replace the calcite of the limestone by dolomite.

Deffeyes, et. al., (1965), have suggested three conditions which must be met in order for a limestone to become dolomitized:

1) A water having a Mg/Ca ratio larger than the ratio that would be in equilibrium with both calcite and dolomite must be produced.

2) This water must flow through the limestone, because magnesium transport by diffusion is inadequate to explain most dolomite occurences.

3) The rate of production and flow of the high-magnesium water must be adequate to dolomitize the rock in the time available.

A mechanism which meets these requirements is a lagoonal type environment in which dolomite is formed by the interaction of sea water concentrated by evaporation with lime sediments. Here, the only environmental requirements are a seasonally or permanently dry climate, so that evaporation may exceed precipitation, and a nearly flat sediment surface near sea level to provide a supratidal environment of sufficient areal extent. It is highly probable that these requirements have been met many times in the geologic past, (Deffeyes, et. al., 1957).

Microfacies 7 of Section 1 is most likely either S or W dolomite. Of these, S-dolomite is most probably the type present. A type W dolomite would have required either uplift, for which the author found no evidence, or regression. The dolomite grades upward into shale which would seem to indicate transgression. Likewise, the dark shale overlying microfacies 7 may have resulted from increased restriction of the basin with resulting stagnation. Microfacies 7 is a homogeneous, concordant bed of dolomite with no indication of its having been formed by hydro-thermal deposition in an old fracture(s), thus eliminating the possibility of its being type T-dolomite.

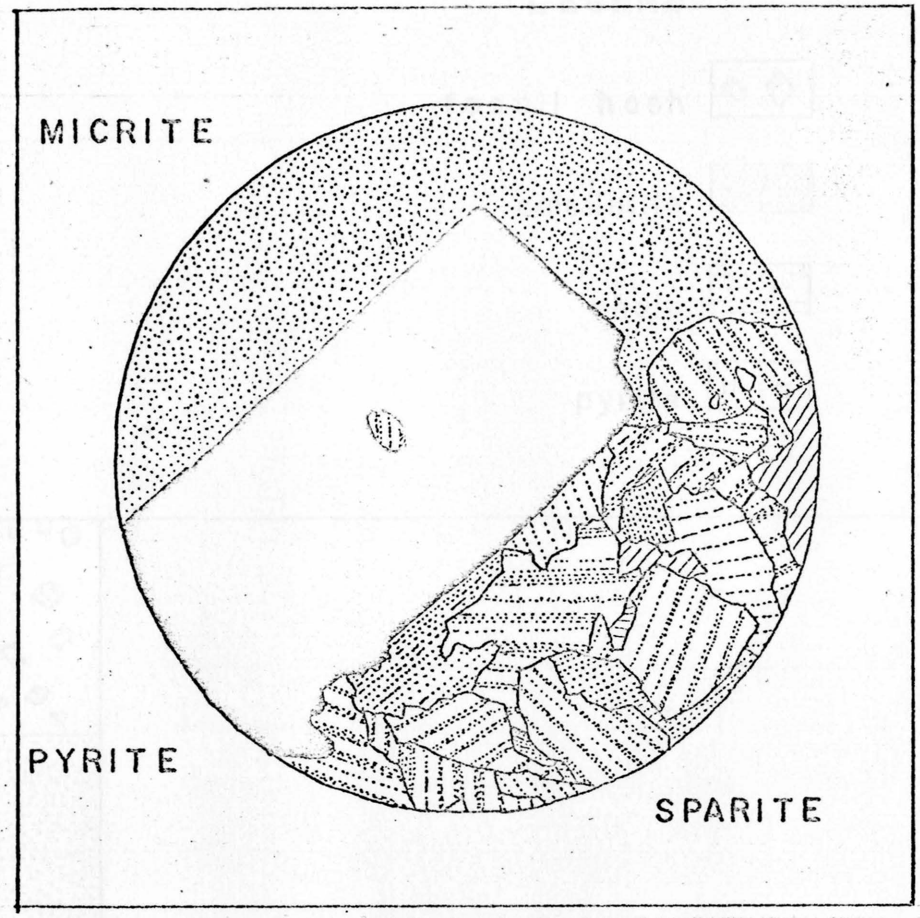
PYRITE

The presence of the mineral pyrite in a sediment, if it is authigenic and not detrital, indicates reducing conditions in the environment of deposition. Pyrite in the New Market formation is apparently authigenic. Evidence for this is seen in thin section. Figure 5 shows a perfect pyrite crystal exhibiting no evidence of transport. It also shows an interlocking texture with sparite crystals. Also, the close association of pyrite with concentrations of fossils (Figure 6) suggests suggests an authigenic origin of the pyrite (Pettijohn, 1957).

Iron sulfide is formed when hydrogen sulfide from bacterial reduction of sulfates reacts with iron. This occurs in reducing environments, as stated above (Ginsburg, 1957). It is also possible that the pyrite formed after the limestone was deposited. In this case the pyrite would still be authigenic and would still have formed in reducing conditions, but the New Market environment itself would not necessarily have been reducing.

CHERT

Chert commonly occurs in association with carbonate rocks. Where present, it typically occurs as nodules a few inches across, normally flattened into oblate spheroids or disclike bodies extended parallel to



(FIG. 5) Drawing made from a thin section cut from microfacies 12 showing euhedral nature of pyrite and its interlocking texture with the sparite.

