Department of Natural Resources

MARYLAND GEOLOGICAL SURVEY

Kenneth N. Weaver, Director

REPORT OF INVESTIGATION NO. 23

STRATIGRAPHY, SEDIMENTOLOGY AND CAMBRO-ORDOVICIAN PALEOGEOGRAPHY OF THE FREDERICK VALLEY, MARYLAND

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STRATIGRAPHY, SEDIMENTOLOGY, AND CAMBRO-ORDOVICIAN PALEOGEOGRAPHY OF THE FREDERICK VALLEY, MARYLAND

by

Juergen Reinhardt

ABSTRACT

Recent mapping in the Frederick Valley of central Maryland has clarified the stratigraphic relationships among lithologies along the western margin of the Piedmont province. A conformable sequence from a Lower and Middle Cambrian metasiltstone, previously mapped as Lower Cambrian Antietam Formation, through the Upper Cambrian Frederick Limestone and Lower Ordovician carbonates of the Grove Limestone is proposed. The Frederick Limestone has been subdivided into three mappable members. The total carbonate section, about 1350 meters (4455 feet) thick, is dominated by two distinct lithotypes: 1) a thinly bedded, laminated, dark gray limestone, composed primarily of silt and clay-sized carbonate, and 2) a thickly bedded to massive, planar or cross-bedded, light gray limestone, composed primarily of peloids and coarse quartz sand.

A shoaling upward pattern from Frederick to Grove Limestone is indicated by changing sediment types, sedimentary structures and the development of well defined sedimentary cycles. An increasing diversity and abundance of trace and body fossils plus the appearance of cryptalgal structures in the sediments sequence indicate a gradual transition from "deeper water carbonates" (>400 meters) to inter- and supratidal carbonate sedimentation.

The stratigraphic and petrologic framework in the Frederick Valley combined with regional stratigraphic relationships indicates a time transgressive clastic-carbonate boundary becoming younger from west to east during the Cambrian. The transition from deep to shoaling water sedimentation within the carbonate sequence in the Frederick Valley indicates an eastward progradation of the Cambro-Ordovician carbonate platform. The conformable relationships and the shoaling upward pattern necessitates a low angle slope rather than an abrupt platform to basin transition for the edge of the carbonate bank during late Cambrian and early Ordovician time.

INTRODUCTION

The Frederick Valley of central Maryland is underlain by a continuous belt of moderately deformed Cambro-Ordovician carbonates and siltstones about 37 kilometers long and up to 9.5 kilometers wide (figure 1). Structurally, the valley is an assymetrical synclinorium bounded on the west by Catoctin Mountain, the normal limb of the South Mountain Anticlinorium (Cloos, 1941, 1947; Whitaker, 1955a), and on the east by the phyllites of the Western Piedmont, separated from the rocks of the Frederick Valley by the Martic Line. In the western and northern portions of the Frederick Valley and to the south in Virginia the Paleozoic rocks are blanketed by Triassic sediments of the New Oxford Formation.

The rocks of the Frederick Valley contain the only known fossils from the Maryland Piedmont and contain much better preserved sedimentary structures than most Piedmont rocks. Therefore, these are the eastern-most rocks which can be related both stratigraphically and paleogeographically to the lower Paleozoic sequence west of the Blue Ridge. As such, they bear critically on interpretations of the stratigraphic relations between the Piedmont and the Valley and Ridge. Sedimentologically the carbonates are quite unlike those of the Great Valley section. An adequate interpretation of this sequence will add to the understanding of shelf-basin relationships during the Cambrian.

Despite their obvious importance, the rocks of the Frederick Valley are inadequately understood. Work on trilobite faunas (Rasetti, 1961) and my own reconaissance during 1970 indicated that systematic remapping for stratigraphic reevaluation of the work of Jonas and Stose (1938) was imperative.

In addition, basic structural and lithologic data seemed critical in light of the rapid urbanization of the Frederick area. Because of the development, outcrops will disappear with time. Data gathered on sink holes, solution pits and winter springs and the lithologic control of these features should aid in development decisions

The distribution and structure of the limestones have been mapped (pocket in back) and a revised stratigraphy is proposed (Table 1). Within each stratigraphic unit the sediments and sedimenatry structures are described and interpretations of the environments of deposition have been made. The final section attempts to tie together the stratigraphic and paleoenvironmental relationships for the central Applachian basin, relying on published and unpublished data from the Valley and Ridge and western Piedmont provinces in combination with this work in the Frederick Valley.

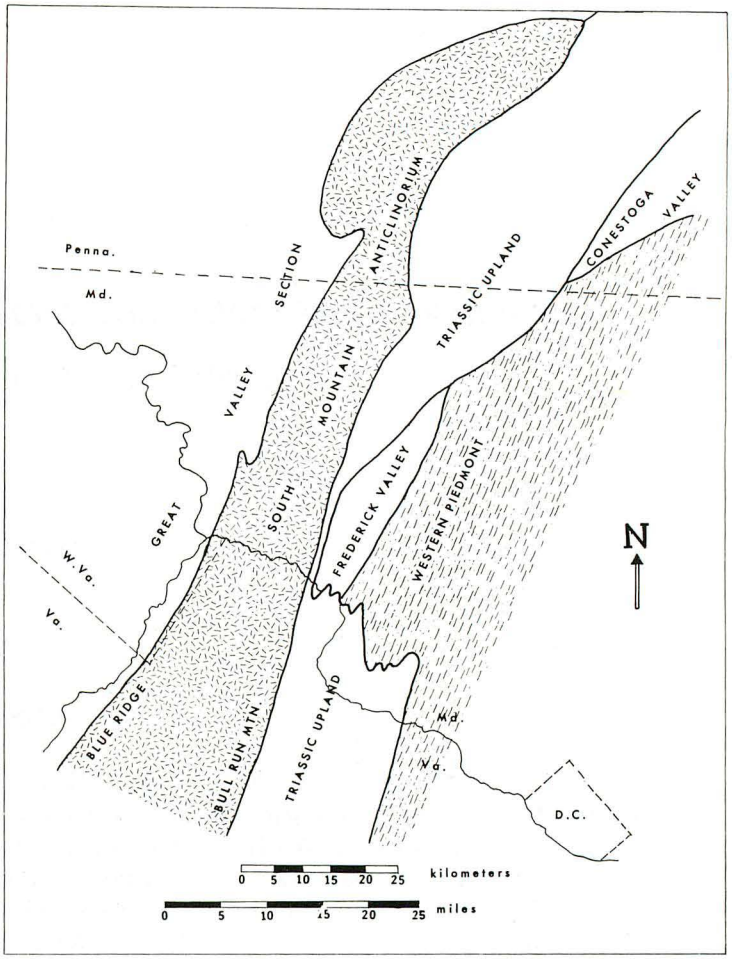


Figure 1.—Location map showing the position of the Frederick Valley and the surrounding physiographic provinces.

ACKNOWLEDGEMENTS

This report is a portion of a Ph.D. thesis submitted to the Johns Hopkins University in 1973. Numerous individuals at Johns Hopkins, especially G. W. Fisher, L. A. Hardie, F. J. Pettijohn and Ernst Cloos, contributed to the completion of this work. Thanks are also due to my colleagues at the Maryland Geological Survey for discussions of and editorial help with the final report. John Goodell drafted plate 2 and assisted in preparation of the line drawings. Financial aid for field work was provided by the German Society of Maryland and the Maryland Geological Survey.

METHODS

A systematic examination of outcrops in the entire carbonate belt was initiated during the summer of 1970, first with the aim of paleoenvironmental analysis and subsequently (summer, 1971) for mapping purposes. Lithologic and structural data were gathered in portions of five 7.5 minute quadrangles at a total of 915 localities. Each locality was plotted in the field on an aerial photograph (1:12,000 scale) and later transferred to a 7.5 minute quadrangle sheet using a Salzman projector.

Each rock sample was slabbed; one slab was polished, etched and stained for dolomite and calcite with Alzarin Red S-Potassium Ferricyanide (Davies and Till, 1967). These slabs were examined under a binocular microscope for mineral composition and distribution, primary bedding features and tectonic overprint. Thin sections and acetate peels were made concurrently or subsequently and a petrographic evaluation was made of a total of 250 samples. The results of this petrographic work will be found within the description of each stratigraphic unit.

During a part of 1972 certain well exposed areas were revisited and sections were carefully measured for use in the description and evaluation of each stratigraphic unit. These type and reference sections have been tabulated in Appendix A.

PREVIOUS WORK

Although the Frederick Valley carbonates have been of economic importance for well over 100 years, surprisingly little research has been done on them. The first mention of carbonates in the Frederick Valley is found in Phillip Tyson's (1860) report to the Maryland House of Delegates. He included the Frederick and Hagerstown Valley carbonates in his Formation No. 10. The first structural hypothesis was proposed by Keyes (1890); his cross-section and others are included in Appendix A. Keyes also listed the first faunas from the Frederick Valley (Appendix B). Bassler (1919) expanded the number of faunas found in the carbonates and made the first stratigraphic distinction between "quarry rock" which was called Beekmantown Limestone and "fossiliferous building rock" which was called Frederick Limestone. On the basis of faunas, local structure and lithologies, Bassler placed the Frederick above the Beekmantown stratigraphically. The thickness of the Frederick Limestone was estimated as greater than 200 feet (~ 60 m.) and the general cross-section of the valley was thought to be anticlinal.

Important work by Jonas and Stose began in 1927 with a geological survey of Frederick County. This work revealed the synclinal nature of the valley. In the most complete reports of this work Jonas and Stose (1936, 1946) presented a generalized column for the Frederick Limestone. The unit was described as a poorly exposed, blue, argillaceous, slabby limestone 480 feet (145 m.) thick. The name Grove Limestone was introduced by Jonas and Stose (1935) for rocks which are purer and more massive than Frederick Limestone and contain abundant quartz sand at the base of the unit. Their thickness estimate was 590 feet (180 m.), based on a section at the Le Gore quarry just north of Woodsboro, Maryland. A complete listing of faunas collected by Jonas, Stose and their colleagues is found in Appendix B. These faunas quite conclusively dated the upper portion of the Frederick Limestone as Upper Cambrian and the Grove Limestone as Ozarkian or lowermost Lower Ordovician. On the basis of these faunas Jonas and Stose proposed regional correlations with a number of Appalachian units, especially those in the Conestoga Valley, Pennsylvania.

Although Wilson (1952) did very little field work in the Frederick area, he included the Frederick Valley limestones in his Upper Cambrian mega-facies or facies belt model. The Frederick Limestone was included in the platy limestone and shale facies.

Whitaker (1955a) reviewed and refined the stratigraphy of the Chilhowee Group on Catoctin Mountain and included the Frederick Valley; he relied heavily on the Stoses' mapping and stratigraphy for the latter area. Field and brief petrographic descriptions are given of the limestones. Whitaker also discussed the amomalous stratigraphic relationships along the eastern slope of Catoctin Mountain. Antietam and/or Tomstown are missing locally; this was explained as the result of either a facies change or faulting.

Rasetti (1959, 1961) added considerable knowledge to the trilobite faunas in several portions of the stratigraphic column present in the Frederick Valley. In his 1961 paper he pointed out that the discontinuous belt of "pure" limestone west of Frederick was incorrectly mapped as Grove Limestone. Rasetti also pointed out similarities with faunas in a number of North American formations. All

faunas described from the Frederick Valley by Rasetti are from the Frederick Formation as defined in this paper. Faunal lists and localities are included in Appendix B.

The bulk of faunal and lithologic data from the Frederick Valley to this date were gathered in quarries or from weathered boulders found in stone walls in the vicinity of Frederick.

STRATIGRAPHIC FRAMEWORK

A major contribution of this study is a revised and detailed stratigraphy for the Frederick Valley carbonates. The previous and present nomenclature are given in Table 1. All new stratigraphic terms introduced in this report should be regarded as formal names. The requirements for proposing formal rock-stratigraphic units as specified in the Code of Stratigraphic Nomenclature (1961) have been met as completely as possible in each case. A generalized geologic column for the Frederick Valley has been presented in figure 2; more detailed columns are presented in plate 2 (pocket).

The unit mapped as Antietam by Jonas and Stose on both sides of the Valley was thought to be Lower Cambrian in age and equivalent to the Lower Cambrian Antietam Quartzite of the Chilhowee Group as defined by Keith (1892, 1894) in Washington County, Maryland. However, the unit is not a quartzite in the Frederick Valley; it is a well indurated, phyllitic siltstone, which more closely resembles the Harpers Formation as described by Schwab (1971).

Jonas and Stose mentioned fossil molds and poorly preserved trilobite spines in the Antietam Formation, but never identified them. Clark (1897) mentioned the discovery of fossils by

Table 1.—Stratigraphic Terminology

Jonas & Stose (1936)	Whitaker (1955)	This Study	Age
Grove Limestone (180 m. thick)	Grove Limestone	Grove Formation (450 m. thick)	Lower Ordovician
Frederick Limestone (145 m. thick)	Frederick Limestone	Frederick Formation: Lime Kiln Member (180 m. thick); Adamstown Member (325 m. thick); Rocky Springs Station Member (300 m. thick)	Upper Cambrian: Trempealeauan; Franconian; Dresbachian
Unconformity	Unconformity		Middle Cambrian
Tomstown Dolomite Antietam Quartzite	Tomstown Dolomite Antietam Formation Harpers Formation	Araby Formation (> 100 m. thick)	Lower Cambrian

Keith in the phyllites east of Araby. Well preserved fossil molds of pelmatozoan columnals found in the upper portion of the siltstone during this study indicate a maximum age of latest Middle Cambrian (J. Sprinkle, personal communication; 1971). These data cast serious doubt on the time equivalence of the Antietam in the Frederick Valley and in the Great Valley. Because of the differences in age and lithology, the new local name Araby Formation is proposed for the rocks previously named Antietam in the Frederick Valley.

A unit mapped as Tomstown dolomite by Jonas and Stose (1938) and Whitaker (1955a) lies stratigraphicaly above the Araby on the western margin of the Frederick Valley. A zone 180 feet (54.5 m.) thick, recovered from a drill core 5 miles southwest of Frederick, Maryland, was designated Tomstown by Hoy and Schumacher (1956), though only the lower 40

GEOLOGIC COLUMN FOR THE FREDERICK VALLEY

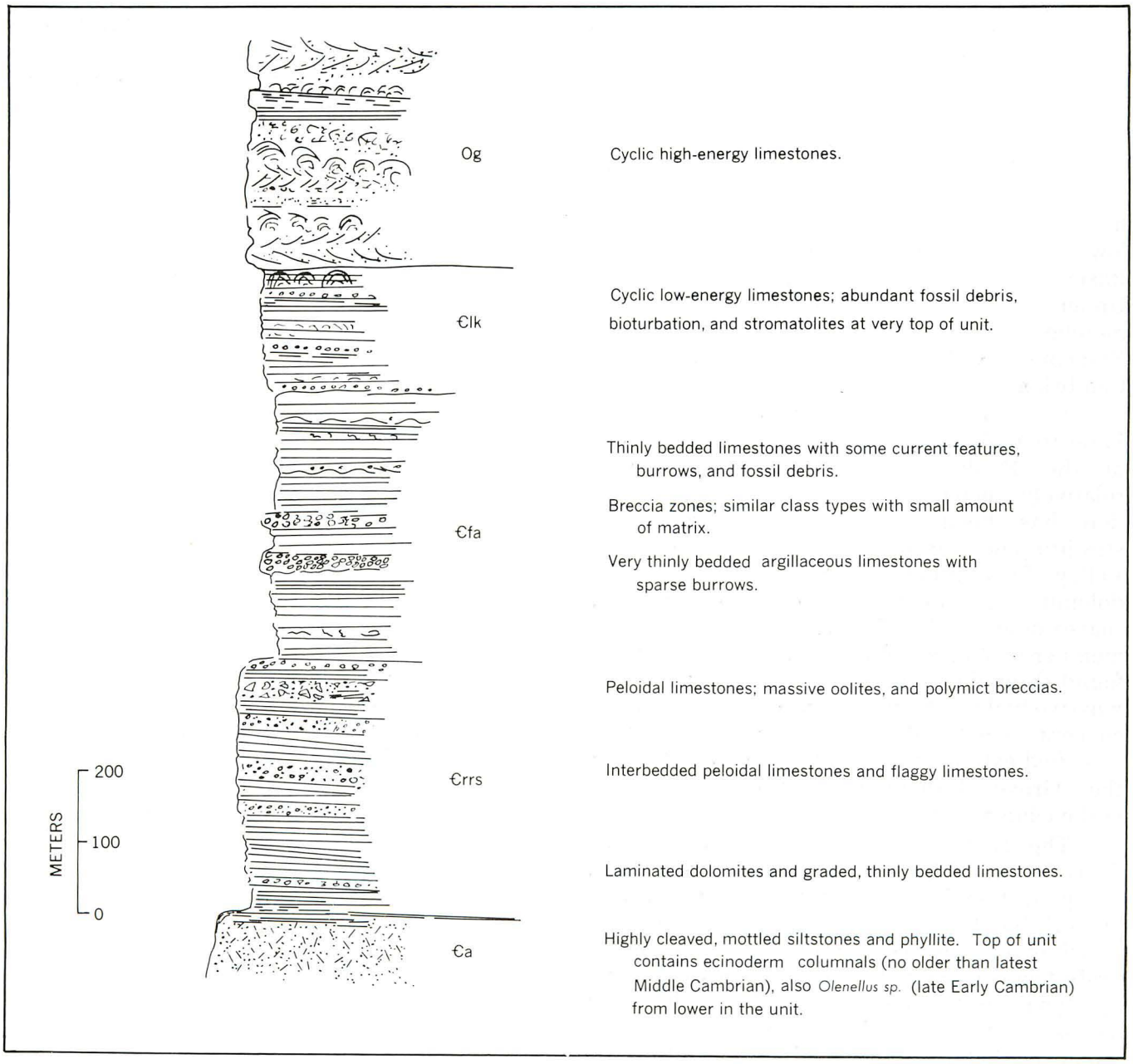


Figure 2.

feet (17 m.) are in any way dissimilar from the overlying Frederick Limestone. There are only one or two outcrops of this dolomite along the western edge of the valley. Southeast of Point of Rocks, Maryland, the dolomite appears to underlie typical Frederick Limestone conformably. This dolomite has been included in the basal member of the Frederick Limestone as it is not a mappable unit.

The Frederick Limestone has been subdivided into three members designated Rocky Springs Station, Adamstown and Lime Kiln from bottom to top. A completely exposed section is available for the Lime Kiln member, and great care has been taken in describing the composite sections for the other members, so that no significant thicknesses have been deleted or overlapped. Type sections for each of these members based on the measured section are found in Appendix A.

The discontinuous "pure" limestone belt west of Frederick, Maryland, mapped as Grove by Jonas and Stose approximates the top of the lowest unit, the Rocky Springs Station member. Rasetti (1961) described Dresbachian (lowest Upper Cambrian) trilobite faunas from this member. The Adamstown Member has yielded Franconian to Trempealeauan (latest Upper Cambrian) fossils.

The unit defined and mapped as Grove Limestone (Jonas and Stose, 1938) in the center of the Frederick Valley syncline remains relatively unchanged. The term Grove Formation has been adopted to formalize the stratigraphic terminology in the Frederick Valley. In addition, a considerable volume of dolomite is included in the Grove Formation. A coarse quartz-rich unit was mapped as a basal member by Jonas and Stose; but coarse sand is found throughout the Grove in thin, thick and massive beds with little lateral continuity, so the concept of a basal calcareous sandstone of a specified extent and thickness is rejected. All of the Grove Formation faunas are Lower Ordovician in age.

The contact of the carbonates with he Triassic New Oxford Formation has been mapped, though no comprehensive stratigraphic work has been completed on the latter unit. Qualitatively, the distribution of the fanglomerate facies is much too continuous on the map by Jonas and Stose (1938). The rather thin Triassic section in the Frederick Valley (≤200 m.) suggests that the degree of down-faulting on either side of this sedimentary wedge is comparatively minor.

ARABY FORMATION

Definition

The unit mapped as Antietam Quartzite by Jonas and Stose (1938) is here renamed the Araby Formation, after its typical exposures in the vicinity of Araby, about 1.5 km. southwest of Frederick Junction, Maryland. The most complete section is exposed along the Baltimore and Ohio Railroad just east of Frederick Junction (figure 4). Other well exposed sections are 4 km. south of Buckeystown along Lily Pons Road between Maryland Route 85 and the Monocacy River and just east of Woodsboro along Maryland Route 550 between Maryland Route 194 and the Lehigh Portland Quarry. A section based on the measurements at several localities is presented in figure 3.

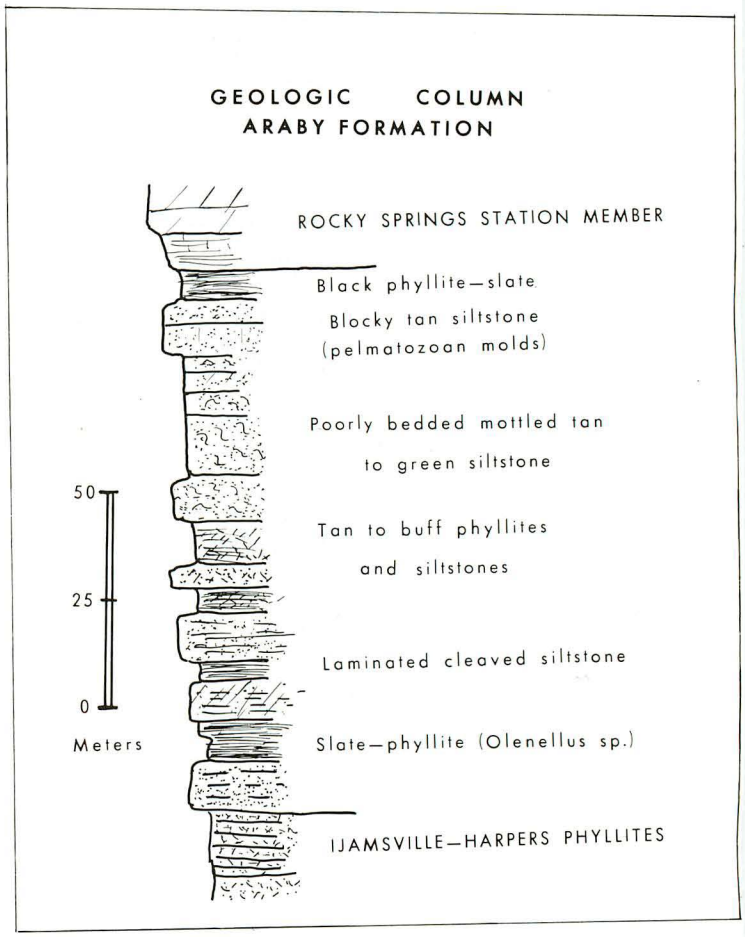


Figure 3.—Geologic column for the Araby Formation based on exposures at several localities.

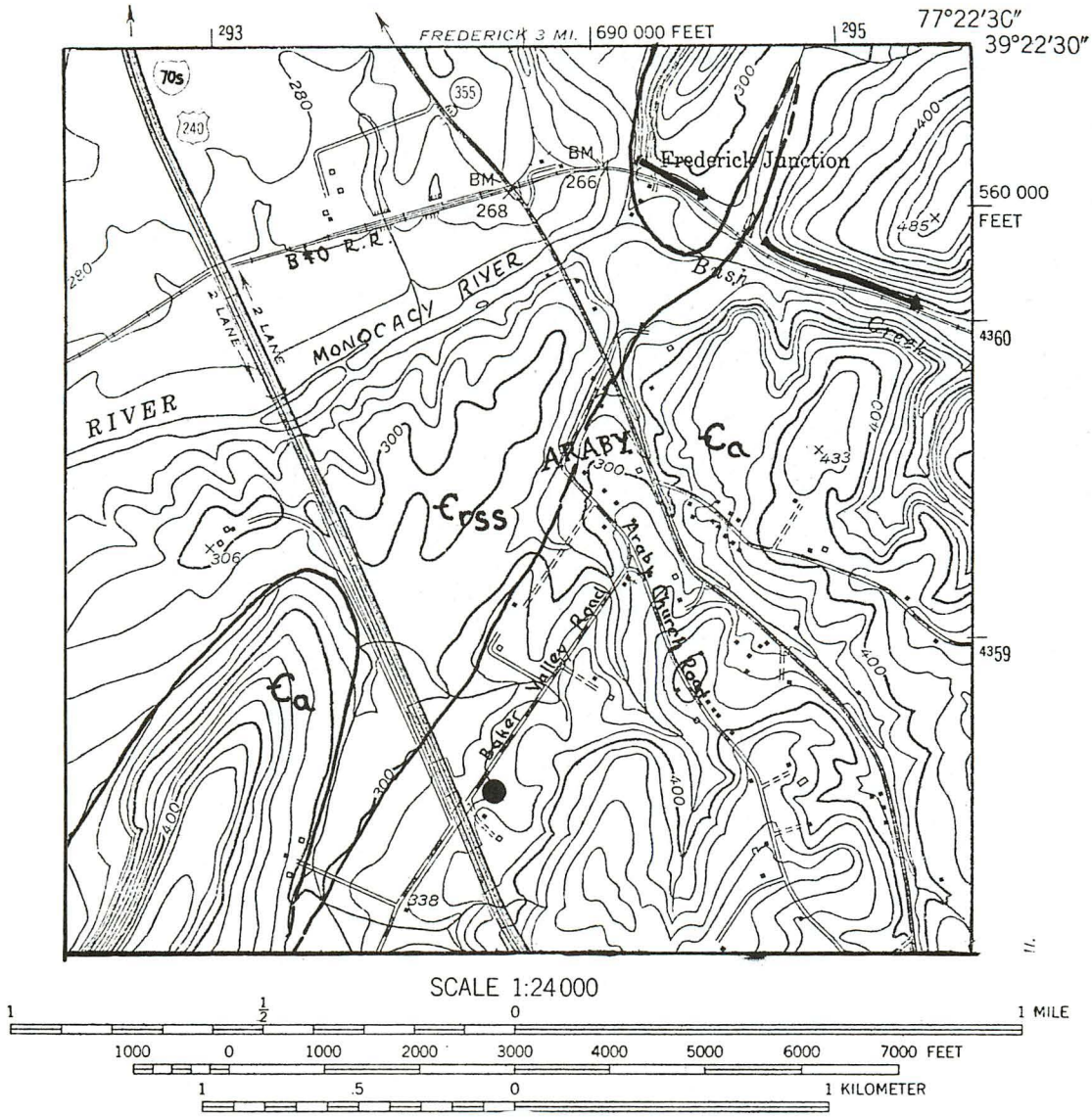


Figure 4.—Sketch map of the Araby Formation type locality. Areas of continuous outcrop are indicated by arrows near Frederick Junction. Black dot on Baker Valley Road is the pelmatozoan locality. (Figure 6).

The Araby Formation is the lowest stratigraphic unit considered in this study. It is a buff or tan to green siliciclastic rock unit, which crops out on both the eastern and western margins of the Frederick Valley. In outcrop it is uniformly very fine grained; it is commonly highly cleaved and/or jointed and bedding is poorly defined. Although the overall structure of the eastern belt is poorly understood and much of the western belt is covered by Triassic sediments or mountain wash, a thickness of 100 meters (330 feet) is estimated from field exposures. Structural complexity and poor exposure prohibit a more precise definition. Along the western margin of the Frederick Valley, Whitaker (1955a) mapped Araby (Antietam Formation) as conformable above Harpers Phyllite. Along the eastern margin the Araby is separated from the Ijamsville Phyllite by the Martic Line; this feature may be a thrust fault contact or more likely is simply a transition from fine to finer grained metasediments.

The first identifiable *Olenellus* sp. has been found during this study in a shaly-phyllite of the Araby Formation (figure 5); this fauna indicates a late Lower Cambrian age (A. R. Palmer, personal communication, 1972). Pelmatozoan molds from the upper 20 meters of the formation (figure 6) have been identified and cannot be older than very latest Middle Cambrian (Sprinkle, personal communication, 1971). It should be noted that strictly on the basis of the pelmatozoan molds, a more probable age would be Middle Ordovician, though the synclinal Valley structure and the absence of major thrust slices would seem to preclude such a possibility.

Figure 5.—*Olenellus* sp. fragment from shaley phyllite zone in the Araby Formation. Note the prominent, slightly distorted, genal spine. Identification and age assignment of late Lower Cambrian courtesy of A. R. Palmer (written communication, 1972).
Bar = 1.0 cm.

This unit is renamed Araby Formation because it differs in lithology and age from the type Antietam of Keith (1892) and because of uncertainties in the absolute correlation between units in the geologic columns of the Great Valley and the Frederick Valley.

Lithology

The Araby is highly cleaved and bedding is only locally recognizable. Virtually all primary bedding structures, such as planar or ripple cross-lamination have been obscured by biogenic reworking of the sediment and/or tectonic overprint. Gross compositional differences between bedding horizons are still preserved, however, and it is this feature which is most useful in determining bedding orientation.

In thin section the most conspicuous elements are the moderately well sorted, slightly deformed quartz grains in a tightly welded framework-matrix mosaic. The quartz grains constitute the bast bulk (80%) of the framework and range from .25 to .50 mm. in diameter (coarse silt to very fine sand). The framework grains are poorly delineated due to the incipient growth of fibrous quartz at the margins of grains and the recrystallization of the sericite-chlorite matrix along the grain margins.

Thin zones ($\leq$1mm. thick) of recrystallized matrix, relatively free of quartz grains, delineate cleavage. In quartz rich zones the silt size grains have been amalgamated into sand or granule size clusters, in which the original grains are delineated by a thin rind of recrystallized matrix. Accessory amounts of

Table 2.—Chemical Analyses of Araby, Antietam, and Wissahickon Formations

	Araby Formation Frederick County[a]			Antietam Formation Washington County[b]			Wissahickon Formation Harford County[c]		
	1	2	3	4	5	6	7	8	9
SiO_2	69.8	67.9	72.1	86.6	93.3	80.0	65.1	65.1	66.3
Al_2O_3	14.4	14.8	14.2	6.0	1.6	10.1	14.8	14.1	15.8
Fe_2O_3	1.6	2.4	.82	3.4	1.9	.63	3.4	5.5	3.1
FeO	2.1	1.3	.80	.64	.60	.28	4.2	3.5	3.7
MgO	.99	.87	.43	.62	.15	.36	1.5	2.0	1.8
CaO	.37	.28	.12	.00	.00	.00	2.0	1.2	1.1
Na_2O	1.7	.96	.40	.00	.00	.15	3.3	3.6	2.4
K_2O	7.6	8.7	8.3	.22	.25	6.6	2.2	1.9	2.2
H_2O+	.26	1.4	1.5	1.6	1.2	.82	.94	1.0	2.3
H_2O-	.19	.30	.17	.23	.62	.58	.06	.05	.04
TiO_2	.86	.86	1.1	.20	.16	.30	1.6	1.1	.60
P_2O_5	.17	.15	.06	.13	.09	.12	.48	.31	.23
MnO	.06	.07	.04	.06	.15	.04	.21	.51	.19
CO_2	<.05	<.05	<.05	.04	.02	.02	<.05	<.05	<.05
	100.	100.	100.	100.	100.	100.	99.7	99.8	99.7

a. Analyses performed for G. W. Fisher, October, 1972.
b. Analyses performed for M. W. Higgins, January, 1974.
c. Analyses performed for D. L. Southwick, 1965, *in* Southwick (1969).

All analyses were performed in the Rapid Rock Analysis Laboratory, U. S. Geological Survey under Leonard Shapiro. (P.L.D. Elmore, analyst for samples 1-6)

1. Mottled metasiltstone at top of Araby Fm., B & O R.R. at Monocacy River.
2. Laminated metasiltstone 12 m. (40 ft.) below sample 1.
3. Thinly bedded metasiltstone 18 m. (60 ft.) below sample 1.
4. Medium sandstone with ferruginous coating, top of Antietam Fm. at Keith's (1892) type locality.
5. White medium to coarse sandstone near middle of the Antietam Fm.; location as above.
6. Argillaceous sandstone near base of Antietam Fm.
7. Garnet-mica schist, lower pelitic lithofacies, Wissahickon Fm. Md. Rt. 23 near Winter's Road.
8. Garnet-mica schist, lower pelitic lithofacies, Wissahickon Fm., Boggs Road near Grafton's Shop Road.
9. Albite-chlorite schist, Upper pelitic lithofacies, Wissahickon Fm., Deer Creek 0.5 miles east of Md. 23.

microcline, mafic grains, and scattered pyrite cubes and clots (mm. scale) are also present as framework components.

Chemical analyses of the Araby Formation show minor differences between the type Antietam Formation and the Araby (Table 2). The high potash to soda ratios contrast with the reversed ratios of some western Piedmont lithologies.

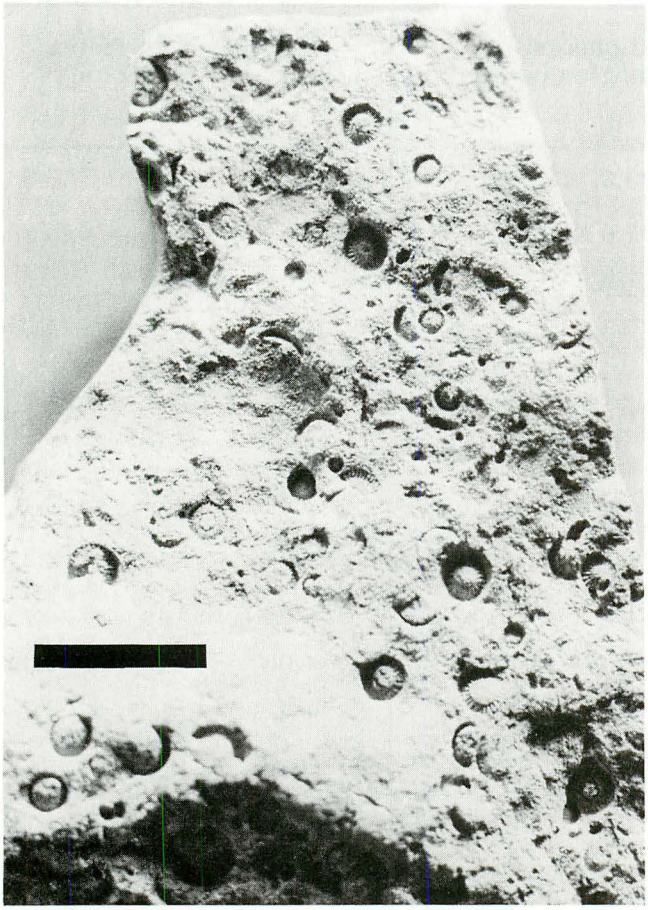


Figure 6.—Molds of advanced echinoderm columnals from buff to tan siltstone at the top of the Araby Formation. These pelmatozoans (eocrinoids ?) are latest Middle Cambrian or younger (J. Sprinkle, written communication, 1971). Bar = 1.0 cm.

Summary and Environmental Interpretation

The Araby Formation offers virtually no sedimentary features which are of use in detailed environmental analysis. Exposures are poor, except in road and railroad cuts. Surficial iron staining on weathered samples and intense cleavage obscure most features which might be of some use. The gross petrographic elements, the fine grained framework fraction and a relatively high proportion of matrix, now recrystallized to chlorite and sericite indicate low energy sedimentation. This is consistent with the presence of sparse horizontal burrows and a generally mottled appearance of the rocks. The presence of trilobite and pelmatozoan debris document a marine depositional environment. A quiet clastic basin with moderately low sedimentation rate well below wave base is postulated. Paleocurrent data is absent; but the K_2O rich character of the Araby suggests kinship with the Chilhowee Group (western cratonic source) (Southwick and Fisher, 1967; Whitaker, 1955b; Schwab, 1971) rather than Wassahickon Formation (eastern source) (Fisher, 1963).

Note added in proof:

The specimen containing the pelmatozoan molds (figure 6) was split on August 7, 1974, following exhaustive efforts to find similar material in the continuous Araby outcrop belt. An associated brachiopod, bivalve (?) and bryozoan (?) strongly suggest a Siluro-Devonian age (R. B. Neuman, oral comm., 1974). The specimen is, therefore, probably an erratic, transported to the site by an unknown agent.

FREDERICK FORMATION

Introduction and Definition

The Frederick Formation is herein formally defined as the 800 meter thick sequence of micritic and peloidal limestones and dolomites overlying the siliciclastic Araby Formation. This unit includes the thin dolomitic interval mapped as Tomstown Dolomite by Jonas and Stose (1938) and Whitaker (1955) plus the Frederick Limestone. The Frederick Formation is divided into three members: the Rocky Springs Station Member, the Adamstown Member, and the Lime Kiln Member from base to top.

The Araby-Frederick contact is nowhere exposed, but there are several localities where less than 3 meters of section are covered. The contact is thought to be conformable and because Dresbachian (lowest stage Upper Cambrian) trilobite faunas in the Rocky Springs Station member lie about 250 meters above the top of the Araby (latest Middle Cambrian), no significant (time) hiatus can be present. In addition, the lithologic transition from fine grained clastic to fine grained carbonate is quite gradational in the contact zone.

Within the carbonate sequence there are no abrupt changes or large time gaps in sedimentation. On the basis of limited faunal evidence, the Frederick Formation members are time equivalent within the valley. The entire Upper Cambrian is contained within this sequence of rocks, documented by scarce, low diversity Dresbachian to abundant, highly diverse Trempealeauan faunas.

ROCKY SPRINGS STATION MEMBER

Definition

The Rocky Springs Station Member, approximately 300 meters thick, crops out on the eastern and western margins of the Frederick Valley stratigraphically above the Araby Formation. It is named for a small community on the northwestern bounary of Frederick, Maryland just north of Fort Detrick. Large portions of this unit are covered by Triassic sediments and/or Quaternary mountain wash along the western side of the valley; one window in the Triassic exposes a large patch of Rocky Springs Station rocks just northwest of Lewistown, Maryland (Catoctin Furnace Quad.). The entire member is rather poorly exposed and lithologically finer grained along the eastern margin of the valley; this is a function of both tighter folding (greater deformation) and perhaps a slightly different depositional environment.

Extremely sparse trilobite faunas described by Rasetti (1961) are present in thinly bedded limestones near the top of this unit. The position is indicated on the geologic column (Plate 2) and this faunal list is included in Appendix B. No faunas have been found within this member on the eastern limb of the synclinorium.

Lithology

The lithology of the Rocky Springs Station Member varies vertically. The lowermost rocks are poorly exposed calcareous shale-phyllite overlain by granular dolomite (laminated and argillaceous on the eastern side of the valley) of variable thickness ($\leq$15m.). The lower half of the member is composed predominantly of thin (1-3 cm.) flaggy limestones, while the upper half is dominated by a thick sequence of coarse detrital limestone. On the eastern side of the valley a slate belt from 0 to 30 m. thick was mapped by Jonas and Stose (1938), though its stratigraphic significance is unclear. Its patchy distribution and association with tightly folded zones suggest that the slate could be tectonic, resulting from large-scale pressure solution with consequent removal of nearly all the carbonate.

A detailed stratigraphic column with thicknesses corresponding to measured sections from the less deformed western belt of this member is found on plate 2. Actual measured sections and locality maps are included in Appendix A.

Petrography

Two broad classes of limestones, thinly bedded carbonates and thickly bedded to massive carbonates, dominate the stratigraphic column in this member and will be discussed separately. These classes correspond roughly to Folk's (1959) micrites and sparites, though some of the coarse allochemical limestones contain significant amounts of micrite matrix. Both the thinly bedded and the thickly bedded to massive limestones contain a strong tectonic overprint, which must be recognized before the sedimentary structures and lithotype genesis can be adequately understood.

Thinly bedded carbonates: Thinly bedded carbonate rocks comprise the bulk of the Frederick Formation. In the Rocky Springs Station Member thinly bedded limestones are present throughout, but are concentrated in thick packages close to the base and up to the middle of the section.

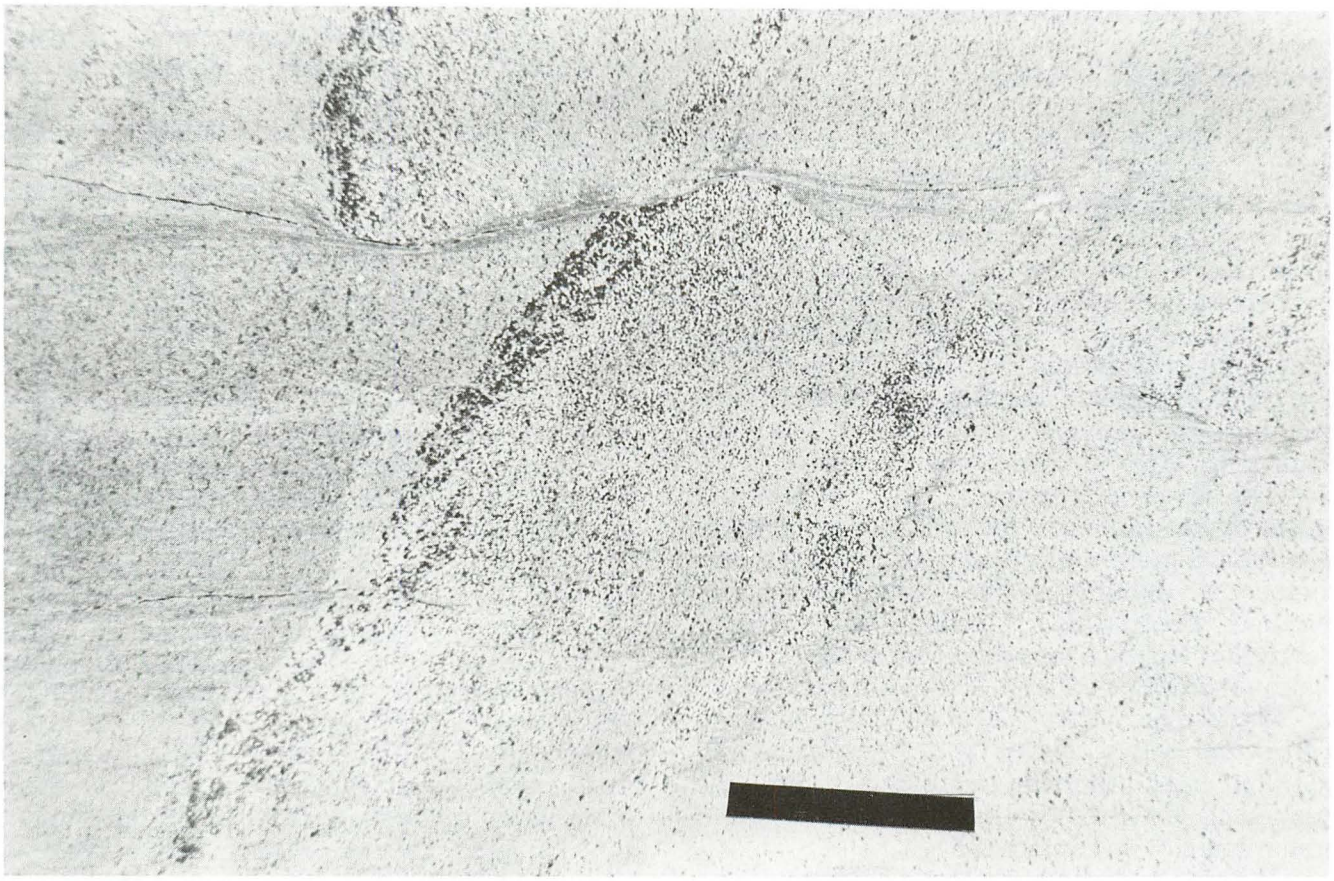


Figure 7.—Highly cleaved laminated limestone; cleavage is horizontal and bedding is oriented at 60° to cleavage. Note offsets along cleavage planes and apparent graded bedding. Bar = 1.0 cm.

Descrimination betweeen tectonic and sedimentary features is fundamental to understanding these limestones. The thinly bedded carbonate rocks are strongly cleaved and show a variety of pressure-solution phenomena. Where cleavage and bedding are at a high angle to one another there is no confusion about the tectonic and the sedimentary features (figure 7). Sutured stylolitic contacts may be either parallel or less commonly perpendicular to bedding. Pressure-solution planes can also be planar, as between beds (Trurnit, 1969). Bedding plane pressure-solution can be recognized by the accumulation of residues more resistant than calcite to solution along the boundary between beds; these minerals include dolomite, quartz, feldspar, clay minerals, and pyrite (Trurnit, 1969). Most partings between thinly bedded limestones show some accumulation of such residues (figure 9). On a smaller scale, laminations which result from planar concentrations of non-carbonate detritus are also possible tectonic features. Elongation of framework grains along cleavage planes and bedding plane pressure-solution can both operate to severely thin a limestone unit and render sedimentary structures virtually unrecognizable (figure 8).

The most common form of thinly bedded limestone, termed flaggy in the field, contains individual beds 1-3 cm. thick, typically defined by a dolomitic silt or argillaceous parting at the base and top (figure 9). These beds are commonly composed of homogeneous micrite, though laminae about 100 μ. thick of silt or fine sand-sized particles may be present. Many of these beds appear to be graded in outcrop, though recrystallization of the carbonate renders recognition of grading difficult in thin section. Only when significant amounts of coarse carbonate or non-carbonate grains are present can grading be satisfactorily documented (figure 10).

Thinly bedded limestones contain abundant laminations, most commonly delineated by the presence of clastic quartz silt (figures 11, 12).

Figure 8.—Tectonically thinned limestone; bedding and cleavage are nearly parallel. Strong pressure solution boundaries along bedding contain concentrations of residues.

Argillaceous material is commonly associated with thinly laminated beds, while arenaceous non-carbonate detritus is typically associated with more broadly spaced laminations.

Laminations may be planar, somewhat discontinuous to lensoid, or inclined within each bed. In thicker beds a number of bed forms may be present (figures 11, 12). The base of these and other thin beds is sharp and occasionally erosive (figure 11). Planar laminations and ripple cross-laminations to over-steepened ripple forms are present. Changes in the proportion and size of non-carbonate particles indicates graded bedding (figure 11), and rare carbonate peloids are close to the base of the beds (figure 12).

Several features are strikingly absent: the laminations are not disturbed by burrow structures or vertical cracks (desiccation or syneresis) and laminations do not drape underlying structures, such as ripple forms or scours.

In short, the laminates are predominantly micrites which have internal variability due to size or mineralogical differences. The very fine grained nature of the sediment, the perfectly preserved laminations and the lateral continuity of most thin beds are the notable characteristics of this lithologic class.

Figure 9.—Typical flaggy limestones (1-2 cm thick beds) showing lateral continuity. Dolomitic partings weather buff. (Pen for scale 0.8 cm high).

Figure 10.—Photomicrograph of flaggy laminate. Coarse peloids at base grade to small peloids with increasing micrite matrix toward top of bed. Bar = 1.0 mm.

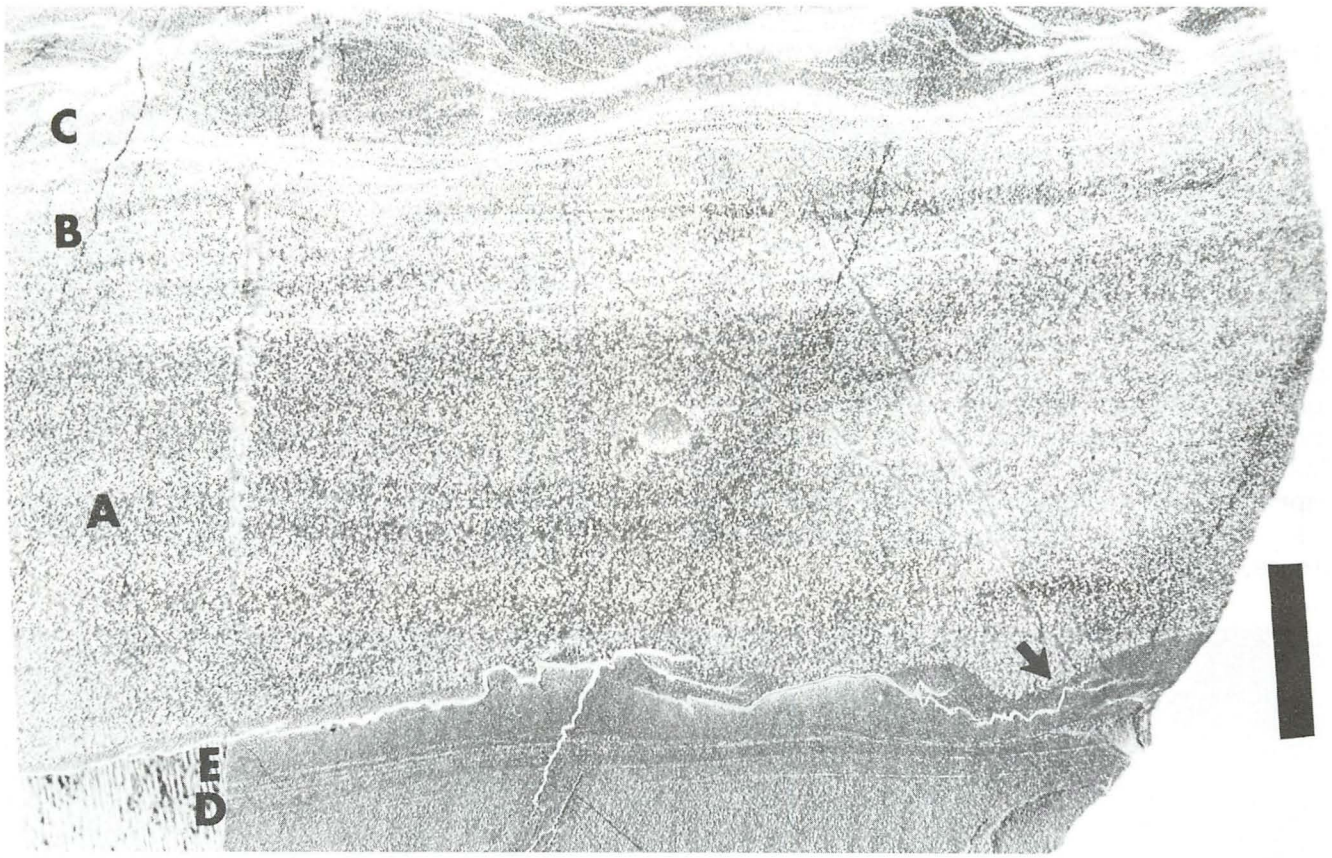


Figure 11.—Atypically thick bed from a section of thinly bedded limestones. The slab shows "features of a classic Bouma cycle". A sharp erosive base (arrow) cuts an unstructured argillaceous limestone (part E of the Bouma cycle). Above the erosive base transitions from a graded, unstructured arenaceous limestone (part A) to horizontal laminations (B) below ripple cross-lamination (C) topped by finer grained horizontal laminations (D). Note the sutured stylolite that follows but does not coincide with the erosive base. Bar = 1.0 cm.

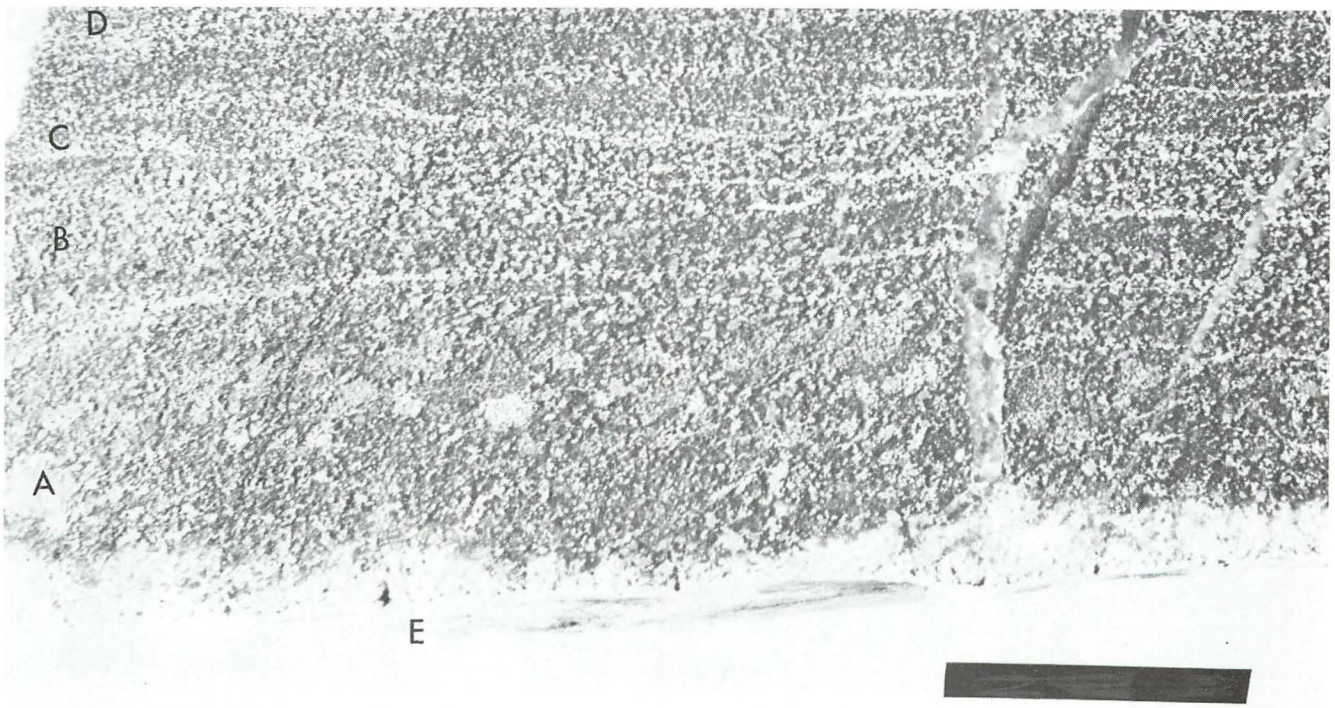


Figure 12.—Thin limestone bed bounded by a sharp lower contact with a calcareous shale. Transitions A through D above the pelitic layer (E) are less well developed than in figure 11, but are all present. Bar = 1.0 cm.

Thickly bedded and massive limestones: The three significant types of thickly bedded and massive limestones within the Rocky Springs Station Member are peloidal limestones, megaclastic limestones (breccias) and dolomites. These lithologies are especially dominant in the upper half of the member.

The nature of the breccias, and the possibility that these could be tectonic rather than sedimentary, must be carefully evaluated, since sedimentary breccias place strong constraints on possible depositional environments. Stylolitic contacts between and around clasts plus solution shadows and in situ fracturing of clasts all indicate a considerable tectonic imprint. The following criteria were used in the field to evaluate the breccias (Blount and Moore, 1969):

TABLE 3.—DEPOSITIONAL-TECTONIC BRECCIA CRITERIA

1. Matrix in depositional breccias is mostly lime mud, but may be sparry calcite; in tectonic breccias it is either sparry calcite or granulated carbonate. The presence of quartz sand grains in the matrix, but not in clasts is a criteria for depositional breccias.
2. Clasts in depositional breccias show fair to poor sorting and are angular to round; extremely poor sorting, mostly angular clasts in tectonic breccias. Clasts which show a complete range from angular to round in a single bed indicate depositional breccias.
4. Clast boundaries may be matching in depositional breccias; excellent matching is common in tectonic breccias.
5. Clasts are infrequently veined in depositional breccia (unless the area has suffered multiple deformations), but are often veined in tectonic breccias.
6. Depositional breccias exhibit primary sedimentary structures, such as graded bedding, while tectonic breccias are close to structural features, such as faults or folds.