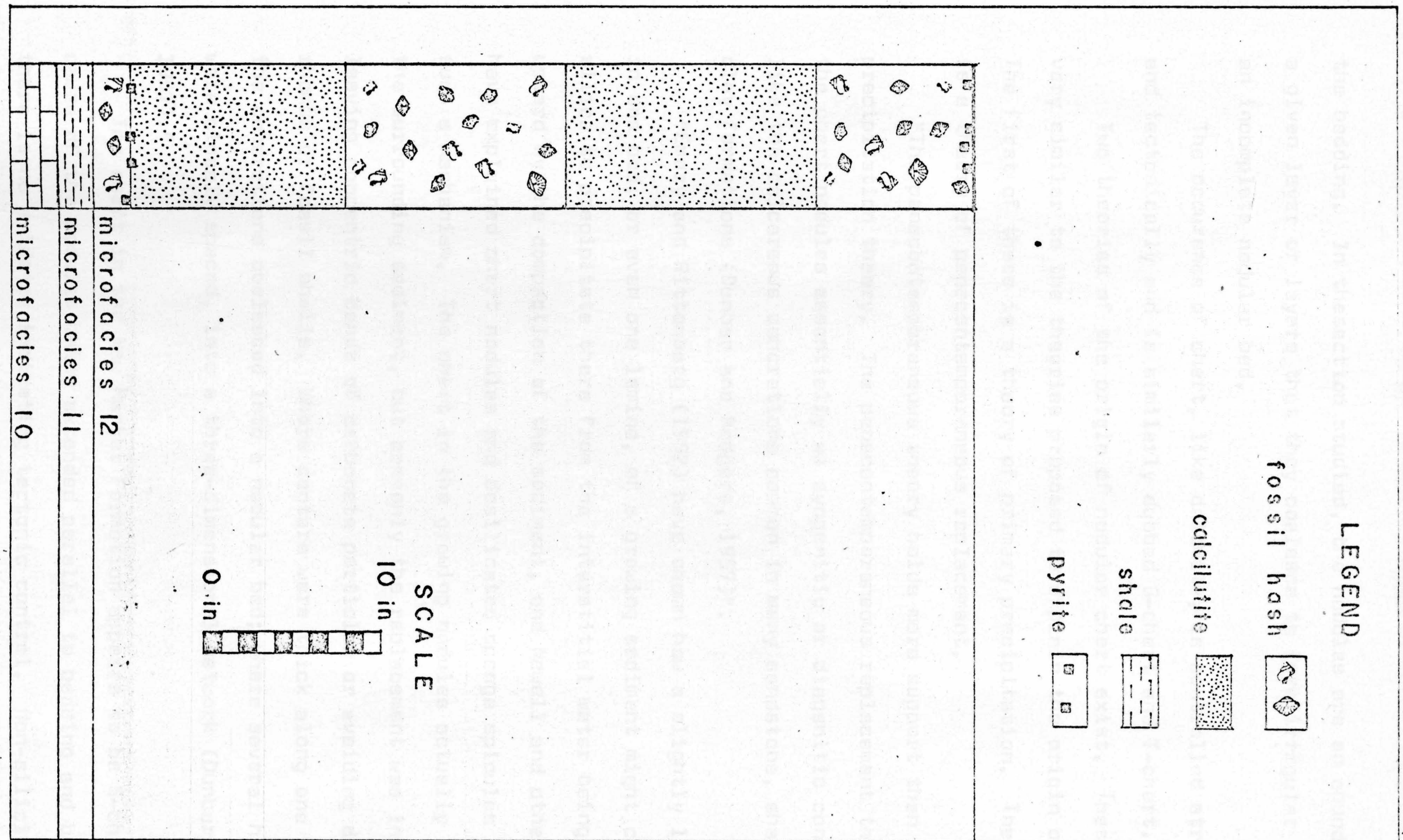


FIGURE 6

Detailed drawing of the first 48 inches of microfacies 12 showing alternating fossil hash and lime mud layers with pyrite concentrations. Fossils are unsorted, mostly broken and randomly oriented suggesting transport into the area by rough water, followed by calm periods.

the bedding. In thesection studied, the nodules are so abundant in a given layer or layers that they coalesce to form irregular masses or an incomplete nodular bed.

The occurence of chert, like dolomite, is controlled stratigraphically and tectonically and is similarly dubbed S-chert and T-chert.

Two theories of the origin of nodular chert exist. These are very similar to the theories proposed to explain the origin of dolomite. The first of these is a theory of primary precipitation. The second is a theory of penecontemporaneous replacement.

"The penecontemporaneous theory holds more support than the primary precipitation theory. The penecontemporaneous replacement theory sees the chert nodules essentially as syngenitic or diagenitic concretions, like the calcareous concretions common in many sandstone, shale and clay formations (Dunbar and Rodgers, 1957)".

"Emery and Rittenberg (1952) have shown how a slightly lower pH in one bed, or even one lamina, of a growing sediment might cause silica to precipitate there from the interstitial water being driven upward by the compaction of the sediment, and Newell and others (1953) have explained chert nodules and desilicated sponge spicules by just such a mechanism. The chert in the growing nodules actually replaces the surrounding sediment, but commonly the replacement was incomplete, leaving concentric bands of carbonate particles or avoiding dolomite rhombs or fossil shells. Where centers were thick along one horizon the concretions coalesced into a nodular bed; where several horizons were closely spaced, into a three-dimensional network (Dunbar and Rodgers, 1957)."

The chert in the New Market Formation appears to be S-chert, because of the nodules being extended parallel to bedding and because there is no evidence indicating tectonic control. Non-silicious sponge spicules seen in thin section from microfacies 19, Section 1 (Plate 1b.), lends support to the penecontemporaneous replacement theory also.

SEDIMENTARY STRUCTURES

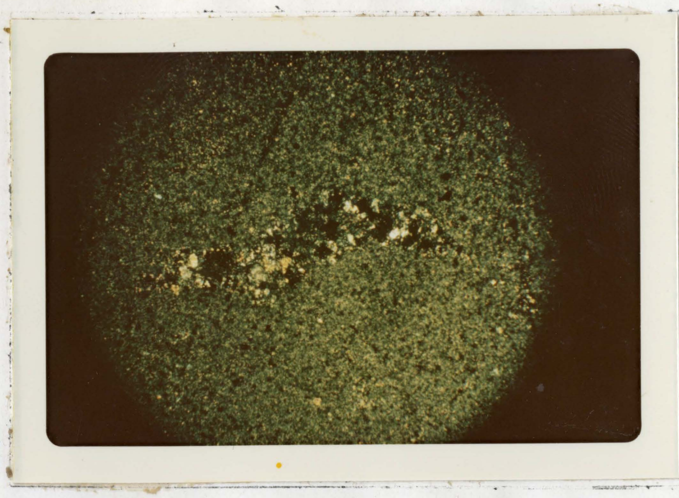
Laminations in the New Market limestone consist of alternating light and dark layers, generally less than one mm thick, but occasionally reaching 3 mm or slightly more in thickness. These laminations are usually slightly wavy or "rolling" in character; and are in many cases broken or disturbed.

Bradley (1931) and Dunbar and Rodgers (1957) suggest that laminations of the sort described above may be non-glacial marine varves, representing some sort of seasonal variation and resulting variation in the influx of sediment. Dark layers are thought to have been formed from organic matter, while the lighter layers consist chiefly of mineral material. If indeed the laminations in the New Market represent seasonal varves, this would indicate a temperate or at least sub-tropical climate, these types of climates are the only types which exhibit significant seasonal variations.