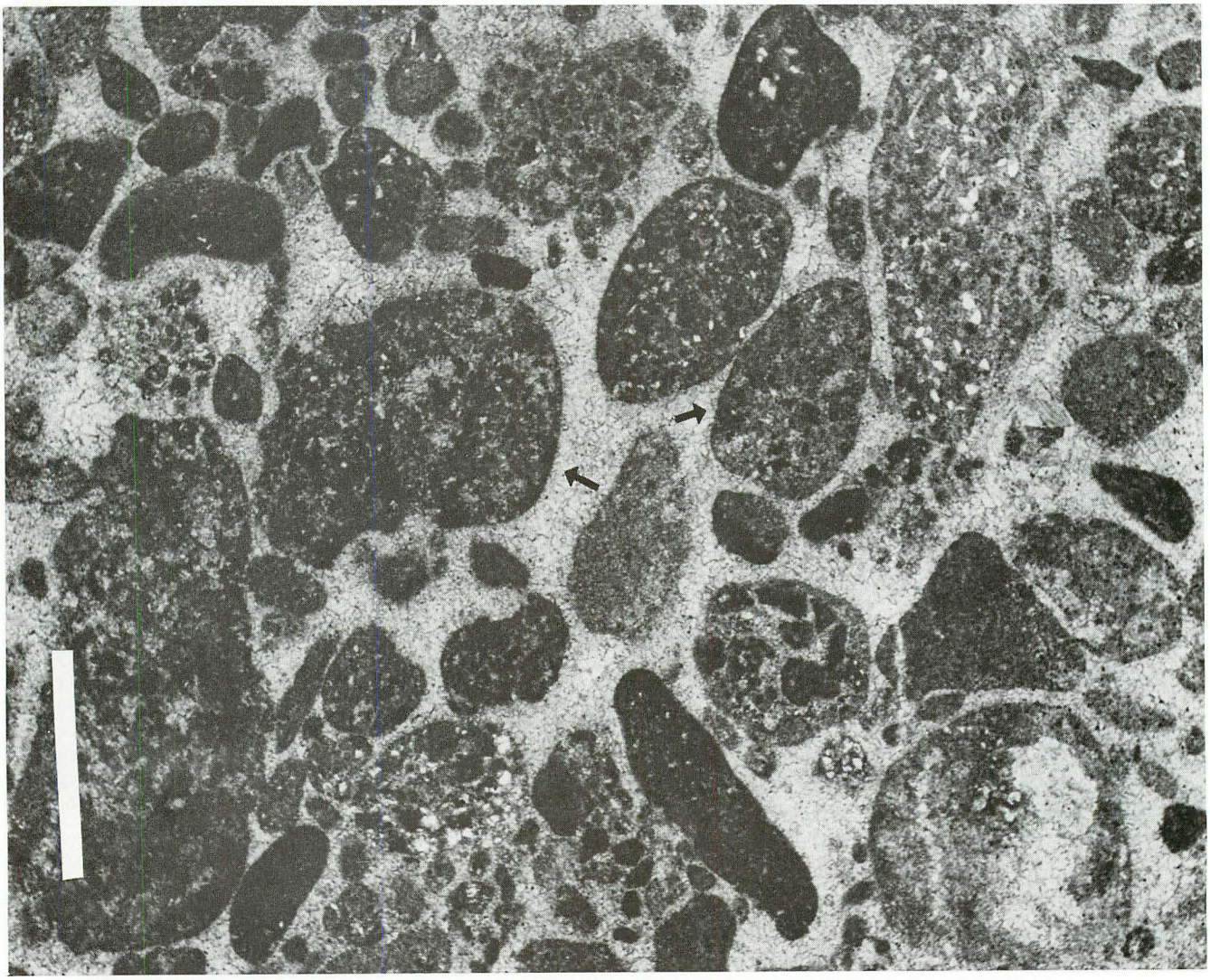


Figure 13.—Photomicrograph of peloidal limestone; some peloids contain quartz silt and/or smaller peloids. Fine spar cements the grain supported lithology; incipient rim cement on several grains (arrows). Bar = 1.0 mm.

Figure 14.—Moderately deformed, massively bedded oolites. Note clot of micritic matrix which encloses oolites in the left center of figure. Oolites in cement and matrix show similar deformation patterns; some oolites are partially surrounded by both matrix and cement. This is evidence of conversion from micrite matrix to spar cement. Bar = 1.0 mm.

Peloidal limestones are the most abundant type of thickly bedded to massive limestone. The major framework components include peloids and quartz grains; oolites, spherulites, dolomitic clusters, coated peloids and bioclasts are present, but less abundant. A single thick bed may include one or more commonly two or three of these particle types (figure 13). Size sorting is generally good, though a few extremely large particles (megaclasts > 2 cm. long) are rarely present. Most of the particles are well rounded to very well rounded at all size levels. Though most of these limestones are spar cemented, some of the best sorted particles are embedded in a micrite matrix (figure 14). The boundaries between micrite matrix and microspar cemented areas are quite ragged; individual carbonate clasts or ooids are partially enclosed by both cement and matrix, suggesting that recrystallization of micrite to microspar or coarse sparry cement is an important diagenetic process.

Beds are commonly defined by planar zones enriched in quartz grains; thick tabular or planar beds are prevalent (figure 15). Large and small-scale scour features are commonly present at the base of thickly bedded limestone units (figure 16).

Most of the megaclastic limestones are coarse polymict breccias with a general range of clast sizes from 5 - 50 cm. long. This size range is much smaller (2-10 cm.) in the breccias on the eastern side of the valley. The composition of the clasts varies, though the most common clast type is compositionally the same as the underlying lithology. For example, the lithology underlying the breccia shown in figure 17 is a thinly bedded micritic limestone. Most of the

Figure 15.—Thickly bedded quartose limestone; planar bedding is delineated by variations in amount of quartz sand. Immediately overlies channel fill in figure 16.

clasts in the breccia are identical micritic limestones; peloidal limestones, oolite and dolomite clasts are subordinate. The matrix is largely micrite with floating quartz grains, fractured and whole ooids, small lithoclasts and peloids (figure 19).

Thin breccia zones (< 20 cm. thick) were observed, but are quantitatively unimportant. Typically, megaclastic zones are 5 to 10 meters thick and show some fining upward in clast size in the upper half of the breccia. The percentage of matrix to framework increases from about 20 to 40 percent from base to top of the breccia sequences.

On the basis of the criteria in Table 3, most of the breccias in the Rocky Springs Station Member are clearly sedimentary breccias. The polymict clasts, the presence of round and angular fragments in both framework and matrix, the presence of quartz sand only in the matrix and graded bedding are strong evidence for depositional breccias. Although these rocks have suffered from deformation, they do not result from it.

Some of the dolomites show extensive fracturing and vein filling (figure 18). These can be mistaken for small scale breccia deposits in the field, especially with a heavy lichen cover present. Calcite veining of these dolomites and angular clasts with matching boundaries are characteristic of these tectonic rocks.

Massive dolomites are abundant in this member. They are quite homogeneous, dominated by fine(<100 μ.) homogeneous or very coarse (up to 1500 μ.) dolomite crystals. In outcrop they have a sugary appearance and contain variable amounts of quartz. Some beds have little or none, while others are quartz rich, dolomitic sandstones. Faint laminations are present in some of the massive, fine grained dolosparites.

Figure 16.—Erosional contact between thinly bedded laminated limestone and coarse, massively bedded, peloidal limestone. Massively bedded limestone contains laminated clasts near base (arrows at extreme right side of figure). Late calcite veining cuts across and is at a low angle to the contact.

Lithologic Packaging

The sediment types in the Rocky Springs Station Member were deposited in thick uniform packages (plate 2). Single lithologies, such as the peloidal limestone at locality 563 (middle of column or Appendix A) or the oolite at locality 279 (top of column or Appendix A). are up to 20 meters thick with no discernible variation in particle size or composition. Thinly bedded limestones are packaged in similarly thick deposits; many of the covered sections probably consist of thick packages of thinly bedded limestones.

Although many thickly bedded deposits show no grading, the upper portions of some megaclastic limestone units are graded. Also, a few thinly bedded limestones immediately overlying thickly bedded deposits contain carbonate clasts or fine quartz sand near the base of the 2-5 cm. beds. The upper portions of these thinly bedded packages are composed of 1-2 cm. thick beds containing only micrite and quartz silt. A fining upward pattern can be documented at a few exposures toward the top of the section (plate 2). Whether this pattern is typical of the entire member is unclear due to poor exposures.

Thinly bedded or flaggy limestones and some of the peloidal limestone sheets can be traced laterally over a distance of 100 meters without apparent variations in composition or thickness. The geometry of the breccia deposits is not as well known. Limited exposures suggest that these deposits are much more lensoid, since variations in clast size and bed thickness occur in lateral distances of 10 meters.

Figure 17.—Outcrop photo of poorly bedded polymict breccia; some imbrication of flaggy clast in center of figure. Stylolites between and around many of the megaclasts.

Environmental Interpretation

To begin we can rule out a peritidal origin for these carbonates. Tidal flat complexes generate rapidly changing vertical sequences (cyclic sedimentary packages) resulting from the interplay of sedimentation rate and subsidence within the range of storm and tidal currents. A wide variety of sedimentary structures such as mudcracks, flat pebble conglomerates, bird's eyes and/or fenestrae and algal structures are common in peritidal carbonates; none of these features are present in the Rocky Spring Station Member.

Carbonate sediments have been documented from a number of deeper water environments (900-7000 m.) adjacent to the Bahama Platform (Rusnak and Nesterhoff, 1964; Andrews, Shepard, and Hurley, 1970; Huang and Pierce, 1971; Bornhold and Pilkey, 1971) and in portions of the Gulf of Mexico (Davies, 1968, 1972; Conolly and Ewing, 1967). The sediments are nearly all derived from the adjacent carbonate platforms, hence the particles consist of reef debris, shell fragments, pellets, ooids, planktonic and benthonic forams and calcareous algae.

Carbonate breccias are known only from Tongue of the Ocean, a reentrant of oceanic depth in the Bahama Platform (Andrews, Shepard, and Hurley, 1970); these appear to be on much smaller scale than the breccias in the Rocky Springs Station Member. Cores of sand size carbonates nearly all show parallel bedding with some ripple cross bedding; beds are up to one meter thick (Huang and Pierce, 1971). Graded bedding is the most common sedimentary feature for sand to silt size carbonate beds; parallel and ripple cross-lamination are present in the calcisilts (Davies, 1968, 1972).

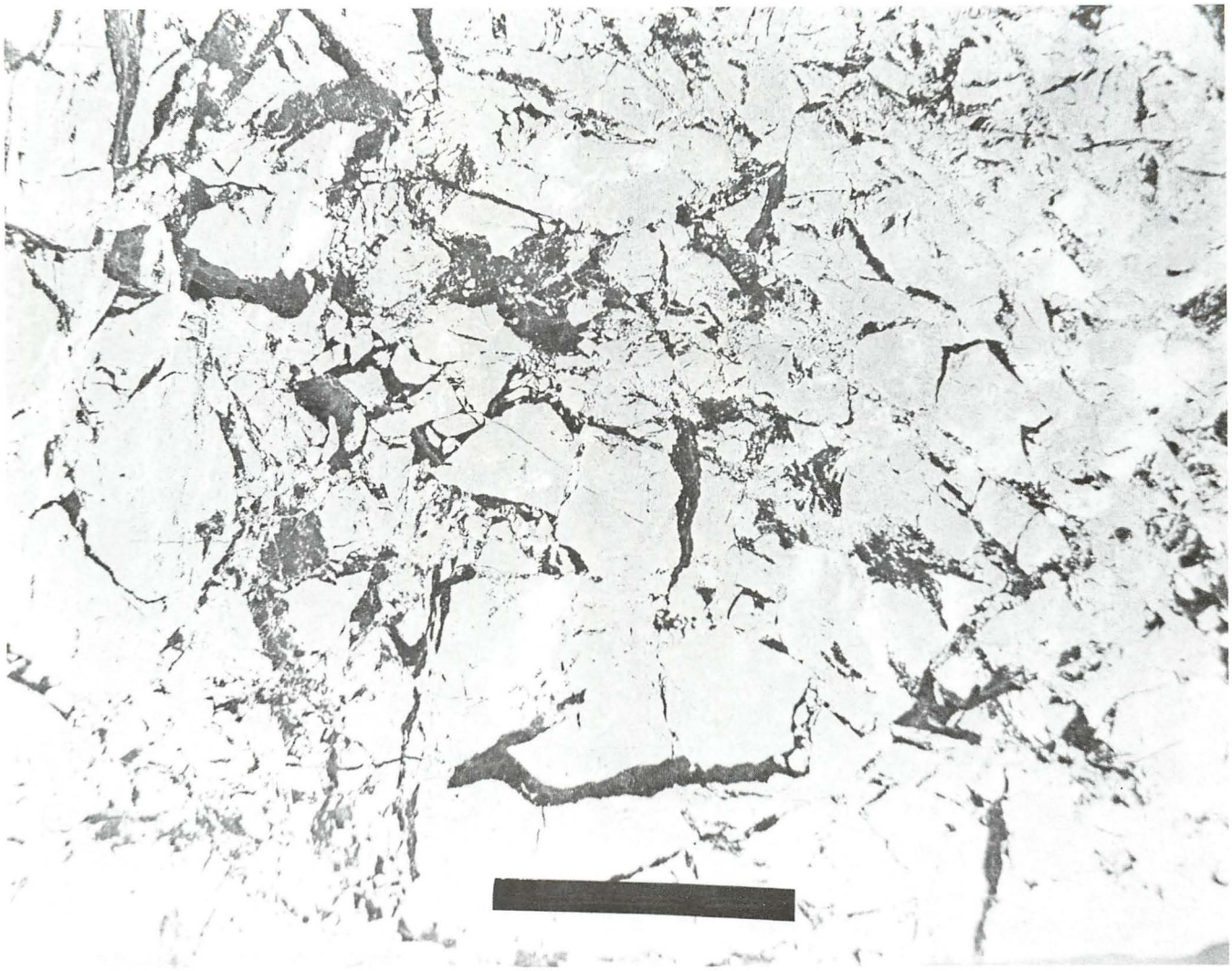


Figure 18.—Fractured massive dolomite with calcite infills. Note brecciated texture and matching "clast" boundaries. Bar = 1.0 cm.

Wilson (1969) has summarized the criteria for recognizing "deeper water limestones" based on well documented ancient non-platform carbonates:

1. Dominance of lime mud.

2. Relatively common calcisiltites and fine grainstones, usually showing small scale graded or ripple cross-laminated pelletoid grains.

3. Dark color, although in places pink and red limestone occurs.

4. Even millimeter lamination.

5. Very even ½ to 1 foot limestone beds interbedded horizontally with thin intercalated shales.

6. Major discontinuities such as large scale cut and fill or slump structures. General rarity of convolute bedding, flame structures or other soft sediment structures.

7. Generally a very specialized benthoic fauna; much more commonly a solely pelagic fauna.

With the exception of criteria 5 and 7 which can not be argued due to lack of good exposure and a paucity of fauna (which is not totally inconsistent), the Rocky Springs Station limestones fit Wilson's criteria extremely well.

Bioclastic turbidites (allodapic limestones of Meischner, 1962, 1971) in the geologic record contain structures and sediment types similar to those from the Recent. Shallow to deep water

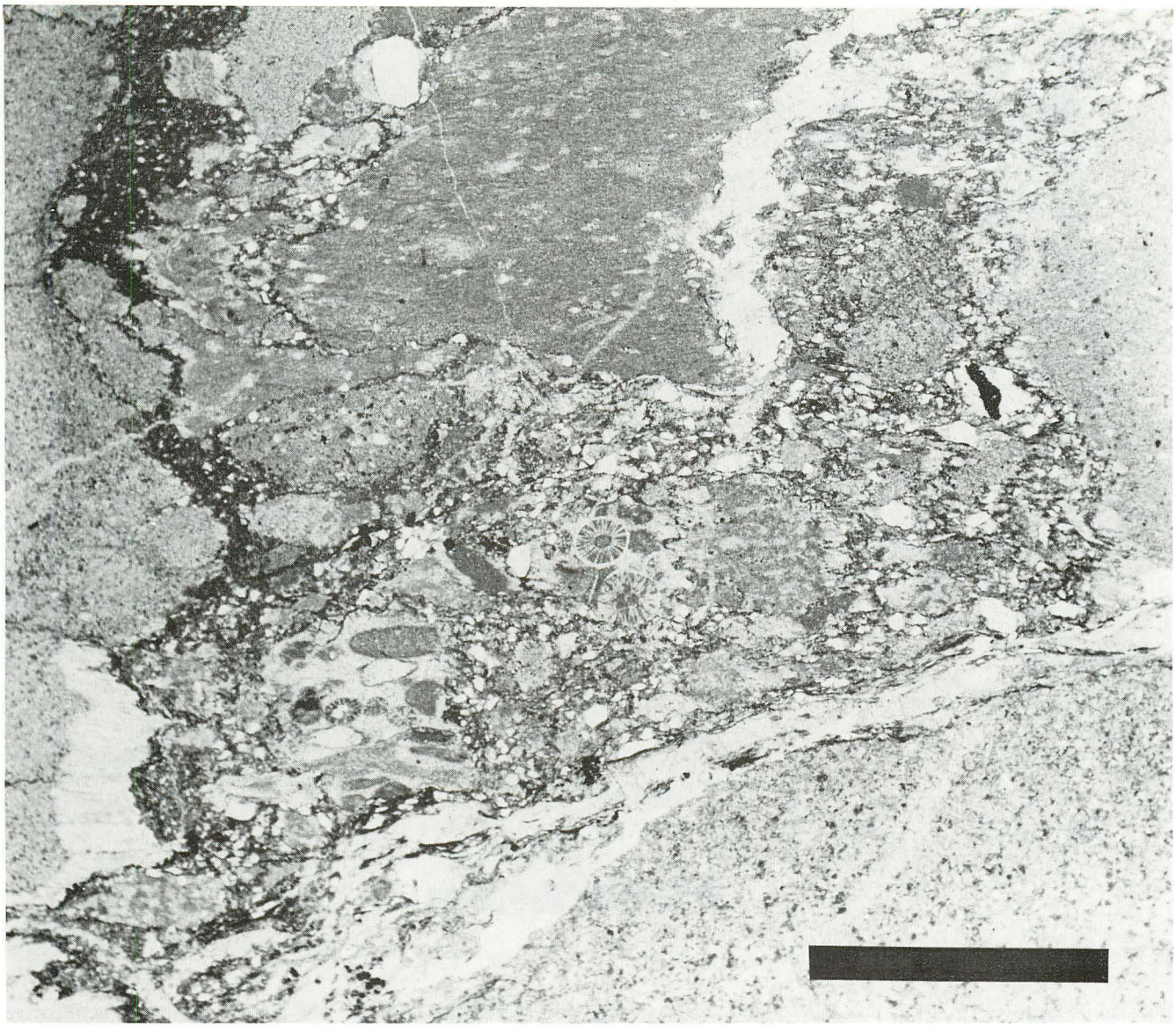


Figure 19.—Photomicrograph of highly deformed polymict breccia. Extensive development of pressure solution shadows behind clasts and quartz grains. Note lithoclast containing undeformed oolites in center of figure. Bar = 1.0 mm.

sediment types and sedimentary structures including distal and proximal carbonate turbidites are present in the Dimple Limestone (Lower Pennsylvanian) in the Marathon Basin of Texas (Thomson and Thomasson, 1969). The setting is a relatively shallow geosyncline; maximum water depth in which carbonates were deposited is estimated as 200 meters. In this and in most other studies of ancient carbonate turbidites complete "Bouma cycles" so characteristic of silicaclastic turbidites are not present. Most beds are on the order of centimeters thick, though a single bed 28 meters thick has been documented from the Monte Antolle Flysch (Upper Cretaceous) of Italy (Scholle, 1972).

The carbonates of the Rocky Springs Station Member are not classic turbidites, but some sedimentary structures characteristic of turbidites are present. Figure 12 shows an unusually thick bed with well preserved turbidite structures; similar bed form transitions are also present in much thinner beds (figure 13). Graded bedding on a gross and fine scale is apparent in both samples. The sharp lower contact characteristics of turbidite beds, segments A (structureless or graded), B (horizontal laminations), C (current ripples and/or convolutions), D (horizontal laminations) and E (structureless pelite) of the Bouma (1962) cycle are all present to some degree.

Sedimentation mechanisms other than turbidity currents are necessary for generating the breccias, the thick peloidal sheets and some of

the laminated siltstones. The sedimentary breccias represent slump deposits based on the low degree of sorting, crude grading and the sedimentary origin. Sliding or slumped material and the subsequent debris flows may be genetically related to the turbidity currents which deposited some of the thinly bedded limestones. Slumps can be related to rapid sedimentation at the margins of a platform or shelf or to a tectonic event such as an earthquake in areas of somewhat slower sedimentation (Menard, 1964). The theoretical and experimental considerations in translating slumps to debris flows to turbidity currents have been presented recently by Hampton (1972). The entire spectrum of sediment gravity or mass flows has been defined and discussed (Middleton and Hampton, 1973); more than one flow mechanism is probably involved in transporting sediment into any depositional basin. Deposits corresponding to hypothetical and experimental grain flows and turbidity flows can be documented in the thick peloidal sheets (localities 563 or 279) and in single hand specimens (figure 12).

Other mechanisms for transporting platform sediments into adjacent basins have been presented by Stanley, et al (1971) and Reineck and Singh (1972). On the outer Continental Margin east of Nova Scotia, Stanley, et al, have documented the importance of current patterns on the shelf in causing sand to spill over the platform margins, resulting in progradation. Reineck and Singh have shown that the development of laminated sands and graded beds in shelf muds in up to 200 meters of water results from retreating storm activity (storm swash); similar structures have been described resulting from hurricanes (Hayes, 1967).

Transport and redeposition of sediments within depositional basins by bottom currents (thermo-haline induced or otherwise) have also been considered important physical agents in generating planar and ripple-laminated structures (Hubert, 1964; Heezen and Hollister, 1964; Hollister and Bouma, 1973). Contourites, as these reworked sediments have been termed, may in some cases be distinguishable from turbidites. In the Rocky Springs Station Member there seems no textural or compositional criteria for distinguishing possible contourites from turbidites.

On the basis of lithologic and structural similarities to both ancient and modern deep water limestones, and because peritidal features are absent, the best interpretation of the Rocky Springs Station Member is that the sediments were deposited in deep water, probably deeper than 400 meters. The abundant fine grained silts and muds probably reflect day-to-day settling of suspended sediment. The intercalated beds of graded and laminated silt to sand size carbonate and quartz suggests deposition resulting from sediment spill-over and/or turbidity currents, which may have been generated as a result of slumping near the edge of the carbonate platform west of the Frederick Valley; carbonate platform sedimentation has been documented in the Middle to Upper Cambrian Elbrook and Conococheague Formation, immediately west of South Mountain (Donaldson, 1969; Root, 1968).

The polymict breccias contain both shelf derived debris (oolites and coarse quartz sand plus oolitic lithoclasts) and interclasts generated during sliding. Size differences in breccia clasts suggest that the carbonate bank was to the west; bed thickness and sediment size also show a decrease from the western to the eastern limb of the syncline beyond that caused by simple tectonic thinning.

ADAMSTOWN MEMBER

Definition

The Adamstown Member is here defined as the 325 m. sequence of flaggy limestones immediately overlying the coarse peloidal-oolitic top of the Rocky Springs Station Member. While no completely exposed section is available for this member, good exposures just east of Adamstown and a carefully measured section west of Lime Kiln define the elements of this stratigraphic unit (Appendix A). The entire member is a poorly exposed sequence of flaggy limestones, which is interrupted by three locally traceable megaclastic limestone zones $\leq$ 30 meters thick. The transition from the Adamstown to the overlying Lime Kiln Member is rarely exposed in the field and is defined as the first appearance of quartz and/or coarse peloidal sediments in thinly to thickly bedded limestones. In the Alpha Portland quarry there is a sharp transition from the monotonous, thinly bedded limestone of the Adamstown to the Lime Kiln Member, which shows variability in bedding. A detailed stratigraphic section is presented on plate 2.

There are several major qualitative differences between this member and the Rocky Springs Station Member. Quartz sand is conspicuously absent from the Adamstown Member limestone. The biogenic component is increased, though still quite sparse and not readily apparent in most outcrops. In addition to trilobites, brachiopods and echinoderms are present, primarily as fossil hash. Bioturbation, or at least moderate burrowing of thinly bedded limestone, is apparent at several localities. The faunas which have been collected and identified from this unit are either late Franconian or early Trempealeauan stage (M. Taylor, personal communication, 1972).

Lithologically the thinly bedded limestones are quite similar to those of the Rocky Springs Station Member. The thickly bedded to massive limestones share few common features. Virtually all of the carbonate within this entire stratigraphic unit is micrite, even the bulk of the megaclastic limestones.

Figure 20.—Etched slab of laminated micrite. Laminations appear to become thinner in dolomitic portions as sample shows grading from calcite to dolomite (arrow). Strong fracture cleavage is present nearly perpendicular to bedding; ragged bedding plane boundaries suggest pressure solution surfaces.
Bar = 1.0 cm.

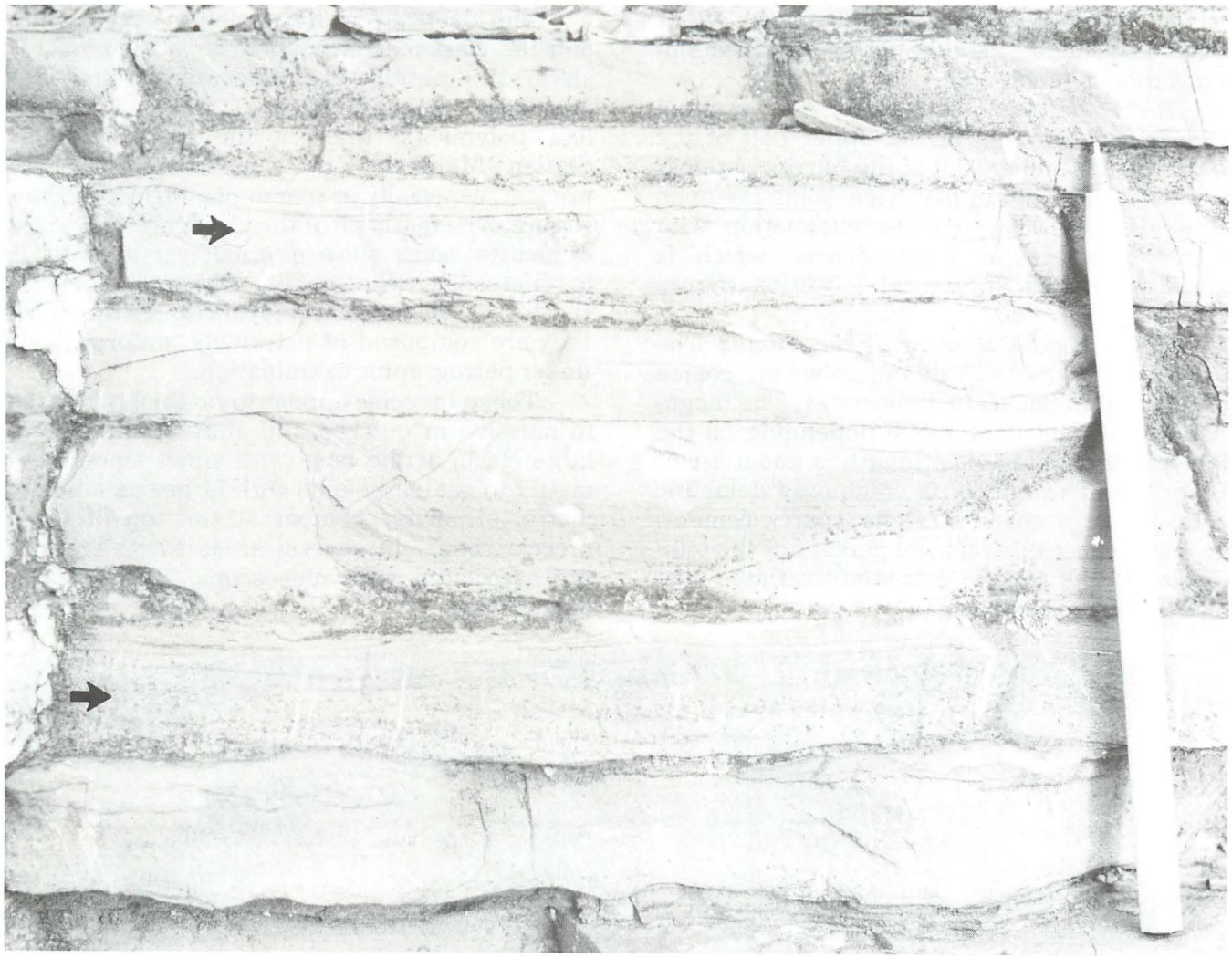


Figure 21.—Typical flaggy limestones toward top of Adamstown Member. A variety of bedforms are present in individual beds. Low angle forsets laminated micrites (lower arrow). Microscours filled by peloids in laminated micrite (upper arrow). Beds are separated by dolomitic partings.