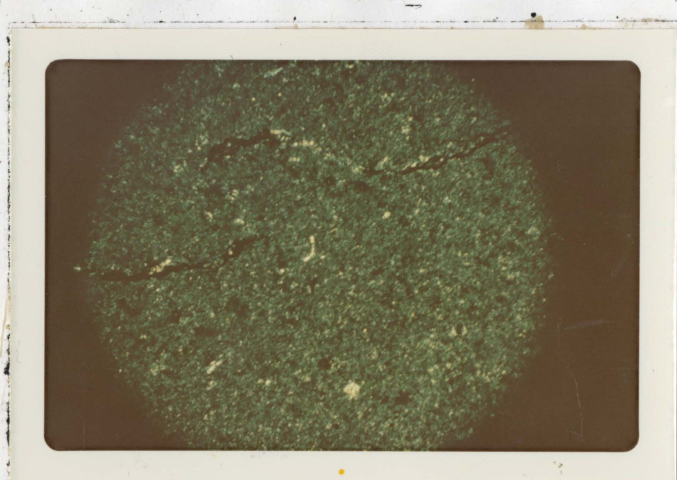
The disturbed nature of the laminations is generally attributed to burrowing organisms, Dunbar and Rodgers, (1957); Eicher, (1968); Folk, (1959); and Laporte, (1968). Dunbar and Rodgers (1957) suggest tidal flats or lagoonal types of enviornments where laminations can form and burrowing worms can thrive.

Cross-lamination was seen in thin section in microfacies 19 of Section 1 (Plate 2b.). This indicates that the micrite mud was deposited in this microfacies by relatively weak currents.

PLATE 1.

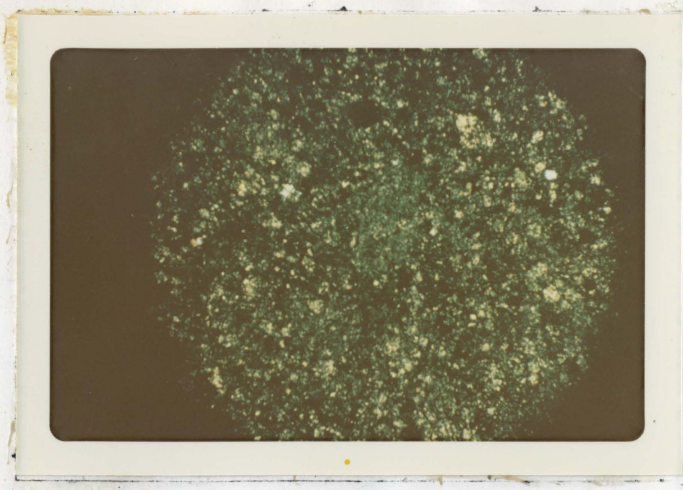


(1a.) Sparite filled "birdseye" in micrite matrix. Micro-facies 9b. Section 1.

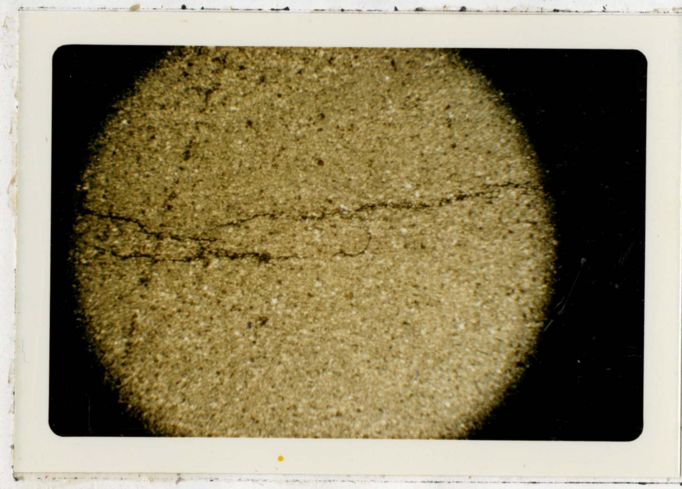


(1b.) Sponge spicule in micrite matrix. Micro-facies 19, Section 1.

PLATE 2.



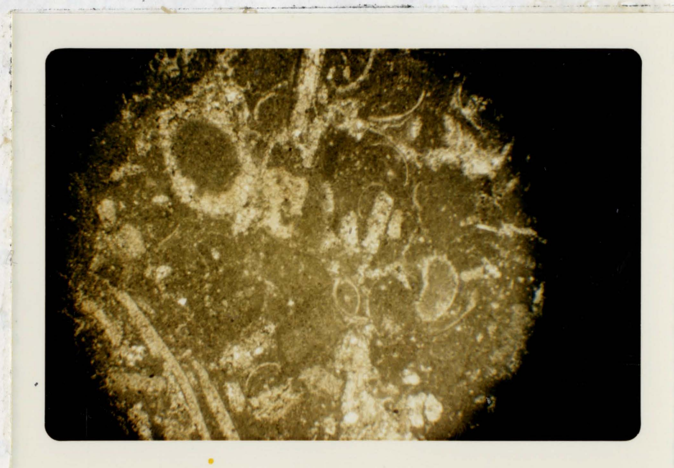
(2a.) Micrite intraclasts in sparite matrix. Micro-facies 2, Section 1.



(2b.) Cross-lamination, in micrite. Micro-facies 19, Section 1.

PLATE 3.

(3a.) Large gastropod in micrite. Shell is replaced by sparite. Micro-facies 18b, Section 1.



(3b.) Biomicrudite. Micro-facies 18b, Section 1.

MAJOR CHARACTERISTICS OF DEPOSITIONAL ENVIRONMENTS

(1) INTRODUCTION

The New Market represents a continuum through time of changing geological environments in which the lithologies described above were deposited. For example; microfacies 1, the initial deposit of the Chayzan Sea, is a conglomerate. This infers a condition of persistant rough water as would be expected as the Middle Ordovician sea transgressed across the old Beekmantown surface. Microfacies 2, 3, & 4 are limestones of Types I and III (Table 3) which are appropriate to the conditions to be expected as the sea transgressed further over the site of Section 1, i.e., a gradual lowering of the energy level of the sea and a deepening of the water. Microfacies 5 is a clastic limestone indicative of regression. Microfacies 6 is a transgressive limestone. Microfacies 7 is a dolomite facies which indicates a restriction of the environment as discussed above. The remaining microfacies in the section consist of alternating shales (8, 11, 16) and limestones which represent similar transgressive--regressive sequences.

Consequently, because the New Market was deposited in such a composite of sedimentary environments it is not possible to specify for it a static basin model. However, it is possible to analyze the New Market depositional environment in terms of the broad characteristics of (1) depositional depth and (2) restriction of the basin, and thus formulate a composite basin model within which these characteristics could have been formed.

(2) EVIDENCE INDICATING A DEEP WATER ENVIRONMENT OF DEPOSITION FOR THE NEW MARKET LIMESTONE

"Deep water" limestones are defined as those deposited below normal wave base, in an enviornment depleted of oxygen and in places on a slope of some magnitude. Such "deeper water" carbonates occur in both miogeosynclinal (marginal cratonic) and intracratonic basins where they have been variously termed basinal, toe of slope, or off-shelf limestones, (Wilson, 1969).

These limestones are generally characterized by mainly fine-grained (lime mud) carbonate sediments. Studies on the origin and distribution of such lime muds in Florida Bay, the Bahamas and west Florida shelf, indicate that lime mud can form abundantly only in very shallow water (less than 100 feet), that its rate of production in this enviornment may be very high, and that it is basically of organic origin (due to disintegration of organisms by chemical means or by biological means; for example, gastropods can reduce skeltal debris to a fine mud, (Ginsberg, 1957); disintigration by abrasion, or by biochemical precipitation from sea water). However, lime mud produced on shelves may be washed across them into deeper water just as easily as it may be carried landward to be deposited in the quiet water of the tidal flat enviornment, (Wilson, 1959).

Wilson (1959) lists three "typical micro-facies" of deeper water limestones. These are:

1) Pure lime mudstone, commonly dark and laminated on a millimeter scale (perhaps varves).

2) A very fine lime sand or calsiltite, with grain size so small

that it is hard to distinguish between grains and matrix. However, many of the particles appear to be micropelletoids derived from abraded skeletal or lithoclastic fragments upon the shelf and washed down into the apron of sediment at the foot of the slope. The only recognizable bioclasts are sponge spicules.

3) Lithoclastic grainstone. Size range of such grains is highly variable. Rock comprised of the finer grains is often referred to as microbreccia. The grains originate as rock fragments, detritus dumped down the slope by slides, turbidity currents, and sand falls. This micro-facies is particulary common in geosynclines and essentially absent in cratonic basins.

Among the small scale sedimentary structures observed in thin section in these type rocks are the following:

1) Grading within centimeter thick units of very fine sand upward to laminated and somewhat cherty lime mudstone.

2) Planer millimeter lamination, probably reflecting seasonal variation in deposition. These laminations have been protected from disruption by burrowing organisms by depth.

3) Thin chert bands, occuring as digenetic products.

Stratigraphic sections of these rocks commonly consist of evenly planar beds each of more or less uniform thickness, varying usually from 4 to 12 inches. Such beds may be either lime mudstones or calsiltites. Intercalated regularly with these beds are shales which are about 1/3 to ¼ the thickness of the limestones presumably because they have compacted whereas the limestone have not.

Another type of bedding which has been observed consists of massive (greater than 3-4 feet thick) beds of pure lime mud which are separated by very thin shale partings.

The main organic constituents are pelagic forms. However, strata of certain geologic periods contain specialized benthonic organisms mostly capable of living in a poorly oxygenated enviornment. When these occur thay are usually extremely abundant and concentrated in certain thin beds. Some of the pelagic organisms occur in the same manner. Sponge spicules are common in deeper water limestones. Though it is probable that the organisms giving rise to them lived "upslope" and their lightweight spicules drifted downslope and were deposited in the quiet water below wave base.

In summary the following are considered to be distinctive of "deeper water" limestones::

(1) Dominance of lime mud.

(2) Relatively common calcisiltites and fine grainstones, usually showing small scale graded bedding or micro-scale cross lamination.

(3) Dark color although in places pink and even red limestones occur.

(4) Even millimeter lamination.

(5) Very even planar ½- to 1-foot limestone beds or massive beds separated by thin shale beds.

(6) Generally very specialized benthonic fauna; much more common solely pelagic fauna. (Wilson, 1969).

Wilson (1969) believes that limestones of "deeper water" character form in three preferred paleotectonic positions: (1) at the toe of slopes below the shelf margins of major carbonate banks, (2) in centers of cratonic basins most of whose area is generally covered by shallow water, (3) within some geosynclinal troughs where they often represent Pettijohn's euxinic or pre-orogenic phase of subsidence.

Certain of the microfacies of Section 1 of this report exhibit characteristics which are "typical" of "deeper water" limestones. These are summarized below:

1) Predominance of very fine grained to aphanitic limestone (indeed, the New Market is commonly described as an aphanitic to fine grained limestone, (Kozak, 1965).).

2) Lithoclastic grainstone with variable sizes of grains; microfacies 5 of Section 1 and microfacies 4 of Section 2 are such rocks.

3) Planer millimeter lamination is very common in several microfacies (microfacies 3, 4, 6 and 9a of Section 1 and microfacies 2 of Section 2). Though these laminations are often disrupted, some microfacies contain relatively undisturbed laminations.

4) Microfacies 6 of Section 2 contains a few very thin chert bands probably resulting from diagenetic processes.

5) Microfacies 19 of Section 1 shows traces of what may possibly be micro-scale cross lamination (Plate 2b.) Harbaugh, (1959), states that it is unlikely that cross-lamination could be produced in a limestone which has been precipitated in place by chemical or biochemical means. Instead, a deposit created by mechanical transportation and settling of discrete particles is implied. In this case transportation of sediment was outward towards deeper water.

6) Alternating beds of thick to massive bedded limestone separated by thin beds of shale exist in the upper half of Section 1.

Evidence indicating a deeper water environment of deposition for the New Market is present. The evidence for this type of environment increases upward in the section indicating a change through time from a shallow environment evidenced by the basal conglomerate, to an increasingly deeper environment, evidenced by the characteristics noted above.

Also present in the section is much evidence pointing to a restricted basin of deposition. The evidence supporting this type of environment is discussed below.