Petrography

Thinly bedded limestones: The thinly to very thinly bedded argillaceous limestones in this member are medium to dark gray, 1 to 5 cm. thick beds of micritic calcite defined by shaly and/or dolomitic tops. Much of the section is composed of limestones containing approximately 70 percent calcium carbonate (analysis of rock from the "Frederick pit" in the Alpha Portland Quarry, Lime Kiln, Maryland). A few thin beds also contain coarse allochems including peloids, fossil fragments and coated grains.

Planar laminations and isolated ripple forms are abundant bedding features in the Adamstown member. Graded bedding is apparent in beds which contain coarse carbonate particles, but the apparent grading seen in most fine grained carbonate beds is difficult to substantiate (figure 20). Planar laminations result from variations in the proportions of dolomite and calcite; the dolomite is finer grained and is more affected by cleavage than the calcite laminae.

Towards the top of the Adamstown Member a variety of primary sedimentary features are present in association with medium to coarse sand size carbonate particles. Low angle ripple cross-laminations, microscours and channel fills are locally abundant (figures 21, 22). The allochems in these current structures are peloids (many dolomitic), coated grains and fossil debris. The coarse carbonate is commonly distributed in well defined lenses or pods as in the channel fills or as homogeneous, laterally traceable beds up to 10 cm. thick. Some of the channel fills have extremely steep sides and appear to deform the underlying micritic

carbonate slightly (figure 21); this may be either a soft sediment loading or a lithification-compaction phenomenon.

Thinly bedded limestones also contain some sparse burrows in the upper half of the Adamstown Member. All of the burrows appear to be horizontal and in plan view some are open spirals (figure 23). In close association with burrow structures is fossil debris, which is partially silicified at several localities (figure 24).

Thickly bedded to massive limestones: The thickly bedded rocks in this member are coarse peloidal and megaclastic limestones. The megaclasts are equant to elongate depending on the lithology; maximum clast length is about 5 cm. (figure 25). The matrix is commonly dolomitic microspar or a coarser calcite sparry cement. The clasts constitute 50 to 90 percent of the total limestone; this ratio is extremely variable over small vertical distances.

The clasts are well rounded to very angular and the clast-matrix boundaries are commonly sharp; the margins are delineated by stylolites or rinds on the clasts (figures 25, 26). Clasts are less polymicitic than in the Rocky Springs Station Member, but some exceptions are present, especially in coarse peloidal limestones (figure 27). Nearly all of the clasts are composed of mcirite; some show internal recrystallization to microspar, (figure 26). Although some of these breccias appear polymictic in the field, they are composed of extremely uniform clasts under petrographic examination.

These breccias appear to be thickly bedded to massive in outcrop and show grading from large clasts at the base with small amounts of matrix to coarse peloids with larger amounts of matrix or sparry cement at the top of these breccia zones. In several areas these breccias are associated with mesoscopic, symmetrical, open folds.

Figure 22.—Coarse peloidal bed shows basal scour; no graded bedding within the coarse bed. Note truncation of planar lamination in the underlying bed.

Figure 23.—Burrowed, thinly bedded limestones. Arrows indicate open-spiral feeding (?) structures. Burrows are essentially horizontal, spherical, spar-filled structures.

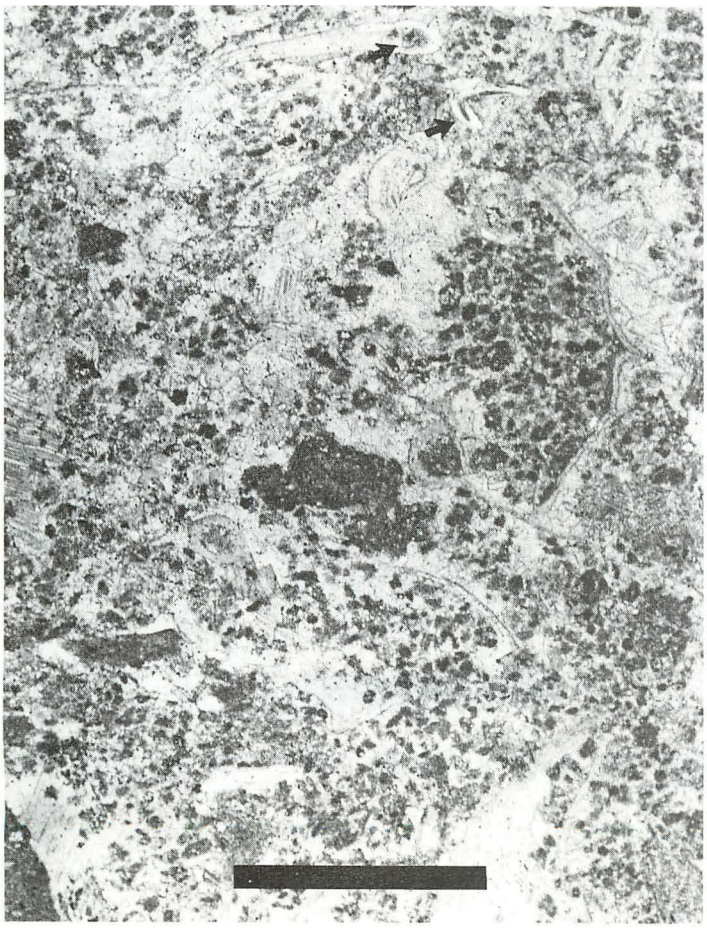


Figure 24.—Photomicrograph of mottled thin beds containing peloids and partially silicified trilobite debris (arrows at top). Debris from pelmatozoan columnals is also present.
Bar = 1.0 cm.

These megaclastic limestones appear to be tectonic breccias, because of their oligomicitic composition, the angularity of the fragments, the matching clast boundaries, their association with mappable folds and the abundance of veining (see Table 3). Recrystallization of micritic limestone could generate the textures seen in such breccias. Explanation of the polymictic sediment in figure 27 is not possible in simple tectonic terms, but the recrystallization of the matrix (and some clasts?) has obscured sedimentary relationships.

Some sedimentary compoments, such as bedding and grading, are present in these rocks, but these may be related to the position of the deposit within the tectonic framework; that is, proximity to fold axes may alter the nature of the megaclasts enough in a tectonically affected area, that apparent grading may be present within a megaclastic zone. The column (plate 2) shows both normal and reversed grading over distances of 10 to 30 meters within the megaclastic zones.

Prior to brecciation the clasts were laminated or structureless, dark gray limestones, probably packaged in thick sequence of thin (1-3 cm.) beds. Fracturing and rotation of these beds during folding plus pressure-solution between clasts has generated the limestone framework and dolomite matrix (less soluble residues) which compose the megaclastic zones. The vulnerability of the fine grained carbonate composing these megaclastic limestones to pressure-solution and recrystallization has precluded their possible usefulness in environmental reconstruction.

Thick beds composed of peloids, oolites, pisolites and quartz grains (figure 27) are rare and poorly exposed in comparison to the thick peloidal sheets of the Rocky Springs Station Member. Particles are generally well sorted and rounded, and the cement-matrix is typically recrystallized. Sparse, thin to thick peloidal limestones interbedded with thin micritic limestones in tectonic areas would lead to the assemblage of clasts seen in the megaclastic zones.

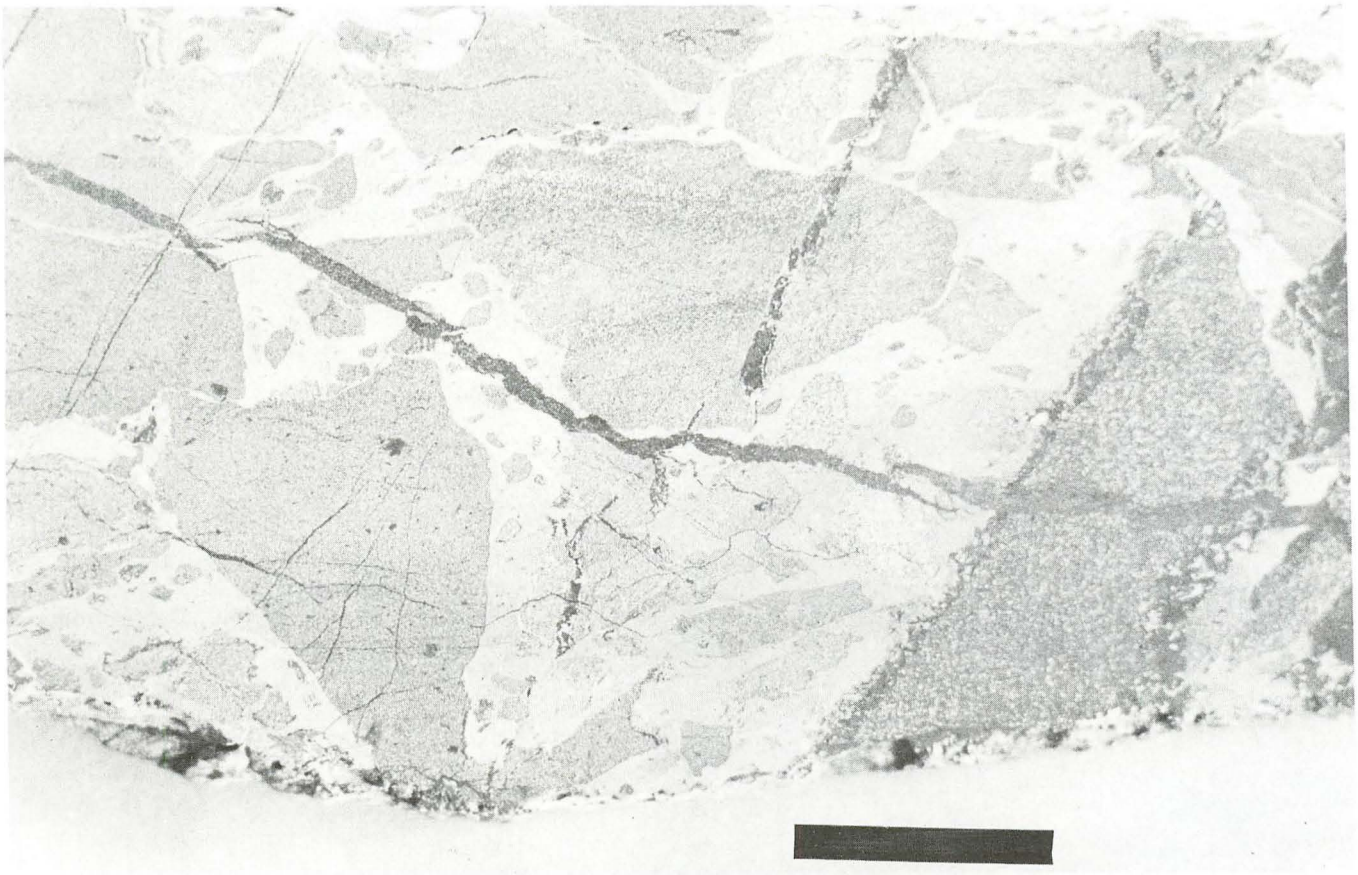


Figure 25.—Angular megaclastic limestone slab. Note the sharp clast boundaries and relatively uniform clast types. Two systematic vein systems cut clasts and dolomitic matrix.
Bar = 1.0 cm.

Figure 26.—Photomicrograph of megaclastic limestone. Note rinds on clasts and abundant stylolites along clast remnants (on right side). Clasts are dense micrite showing some internal recrystallization. Bar = 1.0 mm.

Lithologic Packaging

The poor outcrops which characterize this member make definitive statements about the lithologic packaging difficult. The top of the member, as exposed in the Alpha Portland quarry, is composed of thinly bedded (≤2 cm.) argillaceous limestones, which show little lateral or vertical variation. Lower in the geologic column the thinly bedded limestones show an increase in argillaceous interbeds from bottom to top of 5-10 meter sections.

At the base of this section carbonate is light gray with sparse pink horizons with virtually no argillaceous interbeds. Sparse burrows and fossil debris are present. Along strike are patches of coarse peloidal limestones (figure 27). Calcite beds become thinner higher in the section until laminated argillaceous dolomite is the dominant lithotype.

Within the Adamstown Member current features are more abundant in the outcrops around Frederick and to the north than in the vicinity of Adamstown and Buckeystown where most beds are more homogeneous and more argillaceous.

Lithologic Significance and Environmental Setting

The dominance of micritic limestone, resulting in many covered sections, indicates a low energy depositional environment. Coarse clastic carbonate is much less common than in the Rocky Springs Station Member; no slump breccias or thick peloidal sheets are evident. The characteristics are still of a "deep water" limestone according to the criteria of Wilson (1969).

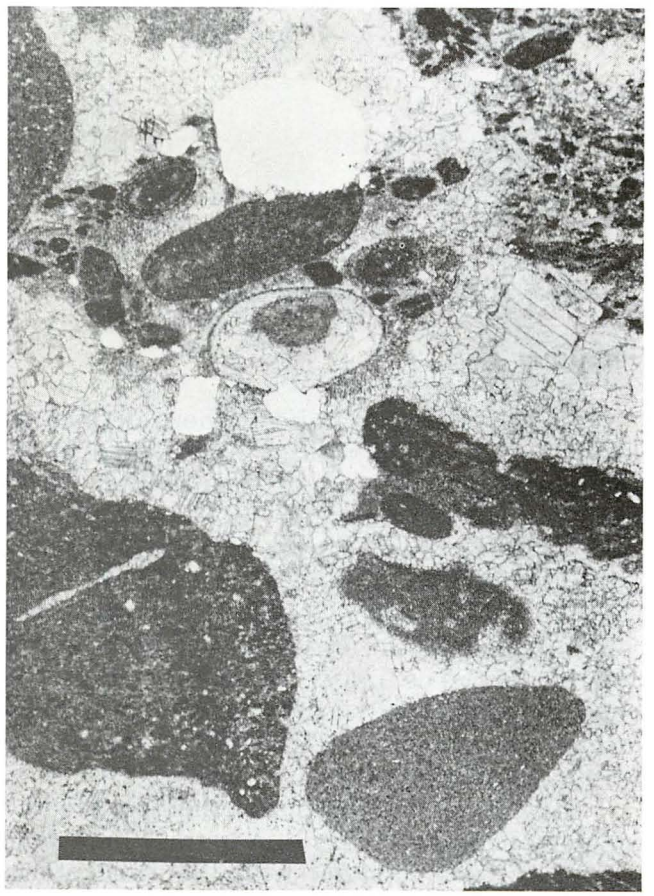


Figure 27.—Coarse peloid-megaclastic limestone associated with breccia zones. Note the recrystallization of matrix around framework grains. Rare quartz sand grains and oolites make the lithology polymictic.
Bar = 1.0 mm.

The sparse oolites and spherulites (figure 27) are inconsistent with the micritic limestones which dominate this member. Coarse carbonate material is associated with current structures and graded bedding in the thinly bedded limestones. Though no "Bouma cycles" are present, these appear to be sediments deposited by waning currents.

There is an increase in the biogenic component in the Adamstown Member. Burrows are locally abundant, possibly an indication that the depositional environment was more favorable to marine life than during deposition of the Rocky Springs Station Member lithotypes. Locally abundant, poorly silicified trilobites and echinoderm debris indicate an increase in diversity as well as quantity of organisms. Though some of this fossil debris may have been transported, much has accumulated in situ, since it is barely disarticulated. The faunas represented are virtually indentical with the "*Hungaia magnifica*" faunas of the Great Basin, which are a shelf edge to basinal biofacies (M. Taylor, personal communication, 1973).

This evidence suggests that the depositional environment for the Adamstown Member was similar to that of the Rocky Springs Station Member. The absence of abundant, coarse detrital limestone, and quartz sand may reflect either a change in relief between the adjacent carbonate platform to the west (Conococheague Formation) and the basin or changing conditions on the platform itself (lower sedimentation rate). Increased biogenic activity and greater abundance of current structures in the thinly bedded limestones may indicate a shallowing of the depositional basin.

LIME KILN MEMBER

Definition

The Lime Kiln Member is here defined as the 180 m. of section stratigraphically above the Adamstown Member and below the Grove Formation. This member is almost totally exposed along the entrance to the "Frederick pit" at the Alpha Portland quarry in Lime Kiln, Maryland. The section (plate 2) was measured perpendicular to the strike of the beds at the type locality. The upper 20 meters of section were compiled from nearby exposures where the contact between the Lime Kiln and Grove Formation is more readily visible.

The Lime Kiln Member is characterized by its highly burrowed, very thin to thick limestone beds. The lower contact with the Adamstown Member is not often exposed and the diagnostic change in lithologic packaging from monotonous thinly bedded limestones of the Adamstown to highly variable thick to thinly bedded limestones of the Lime Kiln can be overlooked in the field. The upper contact with the Grove Formation is a sharp transition from medium or dark gray, thinly to thickly bedded, mottled limestone into light gray, highly quartzose, thickly bedded to massive limestone.

The amount of biogenic activity is dramatically greater than in the lower members. Some beds are thoroughly homogenized and show no primary mechanical structures; others contain horizontal or inclined burrows, tracks or trails which modify bedding slightly. Another important and added element is the presence of cryptalgal structures at the very top of the member.

All of the fossils, including echinoderms, trilobites, brachiopods, and cephalopods, found in this member are Trempealeauan in age; specific zones and subzones such as the *Saukiella junia* and *Saukiella serotina* subzones of the *Saukia* zone in the Great Basin can be recognized (M. Taylor, personal communication, 1972). Much of the fossil material occurs as fossil debris concentrated in thin beds or within thicker mottled zones.

Virtually no thick to massive beds are present within the entire member, so no specific petrographic discussion has been set aside for this grouping.

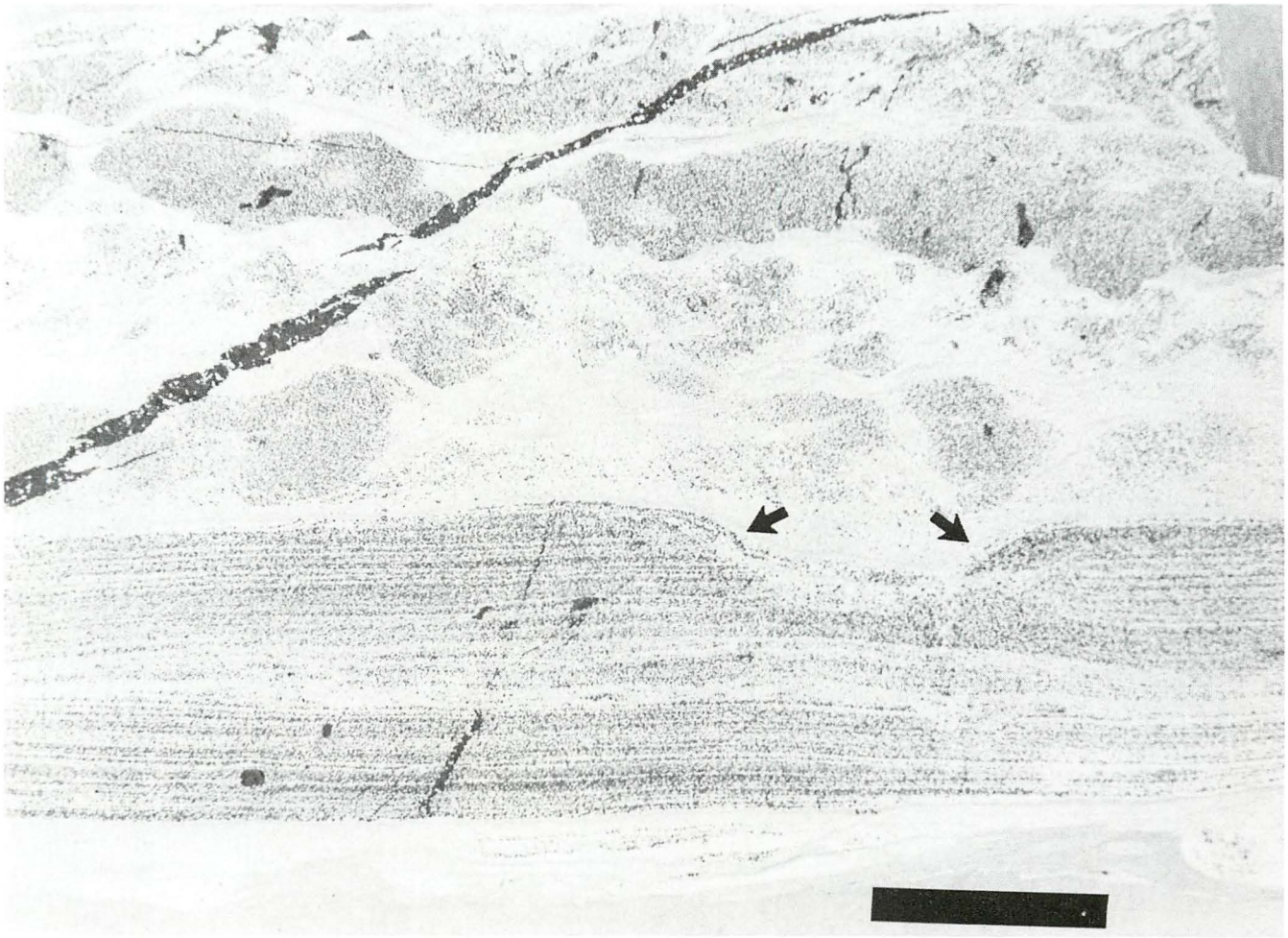


Figure 28.—Planar laminate scoured at top and overlain by irregularly bedded limestones. Arrow (left) points to sedimentary drape of the scoured laminate. Arrow (right) shows thicker unstratified fill in scour. The above observations indicate that current was moving from left to right.

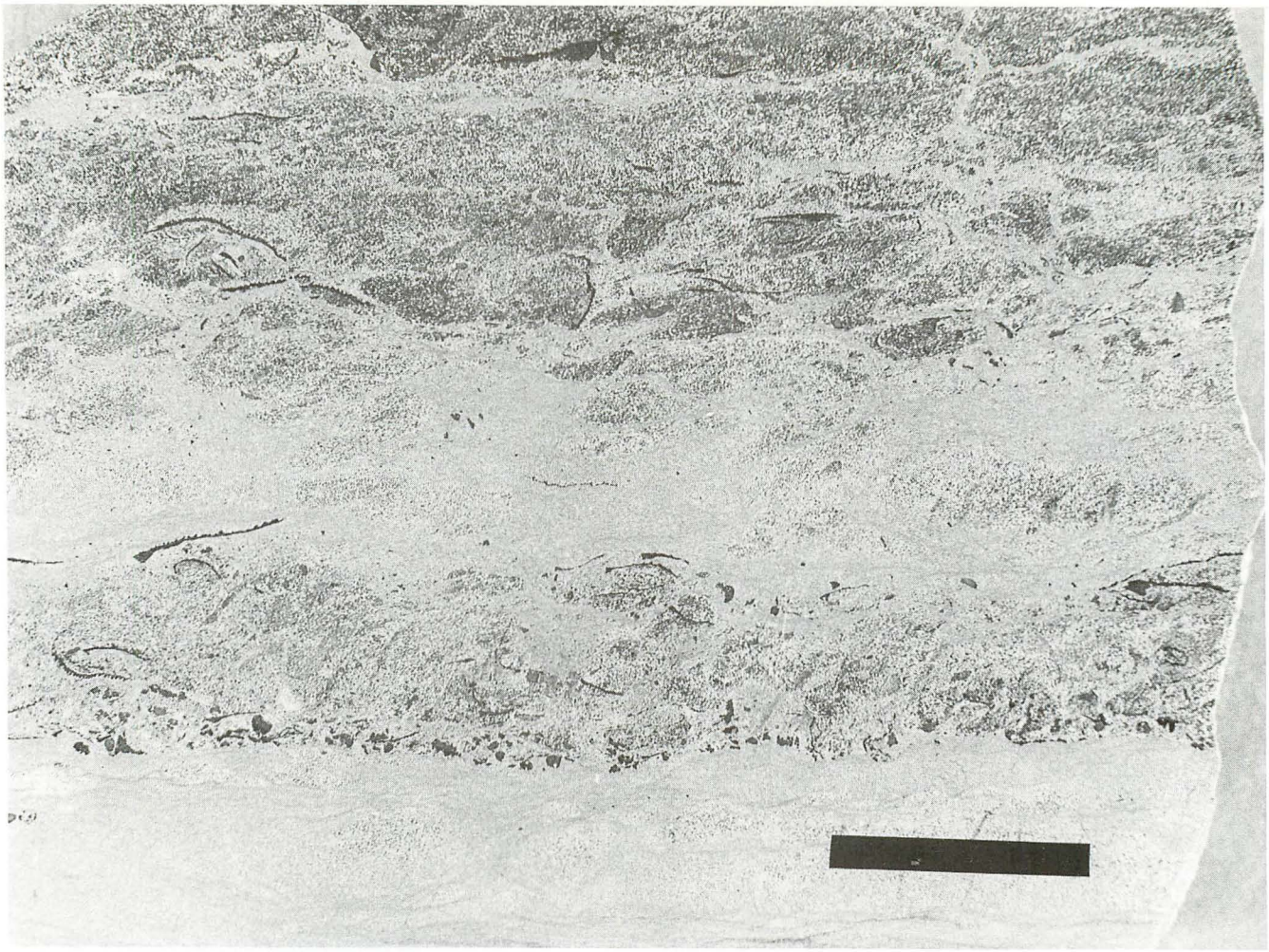
Petrography

The entire spectrum from relatively pure laminated limestones to discretely bedded ($\leq$3 cm. thick) limestones lacking internal structure and defined by argillaceous partings or interbeds is represented in this member. The carbonate is predominantly micrite, recrystallized to microspar; coarse particles composed of peloids, fossil hash and quartz grains are present.

Near the base of this member size and mineralogical variability on the millimeter and centimeter scale are conspicuous. The sedimentary components are chiefly peloids and quartz grains embedded in a micrite matrix. Size sorting at any given horizon is excellent. Laminations are defined both by abrupt changes in particle size and by concentrations of dolomitic or argillaceous sediment. Argillaceous seams are often sutured stylolitic boundaries.

Although some thin beds are quite uniform compositionally, many of these limestones are interrupted by irregular dolomitic stylolites which subdivide the lithology into units of dubious sedimentological significance. More commonly the distribution of dolomite is related to primary sedimentary features such as planar lamination (figure 28). As in the lower members of the Frederick Formation laminations are typically planar, though a few ripple forms or load features interrupt the horizontal trend of the laminations.

Laminations are commonly defined by dolomitic or argillaceous horizons; these contain either mechanical features such as truncated ripple forms (figure 28) or are distorted in harmony with the surrounding sediment. The laminated beds are primarily dolomite, often containing cross-cutting argillaceous wisps (figure 29), which define cleavage and tend to obscure primary bedding features.



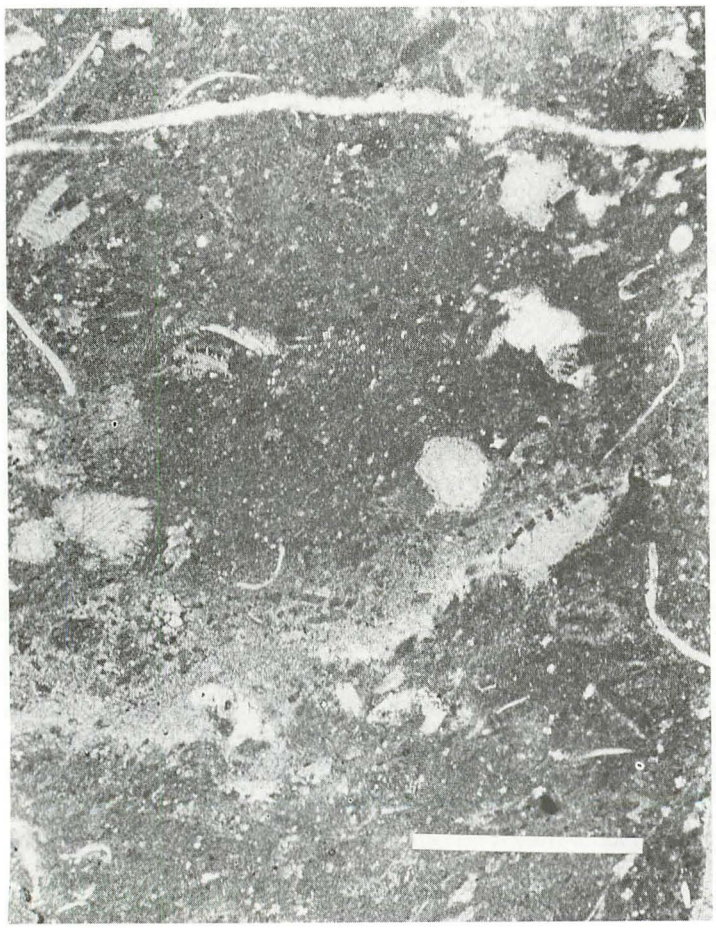


Figure 29.—Thinly bedded limestone containing trilobite debris. Fossil lag at base of calcite above wispy argillaceous beds; note high incidence of convex upward debris.
Bar = 1.0 cm.

Figure 30.—Abundant sparry fossil debris and peloids in a dense micritic matrix. Sample is from massive deposit at the base of a sedimentary cycle.
Bar = 1.0 mm.

Much of the fossil debris is concentrated at the base of beds (figure 29) with coarse calcareous particles, but some is floating in a micrite matrix (figure 30). On the basis of good sorting, grading and preferred orientation, some of the fossil hash has been mechanically transported, concentrated and deposited (figure 29), while the biomicrites (figure 30) with their lack of orientation and homogeneous matrix suggest in situ accumulation.

Burrow structures are common bedding modifiers. The mottled limestones (figures 28, 29) do not show discrete burrow structures, but disruption of primary bedding features may be the result of biological activity. Exposure of abundant large and small, inclined and horizontal burrows on bedding surfaces (figure 31) is most common in the upper half of the Lime Kiln Member, especially in flaggy micritic limestones. Horizontal burrows are the most numerous and stratigraphically widespread. Small burrows are commonly concentrated in the dolomitic-argillaceous partings between the 1-3 cm beds and hardly modify the primary bedding features. Larger spar-filled burrows disturb the sediment around the structure slightly. The compaction-draping of fine grained carbonate (figure 32) indicates rapid and early cementation within and immediately around burrow structures. Various tracks and feeding trails are also on bedding planes, though these features are easily confused with tension-solution features.

At the very top of the Lime Kiln Member, the flaggy beds become wavy with irregular, highly argillaceous partings. This lithotype is associated with distinctive stromatolitic structures (figure 33) which vary in size and internal structure. The interior of the poorly laminated cryptalgal structures is composed of finer

Figure 31.—Weathered bedding plane showing abundant horizontal burrows; note the crossing relationships. The thin linear patterns on the surface are tension solution patterns (depressions) and calcite veins (highs). Bar = 1.0 cm.

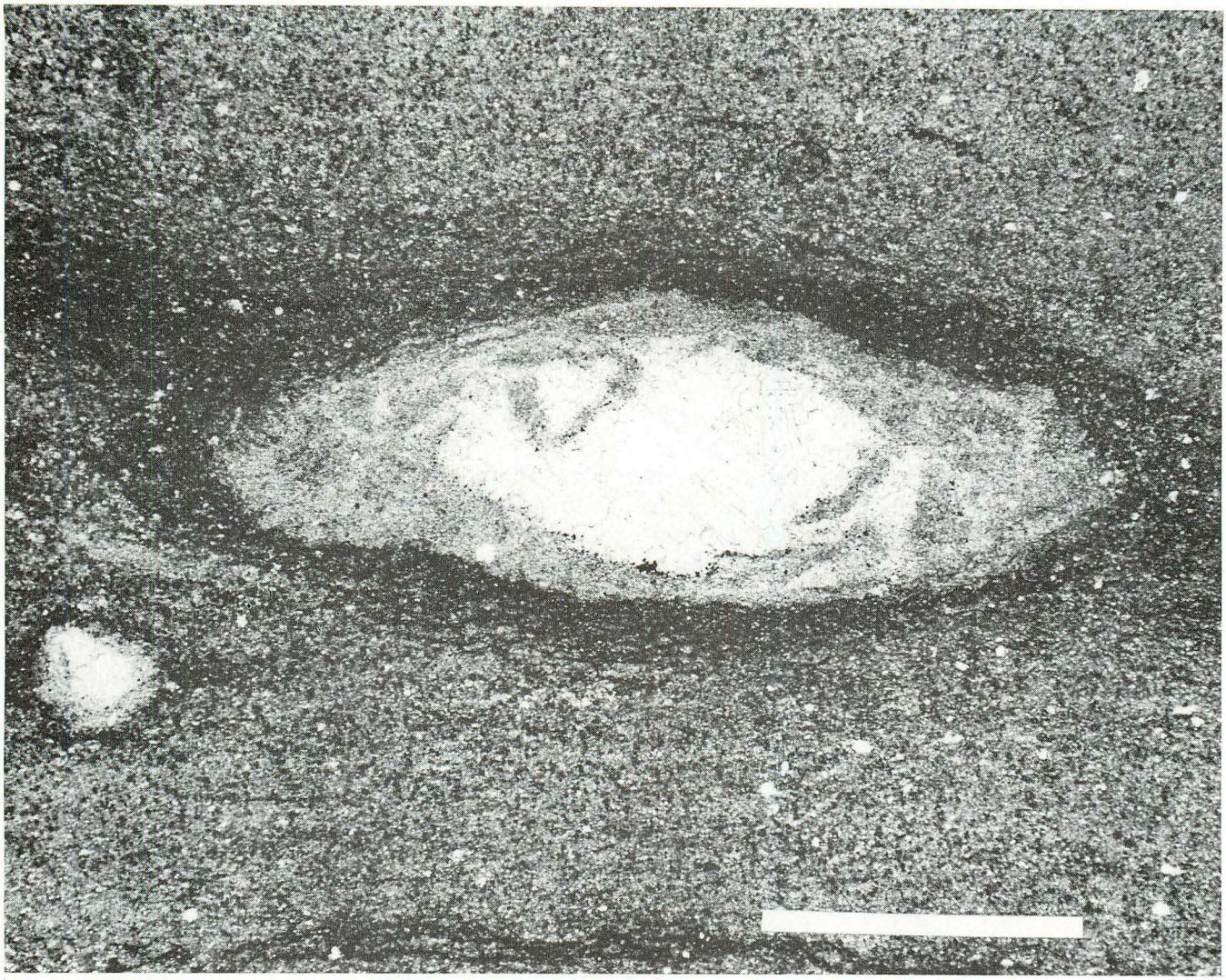


Figure 32.—Photomicrograph of a spar filled burrow. Note the dark dolomitic-argillaceous halo around the burrow structure. Incipient collapse of micrite into the burrow structure followed by early cementation have been recorded prior to total compaction of the sediment.
Bar = 1.0 mm.

grained carbonate than the enclosing wavy beds. The stromatolites, consisting of discrete heads, and the associated wavy bedded limestones lack abundant coarse carbonate in this member.

The distinctive petrographic features of the Lime Kiln Member are the dominantly micritic sediments, the small size range in peloids, the abundant laminated limestones and the increased amount of biogenic debris and activity over the underlying carbonates (Rocky Springs Station and Adamstown Members).

Lithologic Packaging

In the completely exposed section at the Alpha Portland quarry consistent repetition of three major lithotypes in the Lime Kiln Member indicates cyclic sedimentation. The section (plate 2) has been subdivided into ten cycles which range from 8 to 33 meters thick. At most other Lime Kiln localities the presence of cycles can not be documented, since much of the section is not exposed.

A "typical" cycle containing the common structures is presented in figure 34. The presence and thickness of the erosive base is the

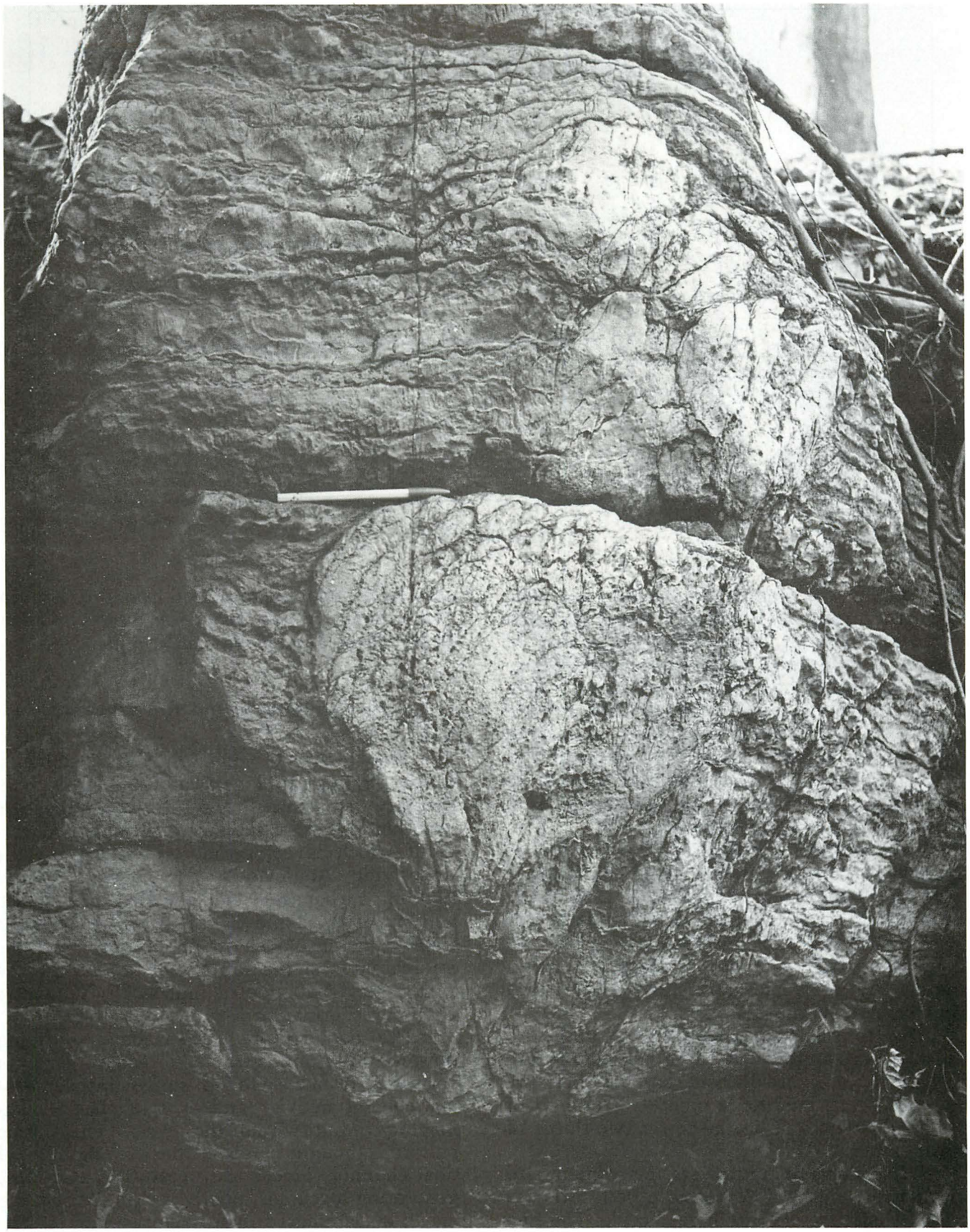


Figure 33.—Head shaped stromatolite encased in wavy bedded limestone. Compound heads show poorly developed internal structure. Sediment both inside and outside the cryptalgal structure is fine grained limestone outlined by dolomitic laminae.

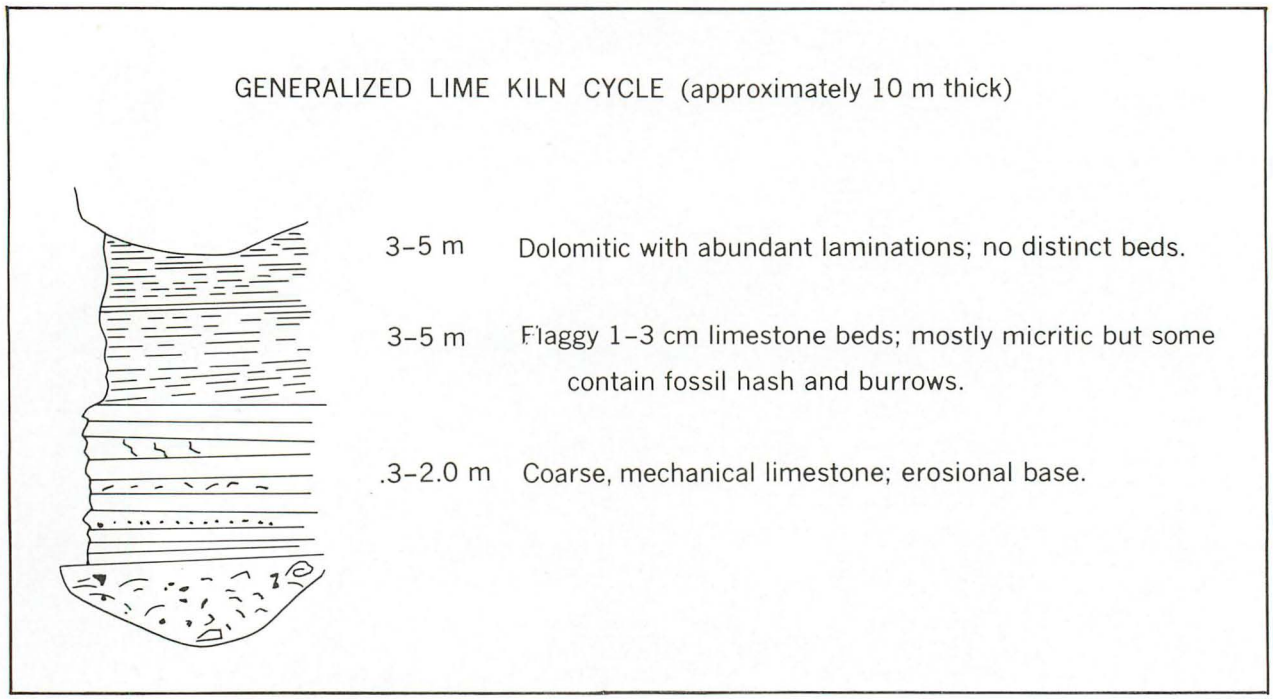


Figure 34.

least predictable element in these cycles. The basal unit is typically less than 1 meter thick and is composed of a polymictic assemblage of peloids, fossil debris, oolites and micrite (figure 30). There are no internal sedimentary structures and rapid lateral changes in thickness are observed. The lack of sediment reworking suggests rapid deposition. This basal unit is thought to represent channel fills, large scale equivalents of the microscour structures present in the Adamstown Member (figure 22).

The central portion of the cycles is composed of thinly bedded, flaggy limestones containing abundant sedimentary structures: planar laminations, ripples, scours, pinch and swell structures and burrows. These are all associated with granular sediments, which grade to micritic laminated limestones which form part III of these cycles.

The top of the cycles is composed of laminated dolomite-calcite. The laminations are millimeter scale; rare starved ripples or burrows interrupt these micritic laminates. This part of the cycles is thickest in the lower two-thirds of the member.

The general fining upward in sediment size within the cycles and decrease in bed thickness are the major trends within each cycle. The fine sediment size and the relatively thick sequence suggest relatively low energy and some environmental constancy. These are not typical peritidal carbonate cycles as described from the Cambro-Ordovician platform carbonates by Pelto (1942), Root (1964), Donaldson (1969) and others.

Lithologic Significance and Environmental Setting

The generally fine grained sediments, which exhibit rapid vertical changes in sedimentary structures and are packaged in sedimentary cycles indicate a physical environment which is somewhat different form the underlying Adamstown and Rocky Springs Station carbonates. In addition, biological activity in the Lime Kiln carbonates shows a marked increase over the underlying rocks; the stromatolites at the top of the section are the first positive bathymetric indicator in the enitre Frederick Formation.

The sedimentary cycles show a fining upward in grain size and a decrease in variability from base to top, suggesting decreasing current activity and/or less clastic sedimentary input within the cycle. This cyclic pattern is thought to result from the migration of tidal channels across the depositional surface, generating a coarser, poorly sorted channel lag and fine, laminated over-bank sediments. The overall variability and cyclicity indicates a physical environment with less constancy than the underlying carbonate units.

The abundant burrows, feeding tracks and fossil debris are evidence for a depositional basin with high organic productivity. Although some of the fossil hash shows imbrication and is well sorted, total disarticulation of fossils is uncommon. Transportation of most fossils into the depositional basin is therefore excluded.

The isolated head shaped stromatolites at the top of the Lime Kiln Member are indicative of very shallow subtidal to intertidal conditions. Holocene analogues from Shark Bay, Western Australia (Logan, 1961; oral communication, 1972) show a strong zonation of algal structures with pustular heads in the zone of maximum wave energy and tidal scour. The heads at the top of the Lime Kiln are associated with fine grained sediments, which are inconsistent with the high energy modern analogue. It is thought that the stromatolites at the top of the Frederick Formation are indicative of shallow subtidal (just below mean sea level) conditions, which existed in portions of the sedimentary basin at the end of the Cambrian.

The maximum depth of limestone accumulation in the Lime Kiln Member is not known, but the onset of cyclic sedimentation, an abundance of trace and body fossils, and the appearance of stromatolites at the top of the section document proximity to mean sea level, and hence a shallowing of the sedimentary basin when compared to the underlying limestones.

GROVE FORMATION

Definition

The Grove Formation corresponds to the Grove Limestone of Jonas and Stose (1936). The limestones and dolomites of this member occupy the axis, hence highest stratigraphic position, in the Frederick Valley syncline. The first appearance of abundant coarse quartz sand above the highly burrowed Lime Kiln Member marks the base of the Grove Formation. Although rather thick zones of highly quartzose limestone are commonly present at the base of the unit, no mappable subdivision like the basal quartz sand suggested by Jonas and Stose (1936, 1938) was recognized within the valley.

The porous sand referred to by Jonas and Stose (1936) as the weathered product of this basal zone is thought to be Triassic in age and origin at all observed localities, though some of the sand may have been derived from erosion of the Grove Formation or the Rocky Springs Station Member. The sandstone is partially to tightly, silica cemented. The strike of the sandstone ridges is typically at an angle to the strike of the carbonates; dips are consistently at a low angle to the west, while the carbonate typically dip at a high angle to the west or a low angle to the east.

At the type locality of Jonas and Stose (1936), the Grove Quarry on the southeastern margin of Frederick, Maryland, the unit is approximately 200 meters thick, but the top is not exposed. A maximum of 450 meters is exposed farther north where the Frederick Valley synclinorium plunges gently northward. A cross-section and stratigraphic description of the Grove Formation have been included in Appendix B to supplement the type section of Jonas and Stose (1936).

This unit is dominated by thickly to massively bedded, light gray limestones and white or buff dolomites which contain variable amounts of coarse quartz sand. The abundant quartz sand and carbonate peloids render the unit compositionally similar to the upper half of the Rocky Springs Station Member, though the sedimentary structures and lithologic packaging are quite different. Previous work on trilobites, brachiopods, cephalopods (Appendix B) and recent work on conodonts (A. Epstein, oral communication, 1973) all indicate an age of early Lower Ordovician for the Grove Formation.

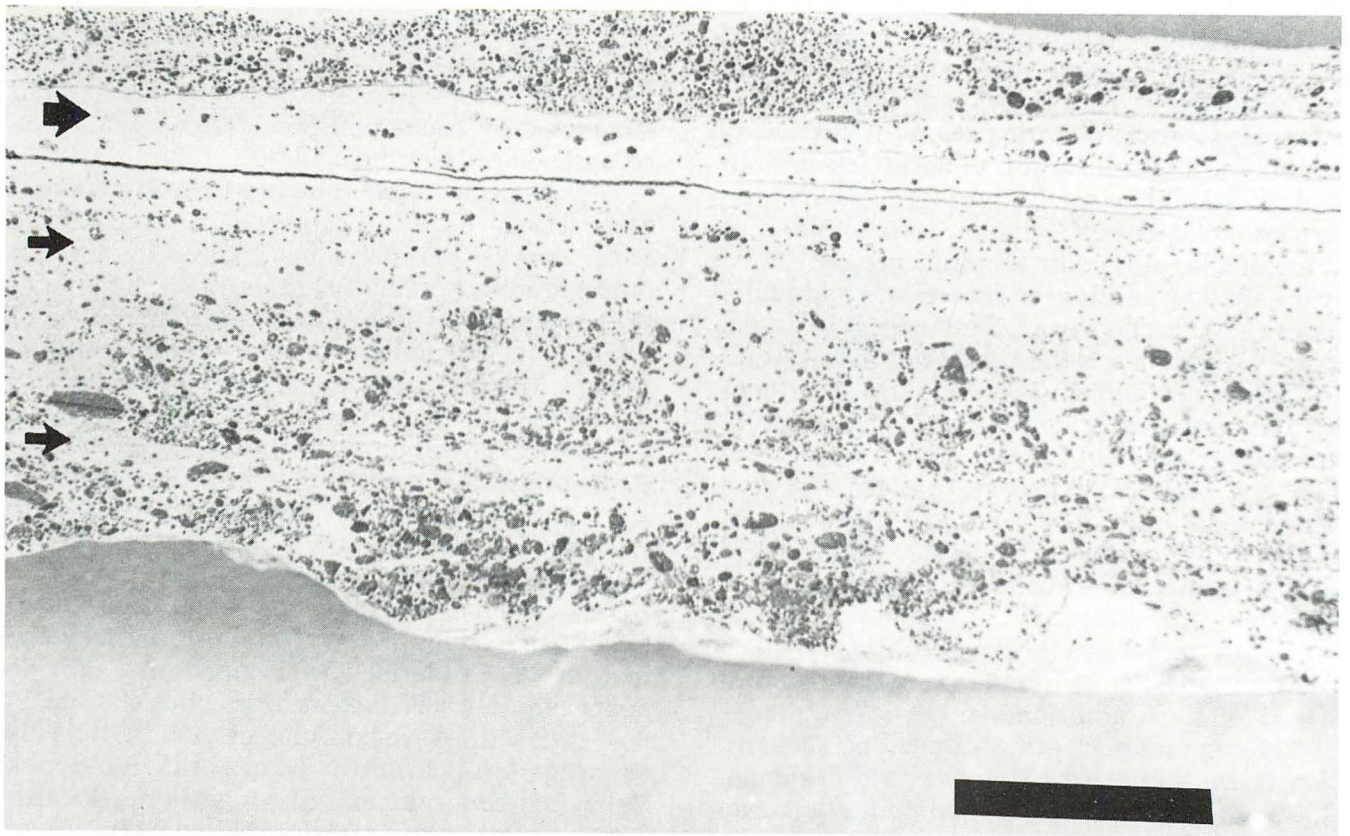


Figure 35.—Thinly bedded peloidal limestone. The range of round peloids to small flat clasts in a dolomitic matrix shows considerable vertical variation. Several distinct breaks in sedimentation are apparent within the bed (arrows); crude graded bedding between the arrows.
Bar = 1.0 cm.

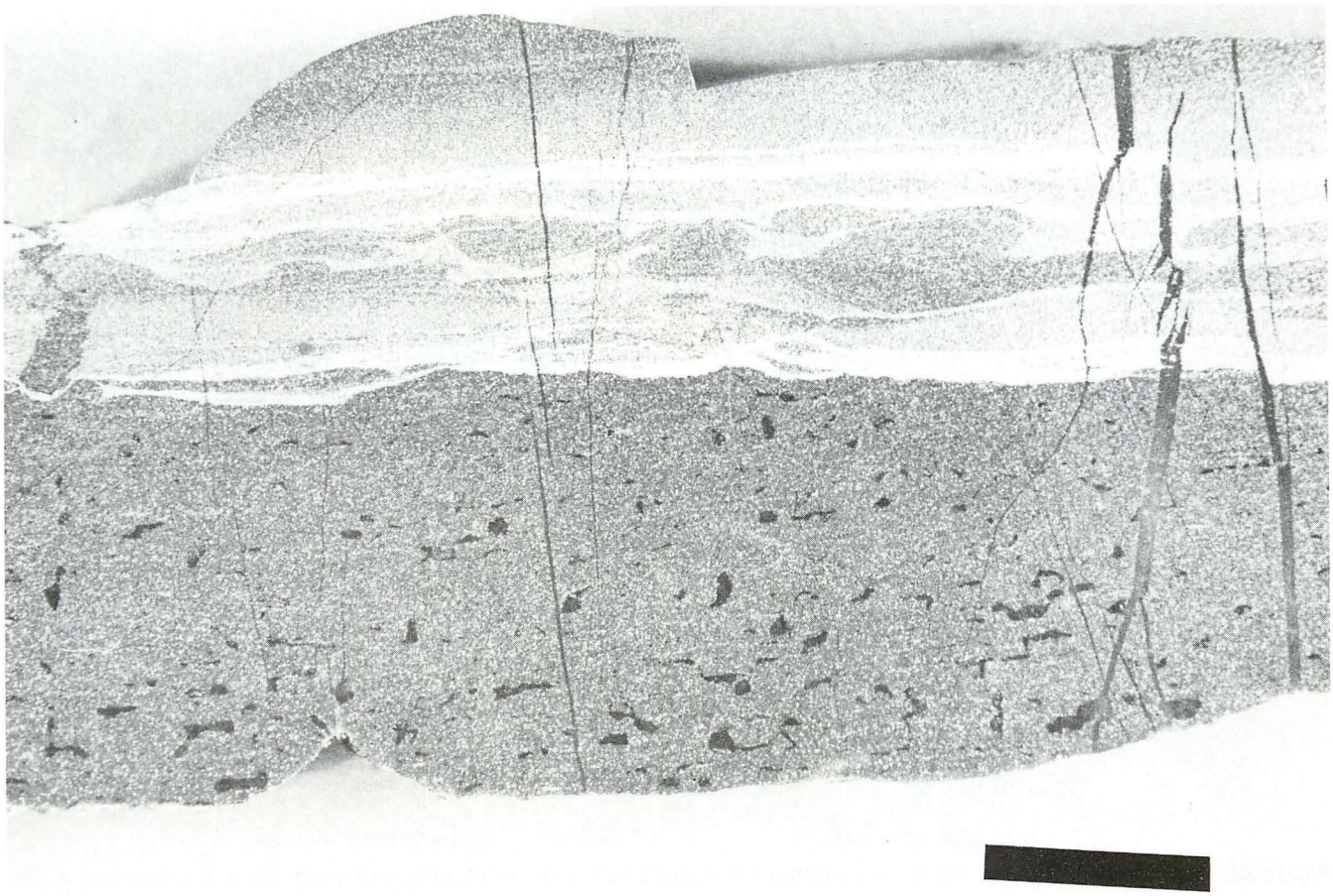
Petrography

Thinly bedded carbonates: Thinly bedded carbonates constitute a relatively minor portion of the Grove Formation, especially when contrasted with the underlying Frederick Formation. Some micritic, flaggy beds similar to those typical of the underlying limestone are present, but are rarely seen in outcrop. Most thinly bedded limestones are composed of fine to coarse peloids, oolites and quartz grains and are laminated. Many of these laminates are interbedded with or gradational to thickly bedded or massive lithotypes.