(3) EVIDENCE FOR A RESTRICTED ENVIRONMENT OF DEPOSITION

Pettijohn (1957) lists nine characteristics of the sediments of stagnant basins (Figure 7). These are:

1) Fine grained

2) Highly reducing

3) H_2S present

4) $CaCO_3$ high

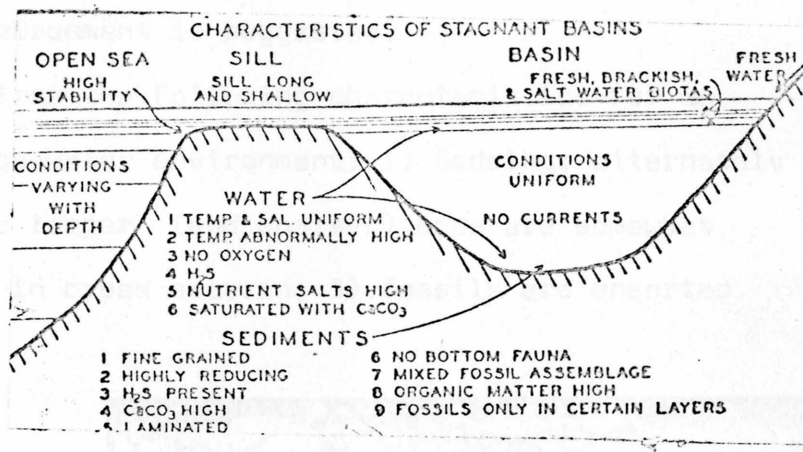
5) Laminated

6) No bottom fauna

7) Mixed fossil assemblage

8) Organic matter high

9) Fossils only in certain layers



(FIG. 7) From Pettijohn, 1957.

New Market sediments are in general fine to very fine grained. That the environment of deposition was reducing is suggested by the abundant pyrite crystals found in many microfacies. The sediments are indeed laminated, as has been stated, in many instances. Fossil assemblages are mixed, and found only in certain layers (Figure 6). The fossils which are most common in the New Market are brachiopods and gastropods (Plate 3a, 3b), these animals are bottom dwellers, thus contradicting characteristic 6 above, unless of course they were transported into the basin after death, (a taphonomic study of the New Market fauna would be a good topic for future research). The presence of dolomite in microfacies 7, Section 1 indicates a concentration of magnesium which would easily be explained by a restricted environment where evaporation exceeds precipitation or reflux of sea water.

Neither the characteristics of deeper water limestones nor the characteristics of a stagnant basin are reflected by the New Market section as a whole; only certain microfacies reflect some of the characteristics of one or the other of the above mentioned environments. Therefore an intermediate environment is suggested.

Pettijohn (1957) summarizes the following characteristics for an intermittently quiet and rough-water environment: 1) Bedding; alternately regular and irregular; 2) The larger (and coarser) beds are somewhat uneven in thickness and wavy in cross section; 3) fossils are unsorted

FIG. 8 Irregular bedding of the New Market limestone

and relatively unbroken. The characteristic state of the fossils also suggests that the energy level of the rough water was not too high or else the fossils would be sorted to some degree and or broken.

These characteristics apply more or less to the entire New Market section.

"It is comparatively easy to distinguish between the turbulent and quiet water environments, i.e., between the sediments deposited above wave base and those deposited below. It is difficult, however, to estimate absolute depth of water." (Pettijohn, 1957).

Microfacies 1 and 5 of Section 1 and microfacies 1 and 4 of Section 2 are easily identified as rough water deposits by their conglomeritic or clastic nature. The rest of the microfacies in each section are either shales or limestones of Types II or III (Table 3), which are indicative or relatively quiet water deposition.

A quiet water environment of deposition may occur where the water is deep i.e., the sediments are deposited below wave base or where the water is shallow, but far from shore. The center of an epeiric sea would meet the conditions for the latter type of quiet water deposition, and indeed the Middle Ordovician sea is defined as an epeiric sea. This method of deposition i.e., chemical or organic deposition far out at sea could easily explain the occurence of the abundant Type II and III limestones, however, the evidence discovered in thin sections indicating deep water and restricted depositional environments forces one to seek a different model of the basin of deposition of the New Market in Rockbridge County.

BASIN MODEL

In formulating a model of the basin of deposition for the New Market of Section 1, several things must be kept in mind. First of all, no attempt has been made to interpret the shape of the basin. This would require many more sections and the compilation of an isopach map. The main emphasis of this report has been vertical trends rather than lateral trends. Secondly, the assumptions made concerning the nature of the various lithologies are in some cases arbitrary and future research may provide evidence for different interpretations. Lastly, that the characteristics of deep water and restricted deposition do not apply uniformly to the entire section. In light of this a compromise must be reached between the two above mentioned depositional environments. The following history of deposition and type of basin which would accomplish this is therefore proposed.

The deposition of the New Market at Section 1 apparently involved 4 periods of transgression and regression. Initially the seas transgressed over the old Beekmantown surface depositing the basal conglomerate (microfacies 1), and the limestones of microfacies 2, 3, and 4. Microfacies 5 represents a regression followed by transgression and the deposition of microfacies 6 limestone. Microfacies 7 (dolomite) tends to complicate the here-to-for simple marine transgressive-regressive sequence in that it apparently represents a closing or stagnation of the basin allowing the rate of evaporation to surpass the rate of reflux of sea water. Microfacie 8 is a shale which could have formed either as the result of further transgression of the sea or of increased restriction of the basin. Microfacies 9a thru 10 are limestones which indicate either regression or an opening up of the basin. A similar shale-limestone sequence is represented by microfacies 11 thru 15. Microfacies 17 thru 19 possess the most evidence for deep water deposition (see above discussion).

In light of the above mentioned history of deposition and characteristics of deep and restricted deposition, the following basin model is proposed.

The seas transgressed and regressed normally over the Beekmantown surface until the time of deposition of microfacies 7 at which time a restriction of the basin is first indicated. This could come about by the formation of a lagoonal type environment such as would form behind a barrier beach. After microfacies 7 time, channels could have been cut through the barrier allowing for a semi-restricted type environment which would explain the continued presence of pyrite in the microfacies above number 7. Up until microfacies 17 it would seem that the basin was situated on a broad, shallow platform because of the dominance of Type II and III limestone. From microfacies 17 thru 19 the basin deepened.

APPENDIX

TERMINOLOGY

For the purposes of this paper, a microfacies is defined as a small scale facies within a larger one, which in this case is the entire New Market Formation. The microfacies in this paper were determined by observing the marked vertical changes in the lithologic characteristics of the rocks in the section; such as limestone grading into shale, a dark limestone grading into a lighter one, or a non-cherty limestone grading into a cherty one.