The thinly bedded limestones show abrupt, rapid vertical changes in sedimentary particles, structures and fabric. These sharp transitions may result partly from pressure solution of intermediate carbonate. Thick laminae containing abundant coarse peloids alternate with thin dolomite laminae (figure 35); fining upward of particle size within these couplets suggests waning of current activity. Recrystallization of carbonate matrix obscures the framework-matrix relationships shown in etched slabs.

The thinly bedded limestones commonly contain large amounts of quartz silt, which delineates bedding and/or current structures (figure 36). Planar and ripple cross-lamination are evident in well bedded limestones. Fenestrae and mottled textures dominate limestones which lack current structures (figures 36, 37).

In addition to the variety of thinly bedded limestones, two distinctly different laminated dolomites are Grove Formation lithotypes. A coarse, irregular laminate contains lenses of quartz sand and coarsely crystalline dolomite alternating with thin, argillaceous laminae, which drape and outline the quartz sand pods. The other variety of laminated dolomite is composed primarily of microspar and the laminae are closely spaced (figure 39). The dense micritic laminae are essentially planar with irregularly spaced peaks and undulations. Rare vertical disruptions, thought to be mudcracks, and spar filled fractures disrupt the laminae (figure 39). Both varieties of laminated dolomite are blocky and laterally continuous; the delicate laminate occurs in thin to thick beds and the coarse laminate is thinly to massively bedded.



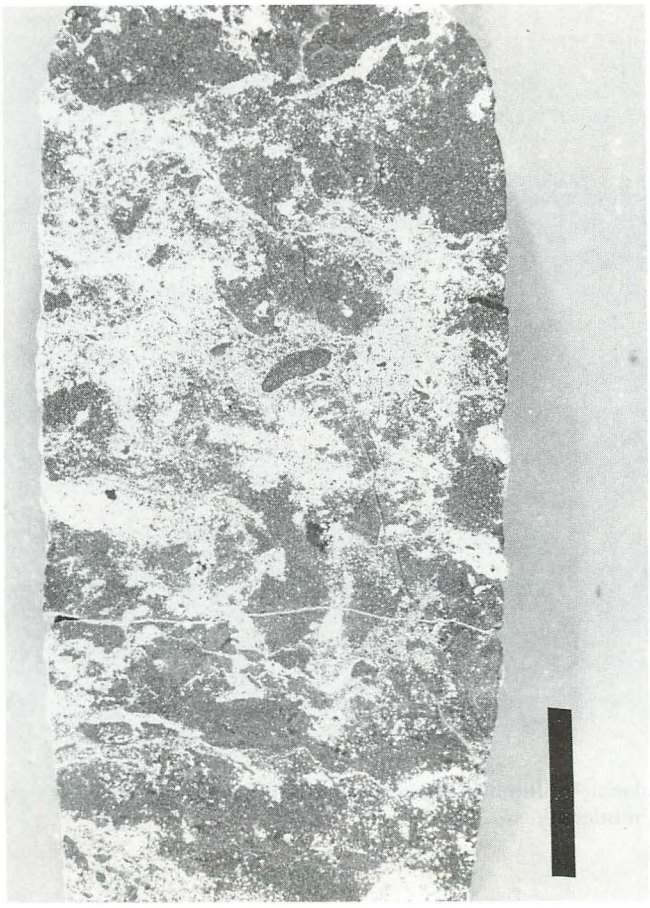


Figure 36.—Sharp transition from structureless limestone containing abundant fenestrae (burrows?) to a well stratified limestone-dolomite. Poorly developed, isolated ripple forms; planar and cross-lamination are delineated by the dolomite distribution within the bed. Vertical components are spar filled fracture fillings (right) and a mudcrack (?) (extreme left).
Bar = 1.0 cm.

Figure 37.—Mottled, unstratified limestone characterized by irregular dolomite (white) distribution and poorly sorted framework components, consisting of clasts, fossil debris and peloids.
Bar = 1.0 cm.

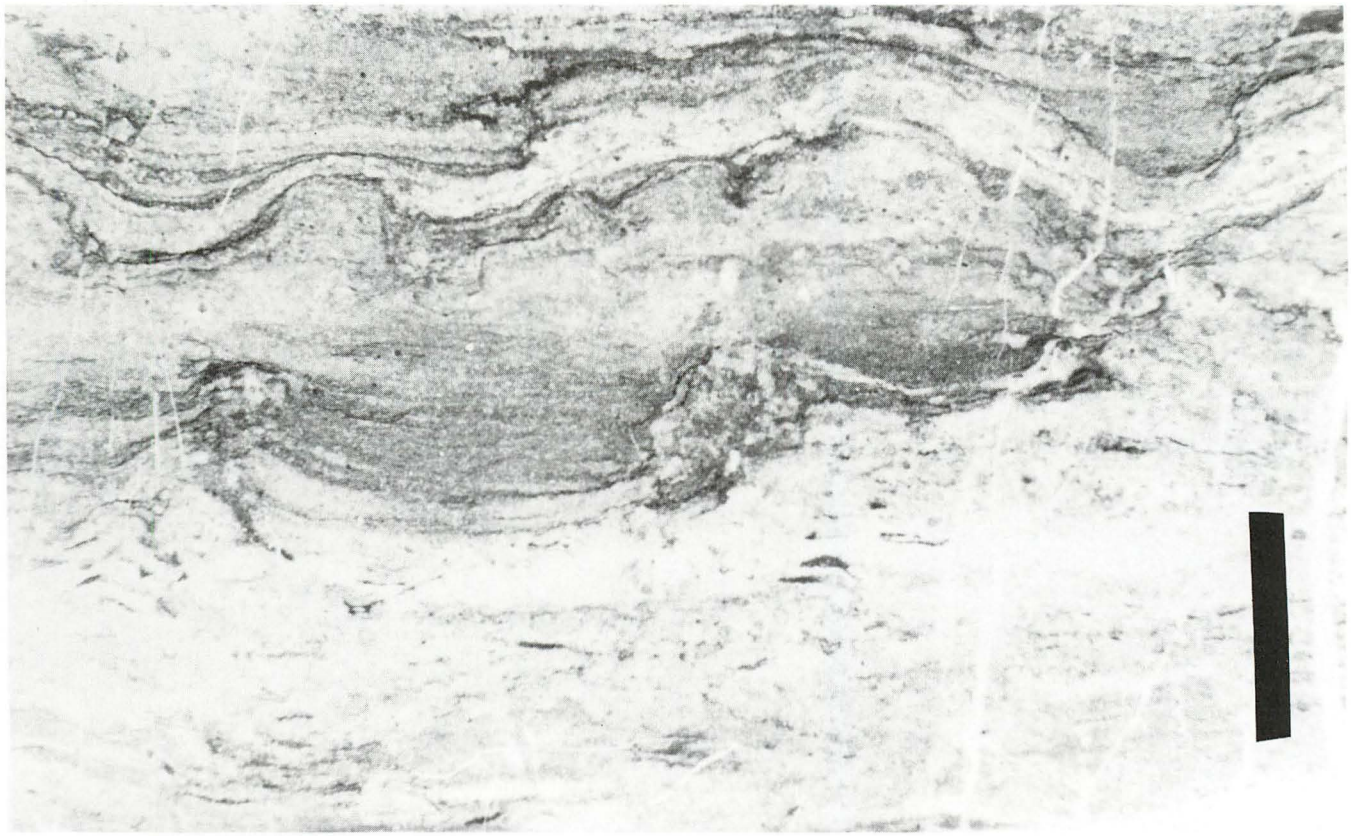


Figure 38.—Irregularly laminated dolomite composed of coarsely crystalline dolomite and quartz sand. Bedding components are pods and lenses of coarse framework grains separated by finer grained laminated carbonate. Note the draping of domes by continuous argillaceous laminae.
Bar = 1.0 cm.

Figure 39.—Fine grained dolomitic laminate showing nearly planar, millimeter scale laminations with irregular tufts and crinkles. Vertical disruption (arrow) is probably a mudcrack.
Bar = 1.0 cm.

Thickly bedded and massive carbonates: Most of the Grove Formation consists of a diverse assemblage of thickly bedded limestones. The most conspicuous, if not the most abundant, are light gray limestones, composed of coarse quartz sand and carbonate peloids, which exhibit small-scale planar to shallow trough cross-beds (figure 40). The cross-beds indicate highly variable and alternating current directions within short vertical distances. Rounding and size sorting of all particles in this grain supported lithotype is very good to excellent.

Rare beds of oolitic limestones (≤20 cm. thick) are associated with the typical cross-bedded units. Peloids and quartz grains act as nuclei for oolites and spherulites; compound grains or grapestones are abundant (figure 41). The grapestones are composed of two or more framework grains bound by a dense micritic matrix. The distribution of carbonate and quartz grains is generally random where both are present; beds are, however, defined by quartz-rich laminae. The sedimentary particles are cemented by fine to coarsely crystalline calcite spar which had corroded quartz sand grains (figure 41).

A variation in the thickly bedded granular limestone is the presence of rare flat to round pebble conglomerates (figure 42). The megaclasts (up to 15 cm. long) are composed of structureless peloidal sediment; the matrix is similar in composition.

Two distinct groups, mottled bioturbates and cryptalgal limestones, are poorly bedded to massive. The mottled limestones are composed of fossil debris, peloids, irregular clasts and patchy dolomite (similar to figure 37). The fossil hash and detrital grains are commonly clustered in small pockets and embedded in a micrite matrix.

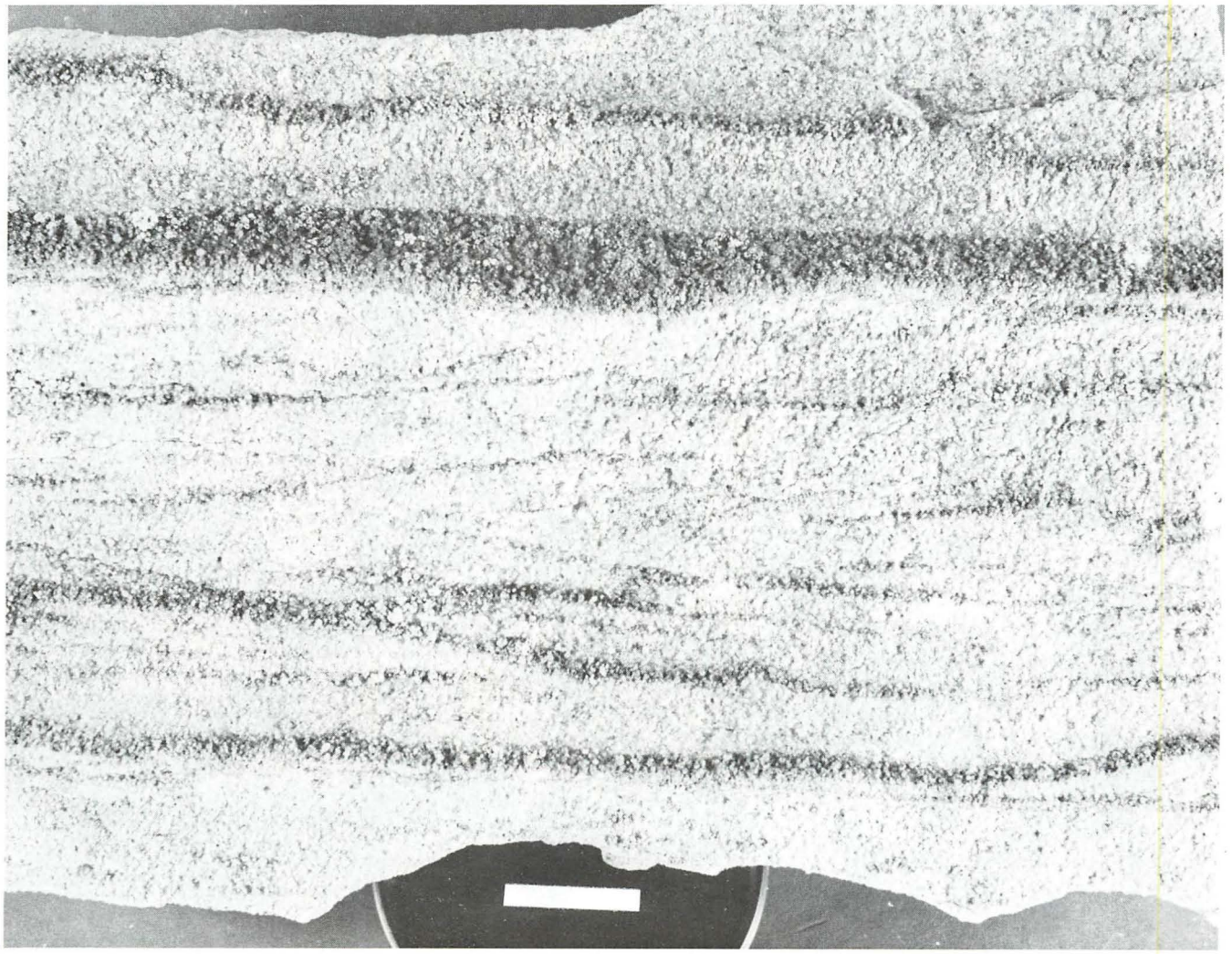


Figure 40.—Weathered slab of mechanical limestone contains "herringbone" cross-beds; stratification is delineated by coarse quartz grains. Planar concentrations of quartz are bedding indicators in more massive beds. Bar = 1.0 cm.

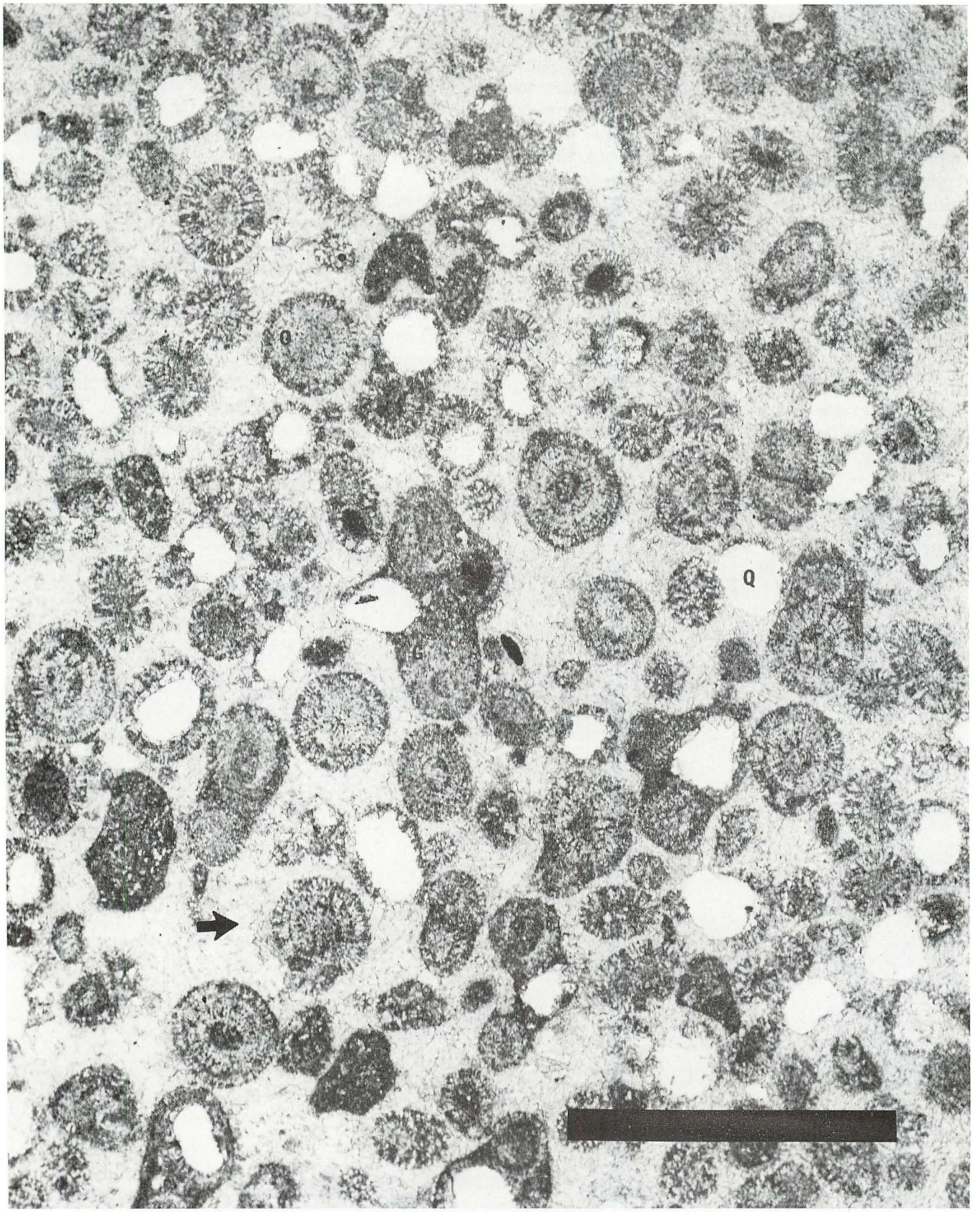


Figure 41.—Photomicrograph of an undeformed oolitic limestone shows oolites (O), grapestones (G), peloids (P) and quartz grains (Q) in a fine sparry cement. Quartz grains and peloids act as nuclei for oolites. Spar appears to grow outward from framework grains (arrow left). Carbonate is corrosive on margins of quartz grains. Bar = 1.0 mm.

Figure 42.—Flat to round megaclasts in a peloidal limestone matrix lie roughly parallel to bedding. Irregular sparry calcite patches dot the matrix. Conglomerates of this type are quite rare within the Grove Formation.

The cryptalgal structures in the Grove Formation are associated with mottled limestones. Two basic types of cryptalgal structures are present: stromatolites, which can be subdivided into several groups using the classification scheme proposed by Logan, et al (1964) and thromobolites, clotted, poorly to unlaminated, head-shaped or mound-like structures (Aitken, 1967). Cryptalgal laminates have been described under thinly bedded limestones.

The stromatolites are strongly to weakly laminated, stacked hemispheroids (SH) with well defined borders typically 20 to 40 cm. across and 30 to 50 cm. high (figure 43). Small non-branching digitate forms 1-3 cm. across and up to 20 cm. high are poorly preserved at a single locality. Laterally linked forms are not recognized in the stratigraphic column. The internal laminations are defined by microcrystalline dolomitic layers up to 5 mm. across. The thrombolites are typically smaller and contain abundant crystalline dolomite knots within the clotted fabric. Coarse peloids, quartz sand and fossil hash occupy the space between stromes (figure 43). The margins of the stromatolites and thrombolites are commonly delineated by a thick dolomite rind which separates the coarse peloidal interstrome channel fill from the finer grained cryptalgal structure (figure 44). Enigmatic spherical geopetal structures (3-5 cm. across) are rarely associated with clotted cryptalgal structures. Some cryptalgal structures are entirely dolomitized, hence internal structure is only preserved where considerable quartz sand or silt has been incorporated into laminations.

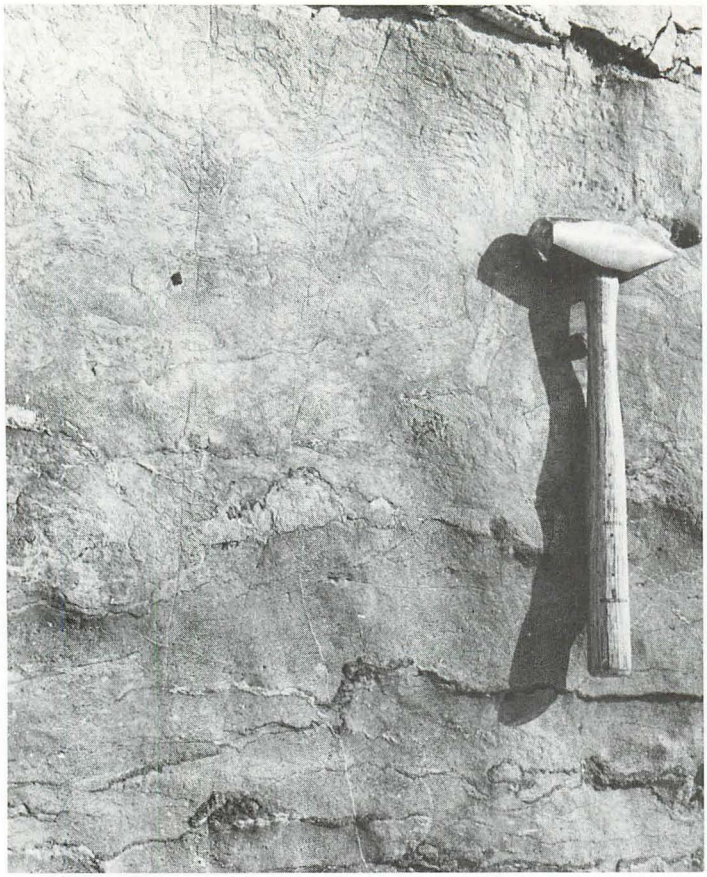
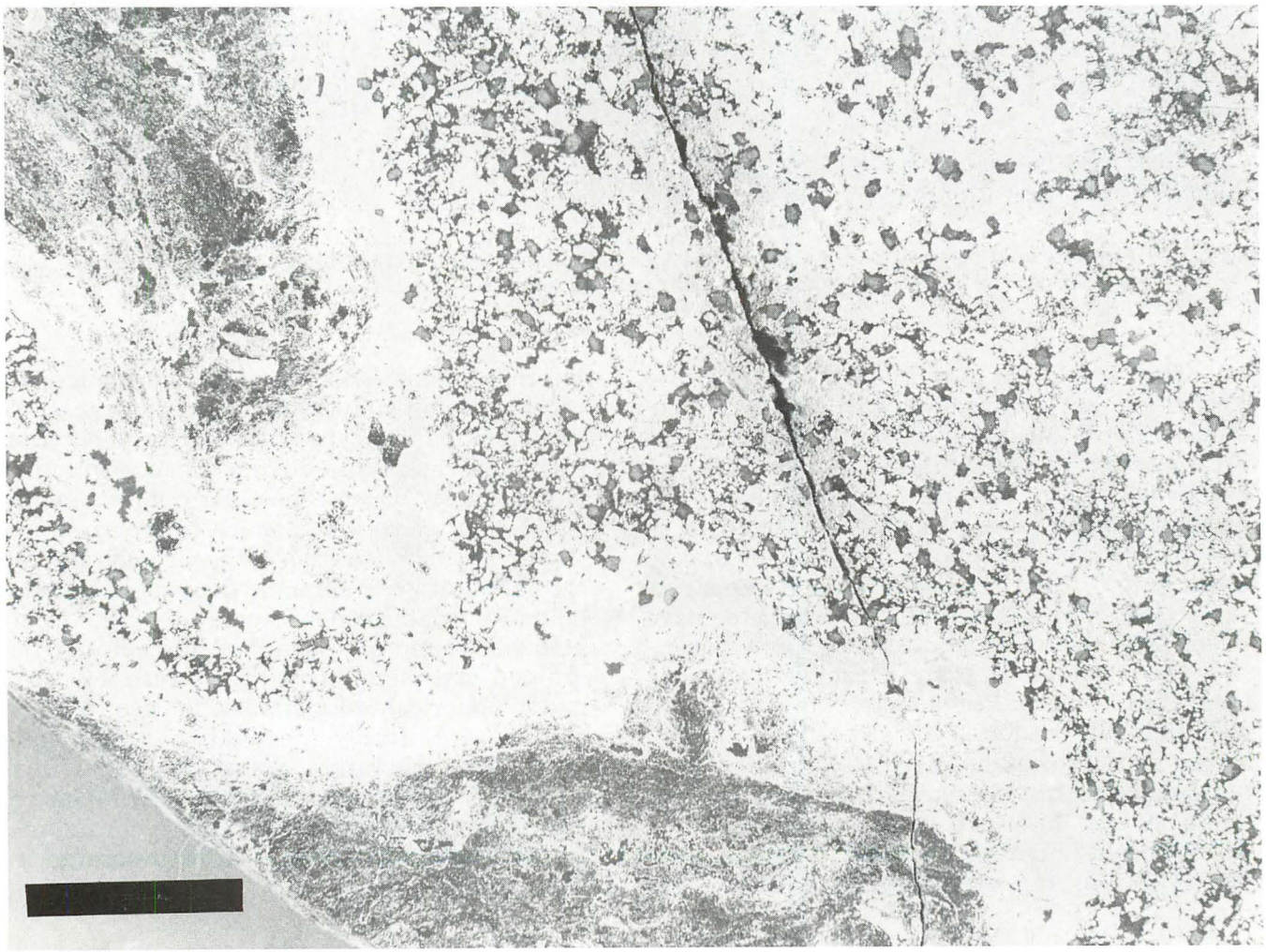


Figure 43.—SH type stromatolites above clotted algal structures (thrombolites) in thickly bedded limestones are above a stylolitic contact with mechanical limestones. Laminations and algal head margins are dolomitic.

Figure 44.—Plan view of the margins of two discrete, poorly laminated stromatolites and typical coarse channel fill between the heads. The heavy dolomitic rind on the margins of the stromatolite and lack of coarse carbonate particles within the algal structure are common. The channel fill is composed primarily of flat and round peloids. Bar = 1.0 cm.



More commonly massive dolomites are structureless or contain faint laminations. Quartz grains concentrated in pods or lenses are components of these microcrystalline dolomites. Massive dolomites are also coarsely crystalline with and without quartz sand.

A final component in these massive lithologies is sparse nodular chert. The nodules are usually elongate and round in cross-section, about 10 cm. in diameter and up to 30 cm. long (figure 45). The nodules do not appear to replace specific sedimentary structures and are restricted to specific stratigraphic horizons.

Lithologic Packaging

Although not all localities within the Grove Formation show consistent lithologic packaging, many sections display well developed sedimentary cycles. Descriptions of measured sections in Appendix A where little covered section is present (for example: localities 789-790 or 815) document these cycles which have been generalized in figure 46. The thickness and lateral persistence of these cycles is highly variable. The presence of well developed sedimentary cycles is fundamental to an interpretation of the depositional environment.

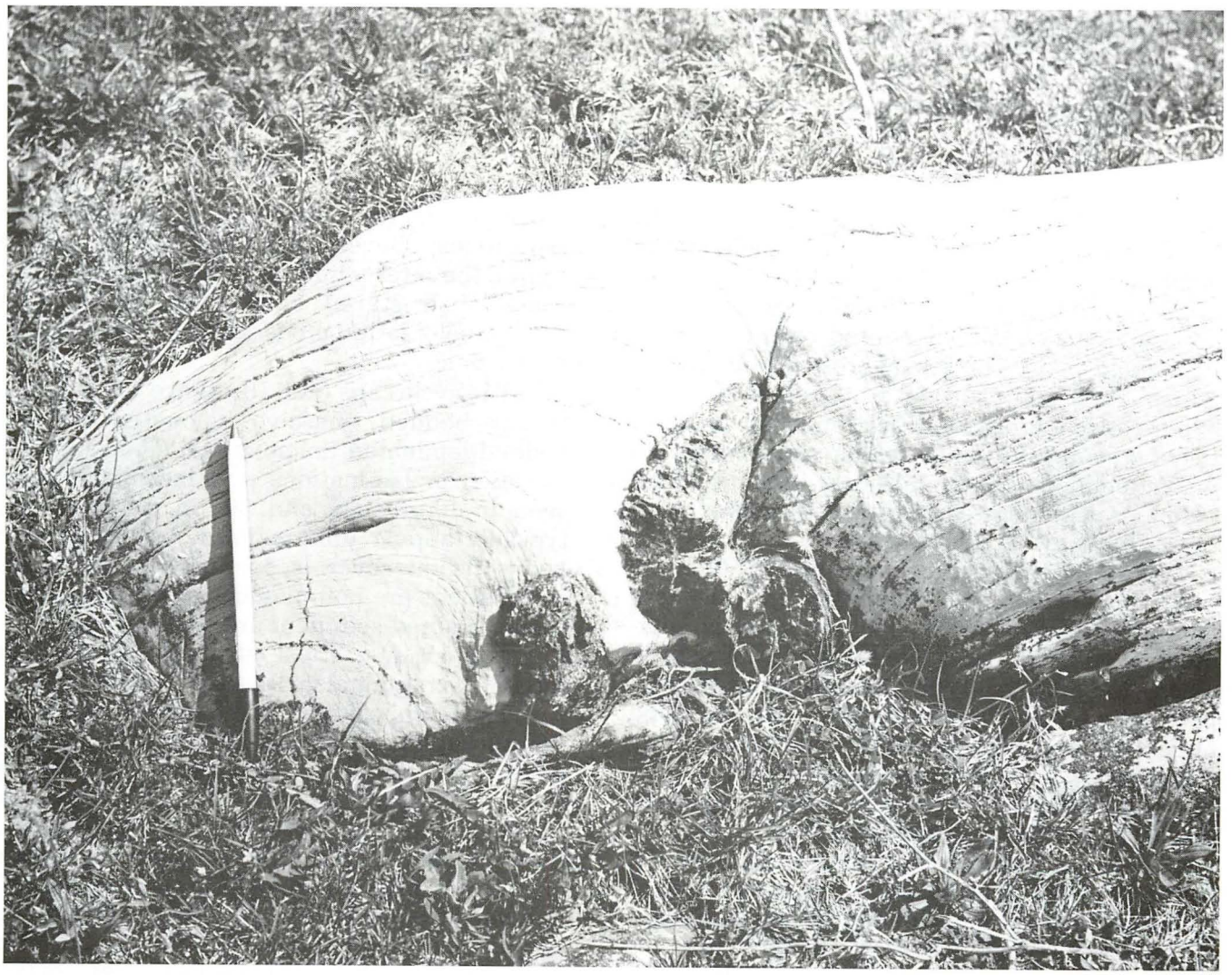


Figure 45.—Nodular chert in finely laminated dolomite. Chert occurs along this stratigraphic horizon over a distance of several hundred meters. Bedding is distorted immediately adjacent to the nodules which are typically irregular to elipsoidal.

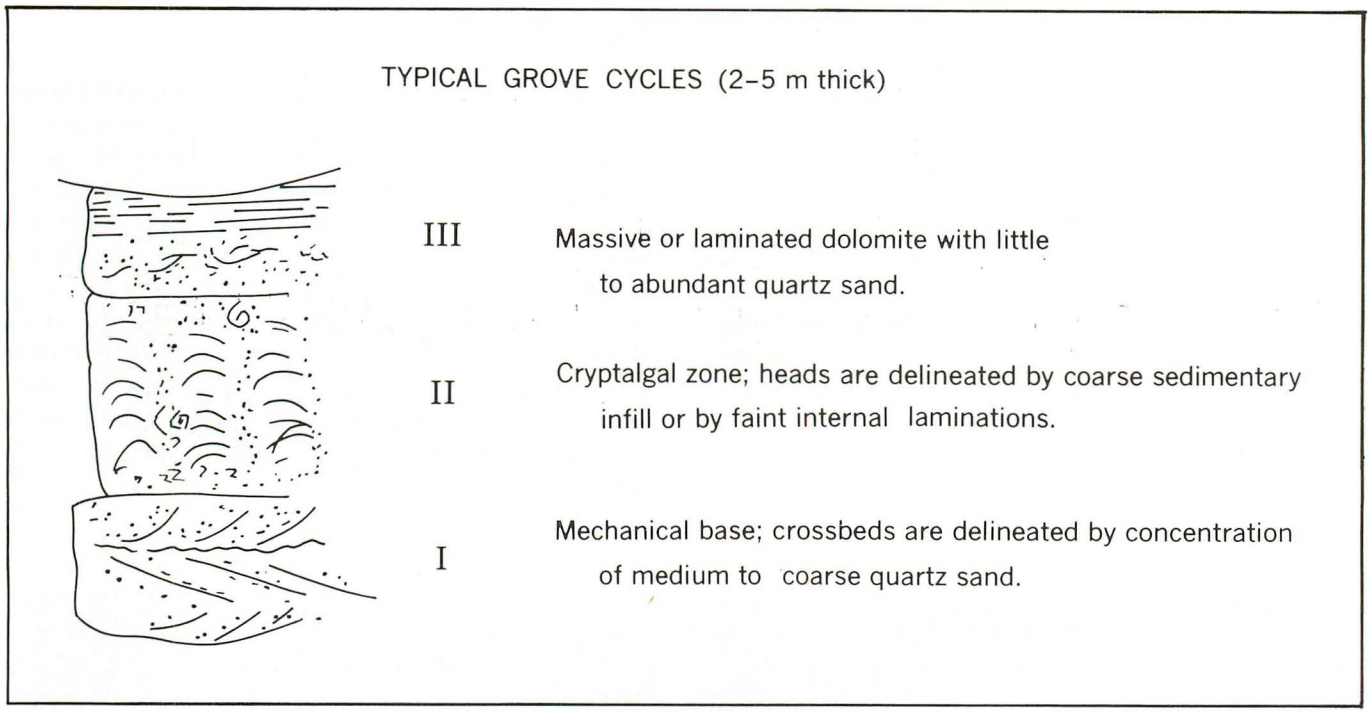


Figure 46.

The basal unit in each cycle (figure 46, unit I) is a cross-bedded pelsparite, which locally contains abundant, well rounded quartz sand. Highly variable current direction over a short vertical distance is documented by the herringbone cross-beds. The sets of cross-strata are 5 to 20 cm. high and are typically shallow troughs. Where strong cross stratification is not present, the coarse detrital limestone is structureless to planar bedded on a small scale. Flat to round pebble conglomerates are also associated with these mechanical limestones.

In well developed cycles unit I is 50 to 100 cm. thick with some variability in thickness along strike. Elsewhere this lithotype is commonly coarser grained, contains thicker sets of cross-strata (up to 50 cm.) and the cross-bedded pelsparite may be up to 5 meters thick. This type of deposit led to the concept of the basal sandy member (Ogq) of Jonas and Stose (1938).

A well defined stylolitic contact separates the basal mechanical limestone from a mottled, poorly bedded limestone (figure 46, unit II; figure 47). This intermediate unit is typically 1 to 3 meters thick and dominated by cryptalgal structures. Transitions from thrombolites or poorly laminated structures immediately above unit I to SH stromatolites are common (figure 43). Irregular beds from one to tens of centimeters thick, containing fenestrae composed of micritic dolomite and calcite spar, are included in the sedimentary fabric of the limestones. Severe recrystallization has obscured the internal fabric of some stromatolites. Thick unstructured beds composed of fossil debris, peloids and megaclasts are also included in this unit.

The cycle caps (unit III, figure 46) are either thickly bedded, massive dolomites or thinly bedded laminated dolomicrites. The range and variation in laminations and internal fabric is seen in figures 38 and 39. In outcrop these typically appear unstructured, especially since heavy lichen cover is common on dolomites. Laminations are non-planar; lenses and pods of coarse grained sediment are typically draped by thin laminations. These structures are characteristic of cryptalgal laminates (Aitken, 1967).

The composition, sedimentary structures and packaging of these cycles strongly resemble cycles described by Root (1968) from the Conochocheague Group (Late Cambrian) in Pennsylvania. The presence and repetition of these cycles indicates rapidly changing environmental conditions and/or close proximity of a number of environmental settings. The repetition of the cycles and the similarity of units from one cycle to the next indicates an overall constancy in subenvironments within the depositional basin. The environmental significance of each lithotype within these cycles is discussed in the following section.

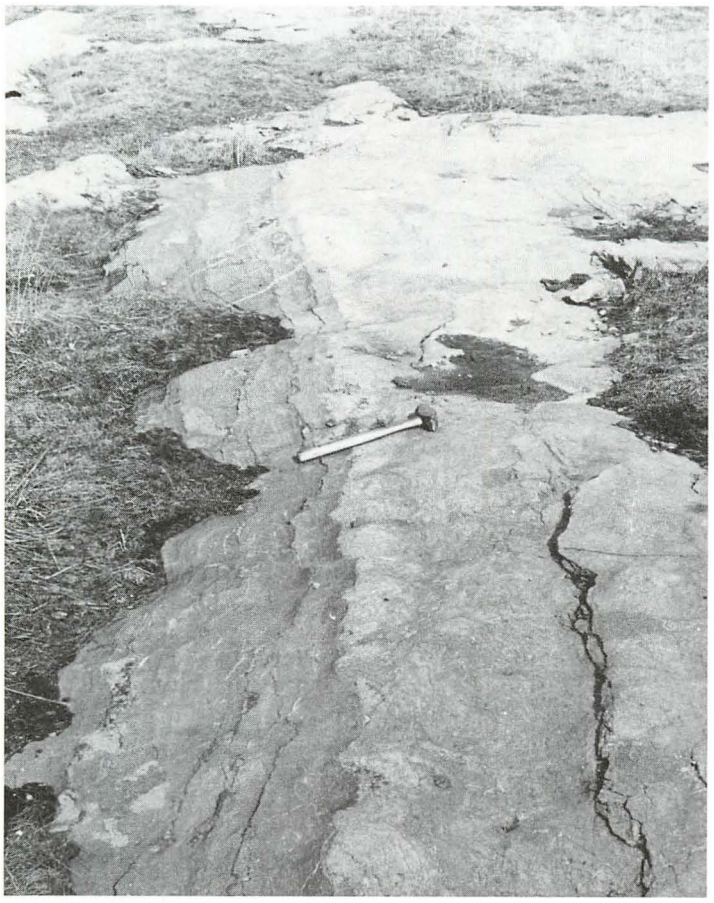


Figure 47.—Contact between basal and cryptalgal zones in the Grove Formation cycles shows some lateral persistence. The contact is stylolitic and somewhat irregular. At the extreme left are poor outcrops of the massive dolomites.

Lithologic Significance and Environmental Interpretation

Comparative sedimentology is a powerful tool in lithologic interpretation; it can be used with some confidence in analyzing the Grove Formation lithotypes and cycles. The lithotypes include many of the elements common to peritidal sediments: sand and oolite bodies, stromatolites, irregular laminates with rare mudcracks and flat pebble conglomerates.

Sand bodies, which would correspond to the basal unit of the Grove Formation cycles, have been well described from the Florida Bay and Bahama Platforms (Ball, 1967). These highly variable bodies are typically found at the break in slope at the edge of a platform or at the ends of embayments in less than 5 meters of water. Stratification of shallow water sand bodies includes 1) steep, tabular cross-strata with coarser grains at the base; 2) gently sloping, curved, tapering cross-strata and 3) flat, tabular strata which comprise avalanche and accretion sets (Imbrie and Buchanan, 1965). The stratification types from mega-ripples and bars are comparable to the sets in figure 40. A thick accumulation of such sands in some portions of the Frederick Valley, may be an indicator of the carbonate platform margin.

Stromatolites and thrombolites in the middle unit of the Grove cycle have Holocene analogues. In addition, descriptions of pre-Cambrian and early Paleozoic stromatolites abound in the literature; an abrupt decline of stromatolites during and after the Middle Ordovician is thought to be related to the expansion of grazing and browsing invertebrates (Garrett, 1970). In the geologic record and in modern environment stromatolites are commonly associated with shallow intertidal to supratidal environments. Black (1933), Geblein (1969), Logan (1961) and others have described a variety of algal stromatolites from the Bahamas, Bermuda, and Western Australia in subtidal to intertidal environments.

Small domes and biscuits formed by an interplay of oscillatoracian and filamentous algae, are found in 3-25 feet of water in Bermuda; form is controlled by current velocity (1-11 cm/sec) and sediment supply (8-60 gm/hr/foot) (Geblein, 1969). Intertidal forms on margins of tidal channels and in brackish water ponds are small SH and LLH domes formed by alternations of algal and sedimentary storm layers (Black, 1933; Monty, 1967; Ginsburg, et al, 1972).

Large, laminated head-shaped structures (up to 2.5 feet above the sediment surface) have been described from the intertidal zone (immediately above mean low tide) in a hypersaline lagoon, Shark Bay, Western Australia. These discrete algal structures best approximate the SH stromatolites of the Grove Formation in their internal structure, size and the coarse sedimentary infill of fossil debris, clasts and peloids. Tidal scour is the major influence on these stromatolitic forms.

By analogy the range of water depths in which the SH stromatolites in the Grove Formation could have formed is limited to the shallow subtidal and intertidal. The presence of abundant, discrete algal structures and coarse sedimentary infill indicates considerable tidal scour and abundant sediment supply. These conditions most closely approximate the Holocene stromatolites and intertidal setting of Shark Bay.

Figure 48.—Modern algal laminate from the levee backslope zone, Sugarloaf Key, Florida. Discontinuous lenses of coarse detrital carbonate and continuous, draping laminations are the diagnostic features. Large vugs (bird's eyes or fenestrae) result primarily from mangrove roots. Thin, non-planar horizontal partings result at algal-sedimentary contacts. Vertical breaks result mainly from the drying of the sediment prior to impregnation. Bar = 1.0 cm.

The dolomitic cap in the Grove Formation cycles is massive, thickly or thinly bedded and is laminated to structureless. Harris (1973) has pointed out that Cambro-Ordovician dolomites need not be regarded as evidence of supratidal sedimentation merely because minor amounts of penecontemporaneous dolomite are present in Holocene supratidal sediments (Illing et al, 1965; Shinn et al, 1965; Shinn, 1968). The laminated structures in the dolomites (figure 38) do, however, have modern analogues. Kendall and Skipwith (1968) and Davies (1970) have demonstrated strong algal mat zonation in the Persian Gulf and Shark Bay respectively. Flat or smooth to crinkled and tufted algal mats seem to result from an interplay of desiccation, sedimentation and algal mat composition.

A similar algal zonation is present on Sugarloaf Key, Florida (Reinhardt, Hardie and Hepp, in manuscript). Comparison of an algal laminate (figure 48) from the levee backslope zone (an area wetted briefly diurnally) with the coarse laminate (figure 38) shows identical coarse granular lenses (resulting from storm lags) and closely spaced draping laminations. The micritic laminates (figure 39) have no convincing analogues in Florida Bay, but preferential trapping of fine sediment by oscillatorian algae involved in planar or flat mats has been documented (Monty, 1967; Geblein, 1969). The mud cracks (figure 39) indicate intermittent exposure, and fenestral fabrics have been used as indicators of intertidal to supratidal conditions (Ham, 1954; Tebbutt, et

al, 1965; Shinn, 1968).

The pattern demonstrated in the Grove Formation cycles represents sedimentation in rapidly changeable environments. By comparison with sedimentary structures in modern tidal flat settings, the sedimentary structures within each sedimentary cycle appear to record progressively shallowing water. The juxtaposition of sand bodies in the subtidal to intertidal and algal laminates in the intertidal and supratidal in modern environments, as a result of changing sedimentation patterns, circulation or sea level fluctuations are the key to understanding the Grove Formation cycles. Although portions of the Grove Formation may have been deposited in 10 or more meters of water, we can conclude with some certainty that a major portion of the Frederick Valley was under conditions of shoaling water during the early part of the Lower Ordovician.

BASIN EVOLUTION: SYNTHESIS AND SUMMARY

During the late Lower and Middle Cambrian the Frederick Valley was a marine sedimentary basin accumulating non-carbonate mud and silt. The general absence of sedimentary structures in the Araby Formation makes assertions about the depositional environment somewhat speculative. Subspherical tubular structures and the mottled appearance of the sediments suggest biogenic reworking and a low sedimentation rate. The depth of the basin is uncertain, but it was certainly below wave base, based on the absence of current structures and the fine grained-high matrix sediment. The high K/Na ratio of these rocks and regional paleogeographic relationships indicate a western sediment source.

The transition from silicaclastic to carbonate sedimentation appears to be gradational and approximates the Middle-Upper Cambrian boundary (base of the Rocky Springs Station Member). The carbonates are characterized by thinly bedded, laminated micrites and massive, peloidal or megaclastic carbonates which lack current structures and biogenic activity. The sediments and sedimentary structures indicate a low energy accumulation site which received episodic impulses of sediment from an adjacent high energy carbonate platform. Directional indicators, such as aligned and imbricated blocks in breccias, give a strong east-west to northwest-southeast trend. Comparison of clast size in the eastern and western limbs of the syncline suggests that the source area was to the west.

The overlying sediments of the Adamstown Member contain abundant current structures in fine grained carbonates and lack the coarse carbonate input of the Rocky Springs Station Member. The breccia-conglomerate zones are considered largely tectonic, but may include intrabasinal slumps. Only a minor amount of the sediment (pisolites, coated grains) suggests an extra-basinal origin. In addition to the increased current energy within the basin there is an increase in biogenic activity. Inclined and open spiral burrows are locally abundant, as are the early Trempealeauan brachiopod, pelmatozoan and trilobite faunas.

The biologic component again increases within the Lime Kiln Member section. Abundant fossil hash, burrow structures and, at the top of the sequence, cryptalgal structures are indicators of relatively shallow water sedimentation. Accompanying these changes is the first indication of cyclic sedimentation. Since most of the Lime Kiln lacks stromatolites, the bulk of the sedimentation is thought to have occurred in the subtidal zone, in perhaps 20-50 meters of water.

The transition to the high energy, strongly cyclic sedimentation which characterizes the Lower Ordovician Grove Formation represents a change from upper slope to platform conditions. Similarity between Recent models and the Grove Formation cycles provides strong evidence of shallow subtidal to supratidal conditions.

The overall trends from the base to the top of the carbonate section in the Frederick Valley are increases in current energy, biological components and lateral and vertical lithologic variability. The current energy is reflected in primary bedding structures which change from planar lamination and ripple cross-laminations in the Frederick to trough and planar cross-beds in the Grove. The change from unburrowed sediments in the Rocky Springs Station to thoroughly mottled sediments in the Lime Kiln Member and Grove Formation and a corresponding increase in the number and diversity of body fossils indicates a dramatic shift in the faunal communities. This change is accompanied by the presence of stromatolites at the very top of the Frederick and throughout the Grove Formation. All of the evidence strongly indicates one large-scale shallowing upward sequence. Although we have positive evidence that the upper third of the sequence represents shoaling water sedimentation, there are no bathymetric indicators for the bulk of the section. The sediments included in the Frederick Formation seem to fit Wilson's (1969) criteria for "deeper water" limestones.

Due to the absence of carbonates in the South Mountain Anticlinorium, it is difficult to construct an actual shelf-basin configuration throughout the Upper Cambrian to Lower Ordovician, but the slope facies was probably the portion of the off-shelf sedimentation represented in most of the Frederick Formation. A model proposed by Asquith (1970) relies on the thickness of slope sediments to estimate basin depth. If only half of the Frederick actually represents slope deposition, the remainder being basinal and perhaps a small amount of platform sedimentation at the top, the depth of water was about 450 meters; 400-800 meters of water is a conservative range of maximum basin depths. This suggests a wide shallow basin model rather than a geosynclinal setting as seen in various allodapic limestones or bioclastic turbidites (Meischner, 1965; Thompson and Thomasson, 1969).

PALEOGEOGRAPHY: REGIONAL FRAMEWORK

Cambro-Ordovician Valley and Ridge Stratigrapy

There is general agreement about the stratigraphic framework of the Cambro-Ordovician sections west of the Blue Ridge in Maryland, Pennsylvania, West Virginia and Virginia (Stose, 1906, 1908; Butts, 1940; Cloos, 1951). Precise time and facies correlations of the stratigraphic units involved is often impossible due to poor exposures, low faunal content and/or a general absence of detailed stratigraphic study on a regional scale. Recent stratigraphic work by Root (1968) in Pennsylvania, and Butts and Edmondson (1966) in northern Virginia, plus stratigraphic compilations by Wilson (1952), Donaldson (1969) and Colton (1970) give the regional relationships for stratigraphic units from the Valley and Ridge westward to the Plateau. The stratigraphy has been summarized in Table 4 and the lateral relationships are presented in the regional cross-section (figure 49).

The basal clastic sequence above the Precambrian basement and volcanics consist of late Precambrian and Lower Cambrian conglomerates, sandstones and shales of the Chilhowee units (Butts, 1940; King, 1950). All of the Chilhowee units (London, Weverton, Harpers, Antietam) were first described by Keith (1892). The remaining stratigraphic units were named Tomstown, Waynesboro, and Elbrook (Stose, 1906), and Conochocheague and Beekmantown (Stose, 1908). These comprise the 4250 meter (14000 foot) section of carbonates (~75%) and clastics (~25%) in the Great Valley section.

Table 4.—Great Valley Stratigraphy

	Root (1968) Franklin County, Penna.	Butts and Edmundson (1966) Frederick County, Virginia	AGE	DESCRIPTION
BEEKMANTOWN GROUP	Pinesburg Station (450 ft.)			Light colored, thick bedded, finely laminated dolomite; includes limestone.
	Rockdale Run (2500 ft.)	BEEKMANTOWN FM. (3000-3500 ft.)	LOWER ORDOVICIAN	Mostly limestone, some dolomite interbeds. Mechanical and stromatolitic; chert.
	Stonehenge (775 ft.)			Stromatolitic and fine mechanical limestones.
	Stoufferstown (260 ft.)	CHEPULTEPEC FM. (500 ft.)		Coarse mechanical limestones with dark gray argillaceous seams.
CONOCOCHEAGUE GROUP	Shady Grove (650 ft.)	CONOCOCHEAGUE FM. (2000 ft.)	UPPER CAMBRIAN	Pure light colored limestones, stromatolitic in part. Abundant pinkish limestones and cream colored cherts.
	Zullinger (2500 ft.)			Cyclically bedded, stromatolitic-mechanical limestone, interbedded limestone and dolomite. Thin quartz sand beds.
	ELBROOK FM. (±3000 ft.)	ELBROOK FM. (3000 ft.)	MIDDLE CAMBRIAN	Light colored, calcareous shale and argillaceous limestone. Limestones and dolomite in middle-ridge former.
	WAYNESBORO (1000 ft.)	ROME (1700 ft.)		Thin basal and upper red sandy units. Middle portion is limestone.
	TOMSTOWN (1000 ft.)	SHADY (1000 ft.)	LOWER CAMBRIAN	Dolomitic limestone to limestone in upper part. Mottled silty dolomite.
	ANTIETAM (500-800 ft.)	ERWIN (800 ft.)		White, coarse grained quartzite. Skolithus tubes and L. Cambrian fauna.
	HARPERS (2700 ft.)	HAMPTON (900 ft.)		Dark banded, hackly schist to slate with prominent quartzite in middle.

Lithologic Interpretation

Schwab (1970, 1971) has studied the Harpers (Hampton) and Antietam (Erwin) in Virginia and interpreted them as a sequence of marine clastics derived from a cratonic source area. The NW-SE paleoslope is indicated by a thinning to the west and by paleocurrent data from the Antietam (Schwab, 1970). This is consistent with earlier paleocurrent measurements by Whitaker (1955b) in the Weverton. The Antietam represents shallow water, nearshore deposition, which is followed by a marine transgression over a topographically reduced craton (Schwab, 1971).

The onset of this transgression is marked by deposition of Tomstown Dolomite, predominantly carbonate but with abundant coarse quartz sand derived from the craton. Following Tomstown deposition Grabau (1936), Rodgers (1970) and others find strong evidence for a major marine regression in the mixed carbonate-siliciclastic Waynesboro Formation. Abundant mud cracks and evaporite molds in red shales and mudstones indicate subaerial exposure during part of this time. A renewed clastic influx from the west might also account for the change in sedimentary features from Tomstown to Waynesboro Formations.

The Middle and Upper Cambrian Elbrook and Conochocheague represent the onset of stable platform carbonate sedimentation in the Great Valley. Laminated micrites, stromatolites, flat pebble conglomerates and cross-bedded carbonate sands are the dominant sedimentary facies; these are packaged into well defined sedimentary cycles recognized by Pelto (1942), Tasch (1951), and Root (1964) in the Gatesburg, Warrior and Conochocheague Formations respectively. These cycles are similar in composition and scale to the Grove cycles described in a previous section.

The most detailed stratigraphy, paleontology and environmental interpretation of the Cambro-Ordovician limestones has focused on the Lower Ordovician Beekmantown Group (Folk, 1952; Sando, 1957; Donaldson, 1959, 1969; Hobson, 1963). Cycles are not as well developed throughout the Beekmantown, but all the lithofacies diagnostic of a tidal flat sequence are present. This pattern of sedimentation continues in the Middle Ordovician as seen in the St.Pauls Group (Matter, 1967).

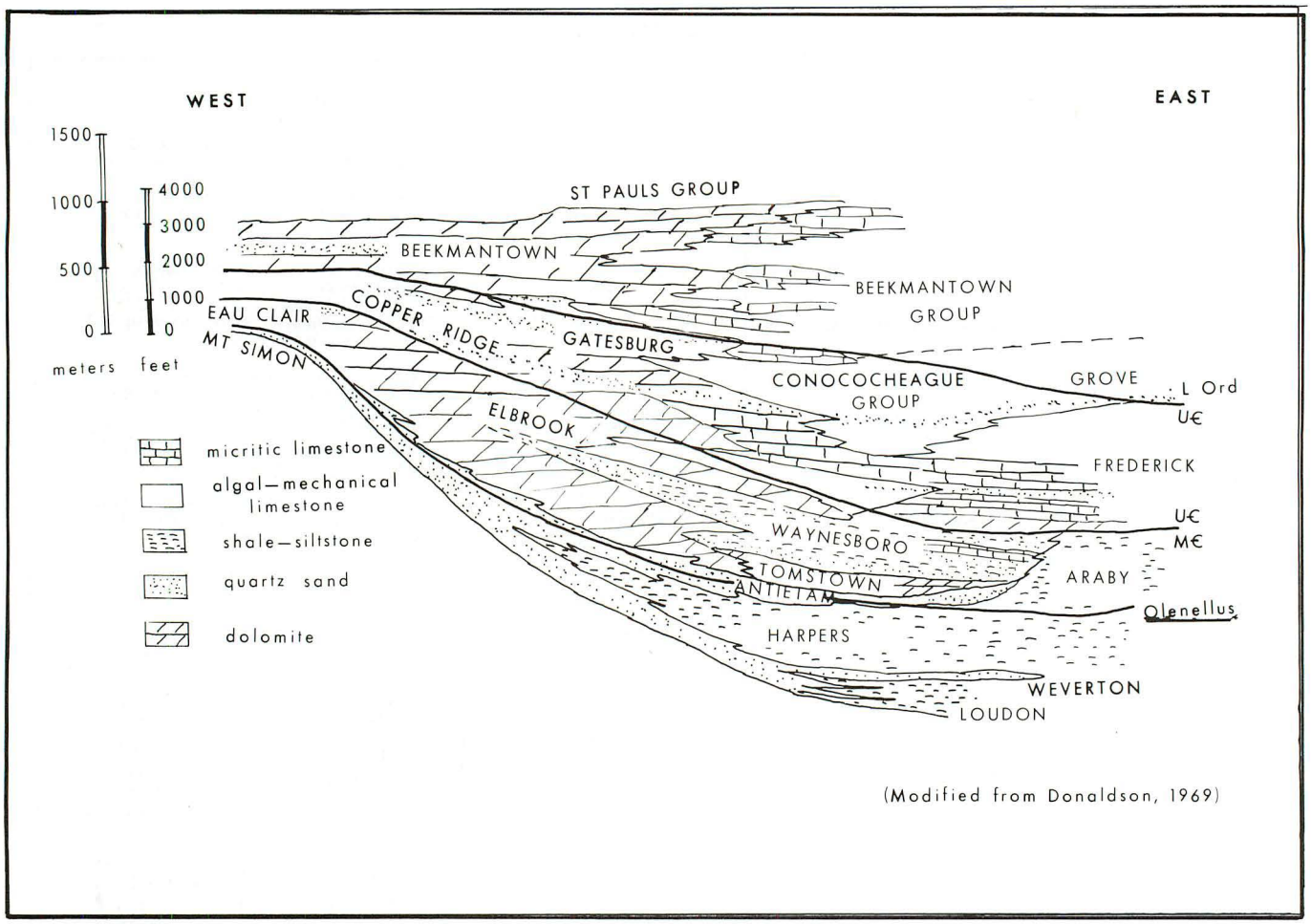


Figure 49.—Schematic cross-section from western West Virginia east to the edge of the Great Valley. Data from the Frederick Valley has been added, but does not intend to represent a complete east-west section. Araby is overly thick, since the underlying phyllites may represent the same lithofacies.