The term microfacies is defined by Chilingar, et. al. (1967) as "consisting of laminae, thickness of which is no greater than the largest diameter of the coarsest grain." In this sense, a microfacies is truly a microscopic facies; that is, it is best observed with the aid of a microscope.

The microfacies of this report are in a sense similar to the micro-sequences of Chilingar, et. al. (1967), which are layers of variable thickness used to define a natural succession of microfacies, which reflect the history of the filling of the basin.

Hand specimens described in Tables 1 and 4, include in the following order:: a visual estimate of the composition of the rock, (limestone, dolomite, etc.); textural modifiers, and statements about grain size (Figure 9); the color of fresh and weathered surfaces based on the G.S.A. color chart, types of fossils present, if any; and special comments about the rock.

A limestone is defined as a crystalline sedimentary rock which effervesces violently in a 10% hydrochloric acid solution, and is

Wentworth Grade Scale (mm.)	Crystallinity size based on average size of crystals (mm.)	Clastic grain size based on average size of grains of sedimentation (after Grabau, 1924) (mm.)	Textural modifiers
pebbles	very coarsely crystalline	calcirudite	Bioskeletal Pellet Crinoidal Argillaceous Arenaceous etc., where these components comprise important percentages of the rock.
2.0			
very coarse sand	coarsely crystalline	coarse-grained calcarenite	
1.0			
coarse sand			
1/2			
medium sand	medium crystalline		
1/4			
fine sand		fine-grained calcarenite	
1/8			
very fine sand	finely crystalline		
1/16			
silt	very finely crystalline	calcisiltite	
1/64			
silt	coarsely aphanitic		
1/128?			
silt	finely aphanitic	calcilutite	
1/256			
clay			

(FIG. 9) Textural classifications for the rocks of the Middle Ordovician New Market limestone. (From Thompson, 1963).

Classification of Strata According to Thickness

Massive	Unbedded
Massive Bedded	24" and over
Thick Bedded	10" to 24"
Medium Bedded	4" to 10"
Thin Bedded	¼" to 4"
Laminated	¼" and less

(FIG. 10) Classification of the strata according to thickness.

assumed to be composed mainly of calcite, (Pettijohn, 1957).

Dolomite is a variety of limestone containing more than 50% carbonate, of which more than half is the mineral dolomite; this rock effervesces very slowly in 10% hydrochloric acid solution, (Pettijohn, 1957).

A shale is a very-fine-grained fissle sedimentary rock that is composed dominantly of argillaceous material, much of which is presumably clay material, (Thompson, 1963).

The terms limestone and shale may be prefixed by the adjectives calcareous, dolomitic or argillaceous where these subordinate constituents make up recognizable portions of the rocks, (Thompson, 1963).

"Micrite is a type of calcite which forms grains 1-4 microns in diameter, is generally subtranslucent with a faint brownish cast in thin section. In hand specimen, this is the dull and opaque ultra-fine-grained material that forms the bulk of lithographic limestones, and may range in color from white through gray, bluish and brownish gray, to nearly black. Micrite (microcrystalline carbonate ooze) is considered as forming very largely by rather rapid chemical or biochemical precipitation in sea water, settling to the bottom, and at times undergoing some later drifting by weak currents. This is analogous with the mode of deposition of snow, which also is precipitated in a fluid medium (the atmosphere), then settles down and either lies where it falls, or may be swept into drifts," (Folk, 1959).

"The term 'micrite' was introduced as a contraction of 'microcrystalline calcite', to serve (1) in referring to the matrix of microcrystalline calcite as a rock constituent (for example, brachiopods in micrite matrix), (2) as a combining term in the classification of carbonates (for example, 'biomicrite'), and (3) to serve alone as the designation for a rock made up almost entirely of microcrystalline calcite. It is both shorter and more specific than the terms 'lime mudstone', 'calcilutite', or 'aphanitic limestone,' all of which, if one goes by etymology as well as by field usage, can refer to silt-sized as well as to clay-sized carbonate, (Folk, 1959)."

"Sparite, (sparry calcite) is a type of calcite which generally forms grains or crystals 10 microns or more in diameter, and is distinguished from microcrystalline calcite by its clarity as well as coarser crystal size. Sparry calcite generally forms as a simple pore-filling cement, precipitated in place within the sediment just as salt crystallizes on the walls of a beaker. Grain size of sparite is dependant upon the size of the pores and rate of crystallization; in most limestones, the spar averages from 0.02 to 0.10 mm, although crystals of 1 mm or more are not uncommon in limestones with large pore spaces. In some rocks, sparry calcite is not an original precipitate but has formed by recrystallization of finer carbonate grains or microcrystalline calcite, (Folk, 1959)."

Allochem is a collective term which embraces all the organized carbonate aggregates which make up the bulk of many limestones. Allochem, (allo--meaning "out of the ordinary," and chem--being short for chemical precipitate) indicates that these are not ordinary chemical precipitates as the chemist thinks of them, but are complexes that have achieved a higher order of organization, and, in nearly all cases, have also undergone transportation. Ther are only four types of allochems that are volumetrically important in limestones: (1) intraclasts, (2) oolites,

(3) fossils, and (4) pellets. Of these, perhaps only intraclasts need be further discussed, (Folk, 1959).

Folk, (1959) uses the term intraclast to describe "fragments of penecontemporaneous, generally weakly consolidated carbonate sediment that have been eroded from adjoining parts of the sea bottom and redeposited to form a new sediment (hence the term 'intraclast', signifying that they have been reworked from within the area of deposition and within the same formation). It does not refer to single fossils, oolites, or pellets momentarily laid down and then picked up, but only to clusters of such grains bonded together by welding, by carbonate cement, or lime mud--proving that they had once been a part of a coherent sediment. Folk concludes that the most common mode of formation of intraclasts is by erosion of portions of a widespread layer of semiconsolidated carbonate sediment, with erosion reaching to depths of a few inches up to a few feet in the bottom sediment".

Of the four above mentioned common allochems, the only types found in the New Market formation are intraclasts and fossils; and only fossils are volumetrically important.

THE MAIN LIMESTONE FAMILIES

Folk (1959), has devised a division of limestones onto three major families or types. This division is made by determining the relative proportions of three end members (1) allochems, (2) microcrystalline ooze, and (3) sparry calcite cement.

Allochems are analogous to the quartz sand of a sandstone or the pebbles of a conglomerate in that they represent the framework of the rock and include, as mentioned, the shells, oolites, carbonate pebbles or pellets which make up the bulk of most limestones. Microcrystalline ooze represents a clay-size 'matrix' whose presence signifies lack of vigorous currents, just as the presence of a clay-mineral matrix in a sandstone indicates poor washing. Sparry calcite cement is mainly a pore filler which fills up spaces where micrite has been washed out or was not available. Sparite may form by recrystallization of micrite in some instances however. Thus it is evident that the relative proportions of micrite and sparite are important indicators of the current strength of the enviornment, (Folk, 1959).

"Type I limestones (designated as 'Sparry Allochemical rocks') consist chiefly of allochemical constituents cemented by sparry calcite cement. These types of rocks are similar to well sorted terrigenous sandstones or conglomerates in that solid particles have been heaped together by currents powerful or persistent enough to winnow away any microcrystalline ooze that otherwise might have accumulated as a matrix, and the interstitual pores have later been filled by directly precipitated calcite cement. The relative proportion of sparry calcite cement and allochems varies within rather restricted limits because of the limitations of packing, since sparry calcite normally does not make a rock in its own right. This limestone type generally forms on beaches, bars, or submarine shoals, but can also form in lower energy areas where for some reason no lime mud is produced or available.

Type II limestones (designated as 'Microcrystalline Allochemical rocks') also contain allochems, but here currents were not strong enough or persistent enough to winnow away the microcrystalline ooze, which remains as a matrix; sparry calcite is very subordinate, or lacking, simply because no pore space was available in which it could form. In these rocks the restrictions of packing impose a certain maximum on the amount of allochems; yet there is no minimum, and Microcrystalline Allochemical rocks are found with percentages of allochems varying continuously from about 80% down to almost nothing. The reason for this is that microcrystalline ooze can form a rock in its own right (comparable with claystone in the terrigenous series), and can accept any amount of allochem material that becomes mixed with it.

Type I limestones indicate strong or persistent currents and a high-energy enviornment, whereas Type II limestones indicate weak, short-lived currents or a rapid rate of formation of microcrystalline ooze.

Type III limestones (the Microcrystalline rocks) represent the opposite extreme from Type I, inasmuch as they consist almost entirely of microcrystalline ooze with little or no allochem material; 'lithographic' limestone belongs to this class. These rocks imply both a rapid rate of precipitation of microcrystalline ooze, together with lack of persistent strong currents; most form in very shallow, sheltered lagoonal areas, or on broad, submerged shelves of little relief and moderate depth where wave action is cut off by the very width of the shelf. Some may also form in deeper offshore areas.

Some microcrystalline rocks have been disturbed either by burrowing organisms or by soft-sediment deformation, and the resulting openings are filled with irregular 'eyes' or stringers of sparry calcite (birds-eyes). Other beds of microcrystalline ooze have been partially torn up by bottom currents and rapidly redeposited, but without the production of distinct intraclasts" (Folk, 1959).

Type IV limestone is what is termed a biolithite; a rock composed of the remains of an ancient mass of colonial organisms such as algae or coral.

Type V limestones are the dolomites.

TABLE I. CLASSIFICATION OF CARBONATE ROCKS

Volumetric Allochem Composition	Limestones, Partly Dolomitized Limestones, and Primary Dolomites (see Notes 1 to 6): >10% Allochems, Allochemical Rocks (I and II): Sparry Calcite Cement > Microcrystalline Ooze Matrix — Sparry Allochemical Rocks (I)	>10% Allochems: Microcrystalline Ooze Matrix > Sparry Calcite Cement — Microcrystalline Alochemical Rocks (II)	<10% Allochems, Microcrystalline Rocks (III): 1–10% Allochems	1–10% Allochems	<10% Allochems: <1% Allochems	Undisturbed Bioherm Rocks (IV)	Replacement Dolomites[7] (V): Allochem Ghosts	Allochem Ghosts	Replacement Dolomites[7] (V): No Allochem Ghosts
>25% Intraclasts (i)	Intrasparrudite (Ii:Lr) Intrasparite (Ii:La)	Intramicrudite* (IIi:Lr) Intramicrite* (IIi:La)	Most Abundant Allochem	Intraclasts: Intraclast-bearing Micrite* (IIIi:Lr or La)	Micrite (IIIm:L); if disturbed, Dismicrite (IIImX:L); if primary dolomite, Dolomicrite (IIIm:D)	Biolithite (IV:L)	Evident Allochem	Finely Crystalline Intraclastic Dolomite (Vi:D3) etc.	Medium Crystalline Dolomite (V:D4)
<25% Intraclasts: >25% Oölites (o)	Oösparrudite (Io:Lr) Oösparite (Io:La)	Oömicrudite* (IIo:Lr) Oömicrite* (IIo:La)		Oölites: Oölite-bearing Micrite* (IIIo:Lr or La)				Coarsely Crystalline Oölitic Dolomite (Vo:D5) etc.	Finely Crystalline Dolomite (V:D3)
<25% Intraclasts: <25% Oölites: Volume Ratio of Fossils to Pellets >3:1 (b)	Biosparrudite (Ib:Lr) Biosparite (Ib:La)	Biomicrudite (IIb:Lr) Biomicrite (IIb:La)		Fossils: Fossiliferous Micrite (IIIb: Lr, La, or Ll)				Aphanocrystalline Biogenic Dolomite (Vb:Dl) etc.	
<25% Intraclasts: <25% Oölites: Volume Ratio of Fossils to Pellets 3:1–1:3 (bp)	Biopelsparite (Ibp:La)	Biopelmicrite (IIbp:La)		Pellets: Pelletiferous Micrite (IIIp:La)				Very Finely Crystalline Pellet Dolomite (Vp:D2) etc.	etc.
<25% Intraclasts: <25% Oölites: Volume Ratio of Fossils to Pellets <1:3 (p)	Pelsparite (Ip:La)	Pelmicrite (IIp:La)							

NOTES TO TABLE I

* Designates rare rock types.

[1] Names and symbols in the body of the table refer to limestones. If the rock contains more than 10 per cent replacement dolomite, prefix the term "dolomitized" to the rock name, and use DLr or DLa for the symbol (e.g., dolomitized intrasparite, Li:DLa). If the rock contains more than 10 per cent dolomite of uncertain origin, prefix the term "dolomitic" to the rock name, and use dLr or dLa for the symbol (e.g., dolomitic pelsparite, Ip:dLa). If the rock consists of primary (directly deposited) dolomite, prefix the term "primary dolomite" to the rock name, and use Dr or Da for the symbol (e.g., primary dolomite intramicrite, IIi:Da). Instead of "primary dolomite micrite" (IIIm:D) the term "dolomicrite" may be used.

[2] Upper name in each box refers to calcirudites (median allochem size larger than 1.0 mm.); and lower name refers to all rocks with median allochem size smaller than 1.0 mm. Grain size and quantity of ooze matrix, cements or terrigenous grains are ignored.

[3] If the rock contains more than 10 per cent terrigenous material, prefix "sandy," "silty," or "clayey" to the rock name, and "Ts," "Tz," or "Tc" to the symbol depending on which is dominant (e.g., sandy biosparite, TsIb:La, or silty dolomitized pelmicrite, TzIIp:DLa). Glauconite, collophane, chert, pyrite, or other modifiers may also be prefixed.

[4] If the rock contains other allochems in significant quantities that are not mentioned in the main rock name, these should be prefixed as qualifiers preceding the main rock name (e.g., fossiliferous intrasparite, oölitic pelmicrite, pelletiferous oösparite, or intraclastic biomicrudite). This can be shown symbolically as Ii(b), Io(p), IIb(i), respectively.

[5] If the fossils are of rather uniform type or one type is dominant, this fact should be shown in the rock name (e.g., pelecypod biosparrudite, crinoid biomicrite).

[6] If the rock was originally microcrystalline and can be shown to have recrystallized to microspar (5–15 micron, clear calcite) the terms "microsparite," "biomicrosparite," etc. can be used instead of "micrite" or "biomicrite."

[7] Specify crystal size as shown in the examples.

(FIG. 11) Classification of the carbonate rocks, from Folk (1959).

REFERENCES AND REFERENCES CITED

Ager, D.V., 1963, Paleoecology: New York, McGraw-Hill Book Co., 371 p.

Beerbower, J.R., 1968, Search for the past; an introduction to paleontology: Englewood Cliffs, N.J., Prentice-Hall, Inc., 512 p.

Bouma, A.H., 1969, Methods for the study of sedimentary structures: New York, John Wiley & Sons, 458 p.

Bradley, W.H., 1931, Non-glacial marine varves: Am. Jour. Sci., 5th series, v. 22, p. 318-330.

Butts, Charles, 1940, Geology of the Appalachian Valley in Virginia: Virginia Geological Survey, bull. 52, part I, 568 p.

Carozzi, A.V., 1960, Microscopic sedimentary petrography: New York, John Wiley & Sons, 485 p.

_______, 1967, Criteres de distinction entre oolithes autochtones et allochtones application au calcaire de Sainte-Genevieve de L'Illinois (U.S.A.): Bull. Centre Rech. Pau- SNPA, p. 279-313.

_______, 1967, Petrography of a carbonate transgressive-regressive sequence: the Bird Spring Group (Pennsylvanian), Arrow Canyon Range, Clark County, Nevada: Jour. Sed. Petrology, v. 37, no. 2, p. 377-400.

_______, 1968, Petrography of selected Chesterian carbonates (Visean-Namurian) from the type area in Southwestern Illinois: Illinois State Academy of Science, v. 61, no. 2, p. 182-200.

Chilingar, G.V., Bissell, H.J., and Fairbridge, R.W., 1967, Carbonate Rocks--origin, occurrence and classification: New York, Elsevier Publishing Co., 471 p.

Clark, T.H., and Stearn, C.W., 1960, The geological evolution of North America: New York, The Ronald Press Co., 434 p.

Cooper, B.N., and Cooper, Arthur, 1946, Lower Middle Ordovician stratigraphy of the Shenandoah Valley, Virginia: Geol. Soc. America Bull. v. 57, p. 35-114.

Cuvillier, J., 1961, Stratigraphic correlations by microfacies in western Aquitaine: International Sedimentary Petrographic Series, v. II.

Deffeyes, K.S., Lucia, F.J., and Weyl, P.K., 1965, Dolomitization of recent and Plio-Pleistocene sediments by marine evaporite waters on Bonaire, Netherlands Antilles: Soc. Econ. Paleo. and Min., Special Publication no. 13, p. 71-88.

Dunbar, C.O., and Rodgers, John, 1957, Principles of stratigraphy: New York, John Wiley & Sons, Inc., 356 p.

Eicher, D.L., 1968, Geologic time: Englewood Cliffs, N.J., Prentice-Hall, Inc., 150 p.

Folk, R.L., 1962, Spectral subdivision of limestone types: Am. Assoc. Petroleum Geologists, Memoir I, p. 62-84.

Ginsburg, R.N., 1957, Early diagenesis and lithification of shallow-water carbonate sediments in south Florida: Soc. Econ. Paleo. and Min., Special Publication no. 5, p. 80-98.

Harbaugh, J.W., 1959, Small scale cross-lamination in limestones: Jour. Sed. Petrology, v. 29, no. 1, p. 30-37.

Hecker, R.F., 1965, Introduction to paleoecology: New York, American Elsevier Publishing Co., Inc., 166 p.

Kozak, S.J., 1965, Geology of the Millboro quadrangle Virginia: Virginia Division of Mineral Resources Rept. Inv. 8, 19 p.

Krumbein, W.C. and Sloss, L.L., 1951, Stratigraphy and sedimentation: San Francisco, W.H. Freeman and Company, 660 p.

Laporte, L.F., 1968, Ancient environments: Englewood Cliffs, N.J., Prentice-Hall, Inc., 115 p.

Moorhouse, W.W., 1959, The study of rocks in thin section: New York, Harper & Row, Publishers, 514 p.

Pettijohn, F.J., 1957, Sedimentary rocks: New York, Harper & Row, Publishers, 718 p.

Rodgers, John, 1957, The distribution of marine carbonate sediments: a review: Soc. Econ. Paleo. and Min., Special Publication no. 5, p. 2-12.

Spencer, E.W., 1966, Basic concepts of historical geology: New York, Thomas Y. Crowell Company, 504 p.

Thompson, R.R., 1963, Lithostratigraphy of the Middle Ordovician Salona and Coburn formations in central Pennsylvania: Pennsylvania Geological Survey, General Report G 38, 154 p.

Wilson, J.L., 1969, Microfacies and sedimentary structures in "deeper water" lime mudstones: Soc. Econ. Paleo. and Min., Special Publication no. 14, p. 4-16.