Regional Relationships

A regional lithofacies pattern for the Upper Cambrian was first proposed by Wilson (1952). Three principal facies, dolomite-sandstone, limestone and platy limestone-shale, were documented from subsurface data in the Plateau and well and outcrop data in the Valley and Ridge and the Frederick Valley. His isopachous map showed an eastward thickening lens of sediment analogous to the configuration in figure 49.

Palmer (1971) has proposed a model with gross sedimentation patterns to represent the lithofacies belts seen in the Cambrian rocks throughout the Appalachians. Four, more or less contemporaneous, lithofacies are recognized: an inner detrital belt, a carbonate belt and a two-fold outer detrital belt. The inner detrital belt is composed primarily of clastic sediments derived from the craton (Chilhowee Group, Waynesboro, Gatesburg). The carbonate belt is represented by the thick platform carbonate sequence (Elbrook Formation through St. Pauls Group and the Grove Formation). The outer detrital belt is composed of sediments accumulating seaward of the carbonate bank (Frederick Formation) plus graywackes and volcanics east of the Martic Line (Western Piedmont lithologies).

Western Piedmont Stratigraphy

The rocks of the western Piedmont are predominantly argillaceous phyllites and impure quartzite with subordinate amounts of greenstone and marble (Table 5). The stratigraphic relationships between these rocks and the Cambro-Ordovician rocks to the west have always been problematic. Jonas (1924) originally regarded these rocks as Precambrian and mapped the boundary with the lower Paleozoic rocks as the Martic Thrust. Later, she (Stose and Stose, 1946, p. 83) suggested that the western

Piedmont rocks could be Lower Cambrian to Ordovician. More recent work (Weaver., 1954; Scotford, 1951; Thomas, 1952; Wise, 1970; Brown, 1970; Fisher, Higgins and Zietz, 1972; Higgins, 1972) has all tended to favor a Cambro-Ordovician age for these rocks, implying that the lithologic differences between the Frederick Valley and the western Piedmont reflect lateral facies changes. Hopson (1964, pp. 128-131) favored a Precambrian age and an eastern source area for virtually all of the western Piedmont lithologies, suggesting that deposition of Piedmont rocks preceded deposition of the Chilhowee Group (western source area).

Recent work by Fisher (oral communication, 1972) has established the stratigraphy shown in Table 5. The sequence of Sugarloaf, Urbana, Ijamsville and quartzite is thought to correlate with the Chilhowee rocks to the west. The stratigraphy is capped by Sams Creek Metabasalt overlain by contemporaneous Silver Run Limestone and Wakefield Marble. The albite-chlorite phyllites of the Wissachickon Formation intertongue with the Ijamsville Phyllite. J. Edwards (oral communication, 1974) has offered an alternative stratigraphy: a volcanic unit composed of interbedded metabasalt and tuffaceous phyllites and containing lenses of marble (Wakefield) is overlain by Ijamsville Phyllite; the Silver Run Limestone caps this sequence.

These lithologies are similar in their stratigraphy and map pattern to the rocks of the Evington Group in the James River synclinorium, central Virginia. This 3050 meter (10,000 feet) sequence of metasediments has been studied by Brown (1941, 1953), Espenshade (1954) and Redden (1963). The stratigraphy of Candler phyllite and schist, Archer Creek graphitic schist and gray marble, Mount Athos quartzite schist and marble, and greenstone from bottom to top is rather well established except in the southern district where the greenstone appears to underlie the Mount Athos (Brown, 1953; Redden, 1963). The lithologic similarity between Ijamsville-Candler, Silver Run-Archer Creek gray marble and Wakefield-Mount Athos marble are striking (Espenshade, oral communication, 1972).

An attempt to correlate the Evington Group with the Glen Arm Series in Maryland and Pennsylvania by Furcron (1935) is similar to the correlation made by Jonas and Stose for the eastern and western Piedmont of Maryland. Brown (1970) has correlated the Evington Group with the Cambro-Ordovician sequence of the Valley and Ridge.

Table 5.—Western Piedmont Stratigraphic Interpretations

	Espenshade (1954); Brown (1970) Evington Group, Central Virginia	Fisher (1972) Carroll County, Maryland	Hopson (1964); Jonas & Stose (1938) Howard-Montgomery; Carroll-Frederick Counties, Maryland
ORDOVICIAN	Slippery Creek Greenstone (1000 ft.)	Silver Run Ls. Wakefield Marble Sams Creek Metabasalt	
CAMBRIAN	Mount Athos Formation (50-900 ft.) Archer Creek Formation (50-900 ft.) Candler Formation (3000-5000 ft.)	quartzite Ijamsville Phyllite (blue-purple) Ijamsville Phyllite (tan-buff) Wissahickon Fm. (western facies) Urbana Phyllite Sugarloaf Quartzite	Chilhowee Group Sugarloaf Quartzite Urbana Phyllite
LATE PRECAMBRIAN			Sams Creek Metabasalt Wakefield Marble Ijamsville Phyllite Wissahickon Formation (western facies)

Lithologic Interpretation

The rocks of the Evington Group are thought to represent deep water marine deposition based on the abundance of thin rhythmic lamination (Brown, 1970). The sedimentary sequence begins with the deposition of clastics from both the Chilhowee shelf and from the east during the late Precambrian to Lower Cambrian. The balance of the Evington Group was deposited between Middle Cambrian and Middle Ordovician as off-platform deep water deposits (Brown, 1970).

The paleogeographic model of Fisher (oral communication, 1973) depicts a volcanic island-clastic basin complex. The Ijamsville phyllites represent the starved clastic basin which received sediment predominantly from the west and intertongues with western facies Wissahickon, which has an eastern clastic source. The Sams Creek metabasalt represents volcanics, which are topped by a paleosol, indicating subaerial conditions, and by the Wakefield Marble, which contains diagnostic shallow water features: cross-bedded oolites and headshaped stromatolites (Fisher, oral communication, 1972). Between the Frederick Valley carbonates and the outcrop belt of the Wakefield Marble lies the highly argillaceous, laminated Silver Run Limestone. Fisher favors a local carbonate derivation from the Wakefield Marble highs; and alternative would be that the Silver Run is the off-platform equivalent of the Grove Formation.

Paleogeographic Models

A synthesis of the data gathered from recent work of others in the Valley and Ridge and western Piedmont plus the data presented from the Frederick Valley results in a relatively complete paleogeographic model for the Cambro-Ordovician of the central Appalachians. The time relationships for the western Piedmont rocks are obviously inferred, but no serious conflicts arise from the paleogeographic scheme presented in figure 50. It should be noted that a strong similarity exists between the lithologies and the paleogeographic model discussed here and the model of Zen (1967, 1972) for the northern Appalachians.

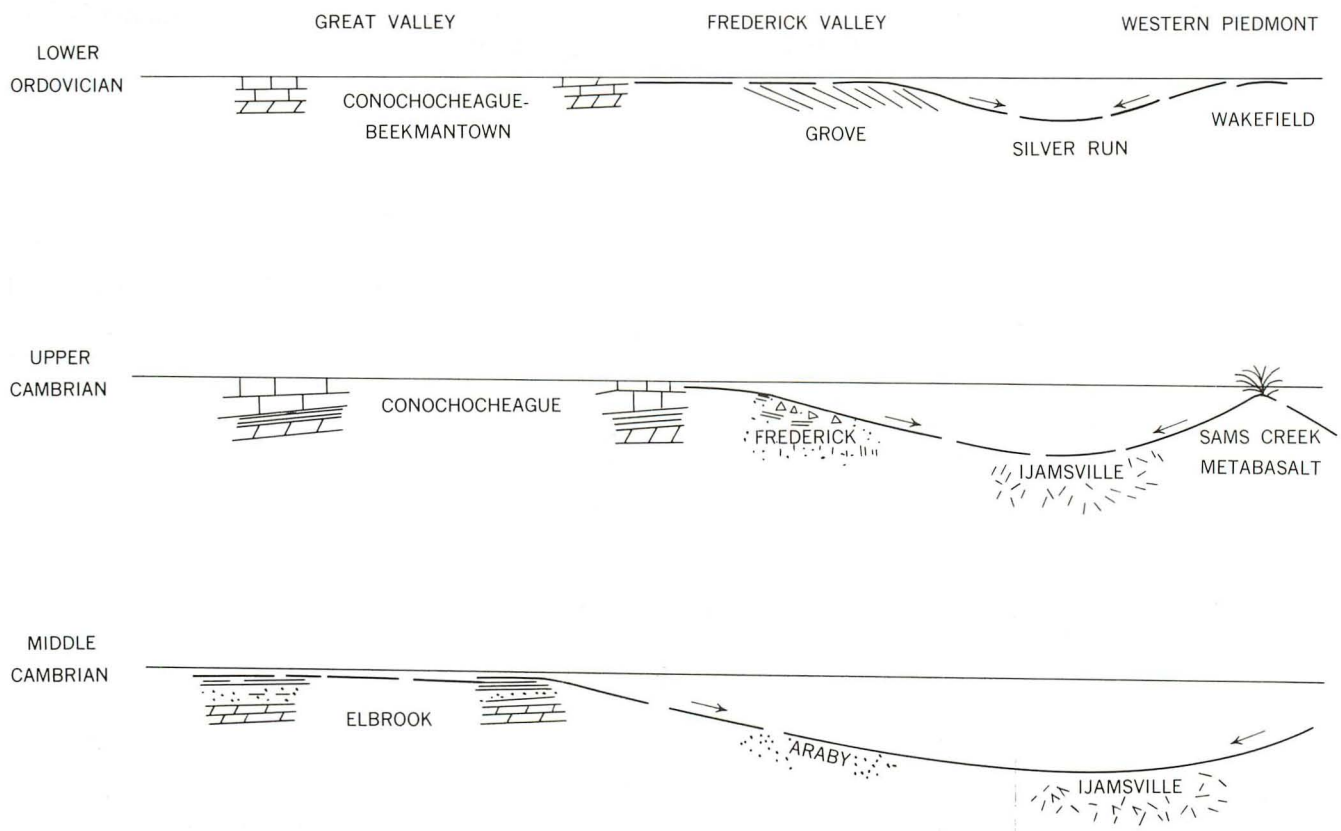


Figure 50.—Paleogeographic sketches for three points in time. The Blue Ridge Province (South Mountain anticlinorium) and the "Martic line" have been eliminated. Arrows indicate direction of clastic sediment influx.

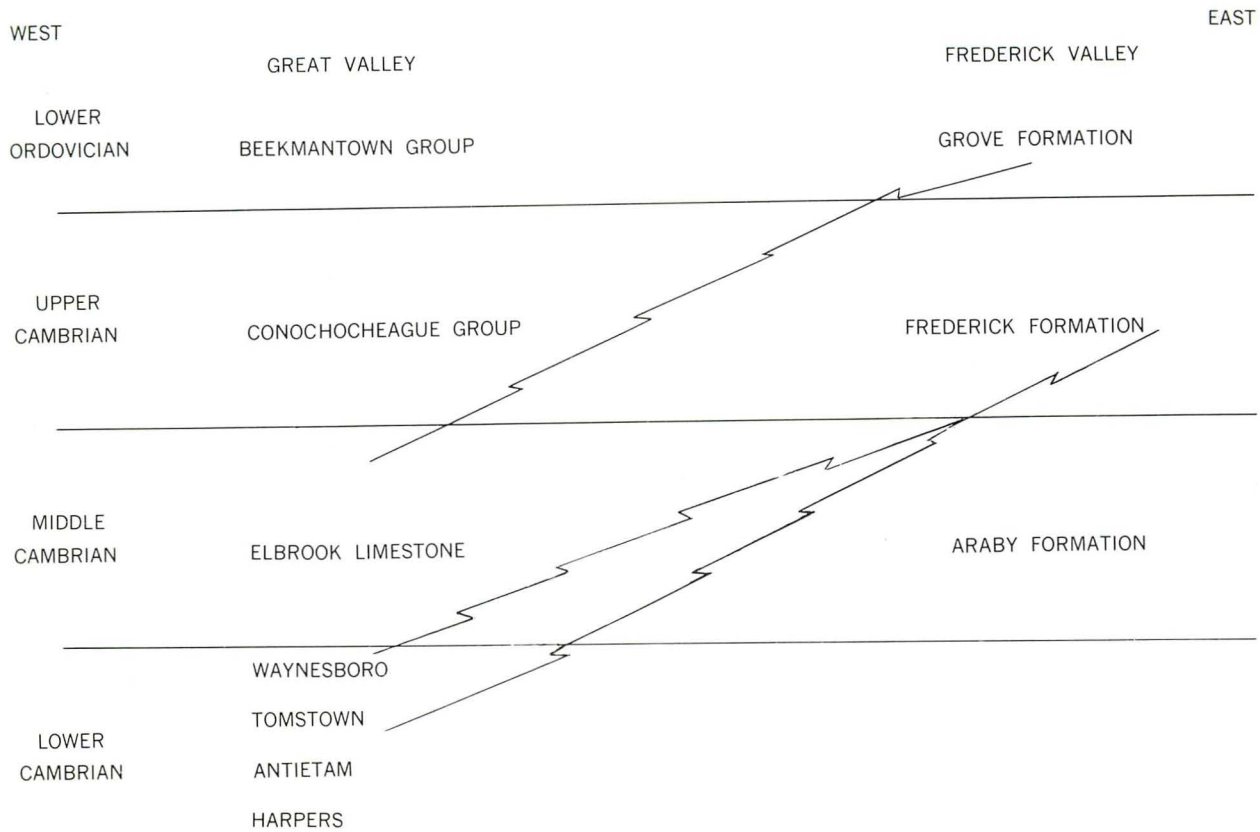


Figure 51.—Schematic lithofacies relationships for the Great Valley and Frederick Valley. Lower line marks the siliciclastic carbonate boundary; the top line marks transition from predominantly micritic to algal and mechanical limestones. Lithofacies show time transgressive relationships, becoming younger to the east.

During the Lower and Middle Cambrian clastic sediments derived from the craton were gradually reduced to a point where carbonates were deposited and a broad, relatively stable, carbonate platform was developed. The carbonate is predominantly fine grained and is packaged in thick sequences of thinly bedded limestones and dolomites. Seaward of these carbonates in the Frederick Valley and farther east was a basin accumulating non-carbonate silts and muds. This basin probably received fine grained clastics from both an eastern source area, as well as the craton and reworked sediments from the west.

The carbonate platform enlarged and began to contribute carbonates to the basin as far east as the Frederick Valley at the beginning of the Upper Cambrian. Fine grained non-carbonates were still being deposited in the western Piedmont during this time, while the onset of volcanic activity occurred farther east.

The Lower Ordovician carbonates represent the maximum extent of the Cambro-Ordovician platform development seen in the central Appalachians. The Frederick Valley carbonates are part of the major carbonate bank which continued across the Valley and Ridge and Plateau provinces, a platform about 1000 kilometers wide, assuming 50% crustal shortening. The contemporaneous platform carbonates of the western Piedmont are isolated, built on local volcanic highs and the intermediate, clastic carbonates are derived from either or both platforms.

The progradation of the carbonate platform eastward from Middle Cambrian to Lower Ordovician time is best documented by the changing lithofacies in the Frederick Valley. The facies migration has been schematically illustrated in figure 51. The siliciclastic boundary is Lower-Middle Cambrian in the Great Valley section and Middle-Upper Cambrain in the Frederick Valley. This model of Walther's law of adjacent facies adds to the previous sedimentological arguments for a gentle slope, rather than a sharp platform-basin transition. The stratigraphic column in the Frederick Valley simply represents migration of depositional facies from an off-shore "deep water" clastic basin to a shoaling carbonate shelf. Since progradation has taken place into a relatively shallow basin, it is unlikely that this area

represents the Cambro-Ordovician continental margin as suggested by Rodgers (1968). The actual configuration and distances between the carbonate platform and the western Piedmont at any time are quite uncertain due to intricate folding, tectonic thinning and/or westward moving thrust faults.

It has not been determined whether this low relief platform-basin configuration is the general rule for the Cambro-Ordovician Appalachians. In the Conestoga Valley section immediately along strike in southeastern Pennsylvania and in the Taconic sequence of eastern New York and western Vermont Rodgers (1968) has made a case for an abrupt break in slope indicated by stratigraphic unconformities and extensive slump breccia deposition. Both of these areas are structurally complex, especially in the case of the Conestoga Valley, where age relationships in the rocks are quite uncertain; careful examination of the limited outcrop is necessary before either model can be applied. Preliminary indications from the literature (Stose and Jonas, 1936; Cloos and Heitenen, 1941; Weaver, 1954; Wise, 1970) and the field relationships suggest that the Conestoga limestone may consist of several units, lithofacies and ages within the Hanover-York-Lancaster Valley, Pennsylvania.

Identification of Cambrian lithofacies and biofacies by Palmer (1971) has presented the broad picture for the Appalachians and the Cordillieren sequence. Off-shelf limestones in the Appalachians should be examined more rigorously, especially where these can be readily related to carbonate platform sequences. Comparison with the sedimentology of the Cordillieren sequence might establish the relative importance of eustatic and tectonic events and the symmetry in sedimentation around the carbonate platform during the Cambrian.

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APPENDICES A and B

APPENDIX A: GEOLOGIC SECTIONS

PART I

During the 1972 field season three major traverses were made across the Frederick Valley to establish comparative stratigraphic sections and to confirm the structural interpretations made during previous mapping. The presentation of typical, as well as type sections, for the stratigraphic units follows the example of Sando (1957) and others in presenting detailed stratigraphic descriptions from field localities. Sketch maps with outcrop locations are included. These are in a loose sense measured sections as well as cross-sections for portions of the Frederick Valley.

An attempt was made to measure sections in the eastern portion of the syncline, but the poor exposures and tight structure led to difficulties in measuring a section which would show much detail or certainty. All measurements were made in feet with a 25 foot tape. The true stratigraphic thicknesses were calculated from small traverses.

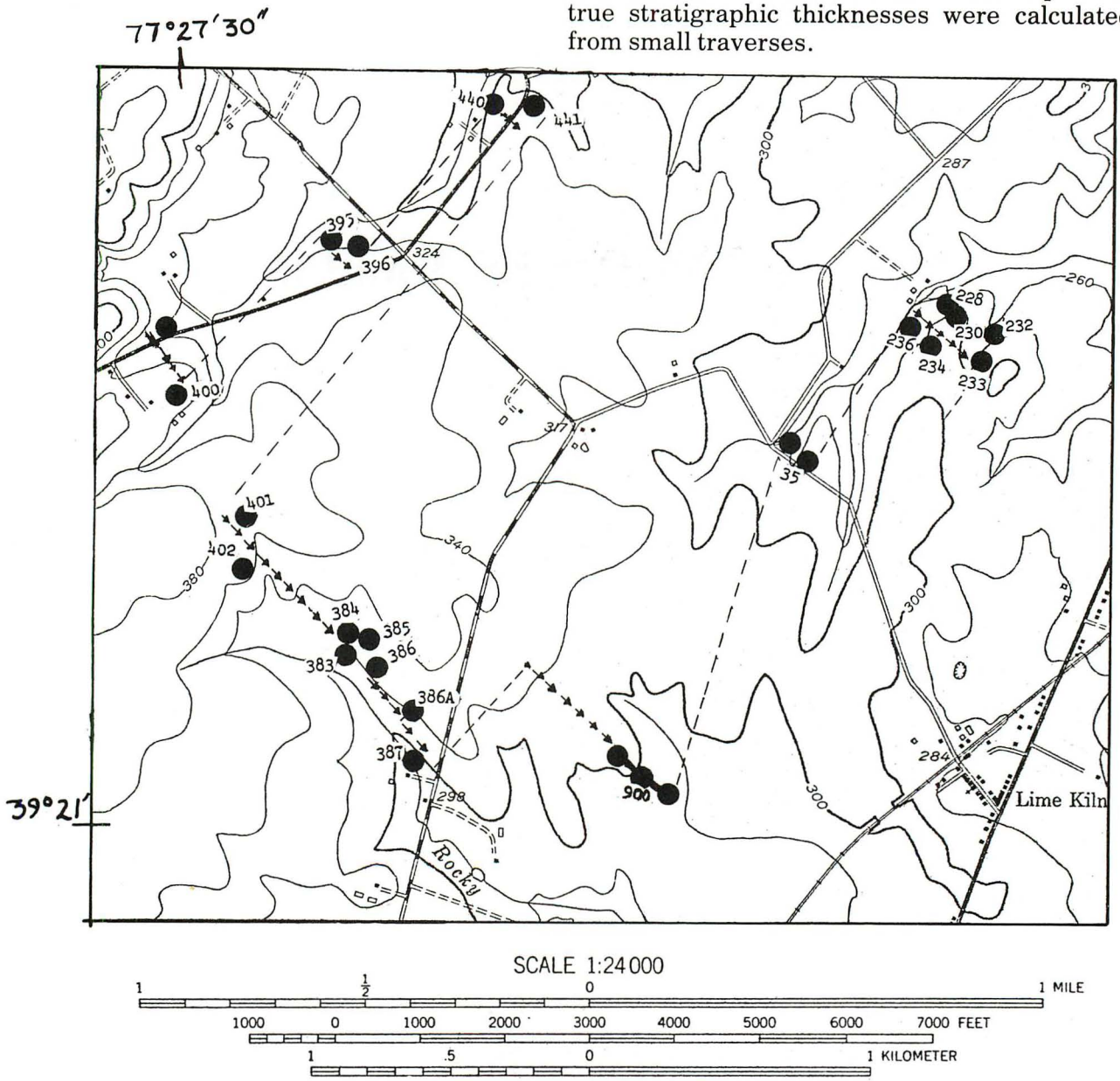


Figure 52.—Sketch map showing traverse for section I. This section includes the type sections for the Adamstown and Lime Kiln Members of the Frederick Formation. Critical outcrops are indicated by black dots; numbers correspond to the descriptions which follow.

SECTION I. Location: West of Lime Kiln, Maryland

Beginning in the most complete section of Adamstown member of the Frederick Formation near the Triassic onlap, the section proceeds upward through the completely exposed Lime Kiln Member and into the Grove Formation.

LOCALITY	DESCRIPTION		THICKNESS M.	FT.
398	Thinly bedded, medium-light gray limestone. Beds are 2-4 cm. thick, laminated near top of bed. Partings are dolomitic.		1.5	5
	COVERED SECTION	Est.	10.0	33
395-396	Polymictic breccia; clasts are predominantly 2-10 cm. long, slightly elongate and composed of micritic limestone. Virtually no matrix to 10% locally (dolomite).		4.7	15.5
	COVERED SECTION	Est.	5.0	16.5
440	Flaggy laminated limestone. Beds are 3-5 cm. thick at base to 1-2 cm. at top of outcrop.		2.1	7
	COVERED SECTION	Est.	50	165
384	Coarse granular limestone; (no quartz sand) peloids to small mega-clasts 1 cm. across and random dolomitic patches.		5.1	17
	Covered (1.2 m)			
	Polymict breccia; flaggy clasts up to 15 cm. across at top. Most clasts are 3-5 cm. across; more granular with more matrix at base; more flaggy limestone and less matrix at top.			
	COVERED SECTION		1.5	5
384	Very coarse granular, light gray limestone; some peloids have oolitic coatings; scattered lime clasts 3 cm. across.		3.03	10
	COVERED SECTION		3.03	10
383	Poorly exposed patches of peloidal limestone similar to 385.		4.55	15
385	Light to medium gray, massive peloidal limestone. Locally veined by coarse sparry calcites.			
	COVERED SECTION		4.55	15
385A	Granular, massive limestone; some peloids have dolomitic coatings.		6.65	22
	Medium gray massive limestone; abundant peloids with dolomitic cores.		3.74	12
	COVERED SECTION		7.71	25.5
385B	Polymict breccia: Base of unit contains small equant clasts up to 3 cm. across. About 2.2 m. from base granular matrix is lost and clasts (15 cm. across) are joined along stylolitic contacts. In-- creased amounts of dolomicrite matrix in irregular patches toward top of section.		8.76	29
	COVERED SECTION		25.8	85
386	Breccia with dolomicrite matrix; clasts are sheared.		.91	3.0
	COVERED SECTION		3.03	10
	Polymict breccia; grades from highly deformed breccia clasts separated by little matrix to highly granular breccia with smaller and sparser coated clasts at top.		6.05	20
	COVERED SECTION	Est.	60.5	200
386A	Thinly bedded, flaggy, medium gray limestone; dolomitic partings. Slickensides on bedding planes.		2.4	8
	COVERED SECTION	Est.	90.8	300
900	Very thinly bedded (1-2 cm) medium to dark gray limestone; argillaceous interbeds (1 cm). Dolomitic argillaceous wisps along cleavage. Local crinkle folds and slickensides are abundant.		62.2	205
900.1	Medium gray, well bedded limestone; beds are 1 cm. thick. Lamination in thickest beds near top.		10.68	35
900.2	Massive, light gray limestone with only a few argillaceous partings becomes thickly to thinly bedded from top to bottom of zone.		15.29	50
TOTAL ADAMSTOWN MEMBER IN SECTION I:			399.2	1318.5
900.3	Massive bed with argillaceous wisps composed of fossil debris in micritic matrix.		0.24	0.8
	Very thinly bedded, flaggy limestone; medium to light gray with maximum bed thickness of 1 cm. defined by argillaceous partings. Thin limestone beds with argillaceous partings become massive beds with abundant dolomitic laminae.		8.0	26.4
900.4	Thick granular beds with pelmatozoan columnals (quartz sand-silt?).		.61	2.0
	Medium gray, laminated limestone; good flaggy beds at base.		1.67	5.5
900.5	Thick bed composed of micrite; absence of bedding features.		.61	2.0
	Well laminated limestone, beds distinct toward top, laminations are segregated into 2 cm. bands.		3.96	13.0
	Medium-light gray limestone with good argillaceous partings at top become wispy dolomitic laminations at the bottom.			

LOCALITY	DESCRIPTION	THICKNESS M.	THICKNESS FT.
	Medium gray micritic limestone; widely spaced argillaceous bands.	3.05	10.0
900.6	Thick bed of fossil hash-- micritic matrix; irregular dolomitic patches.	.45	1.5
	Thinly bedded limestone contains incipient boudines; thick argillaceous partings.	1.08	3.5
	Very thinly bedded (1-2 cm.) light to medium gray limestone; peloidal and fossil hash horizon (3 cm. thick).	4.57	15.0
	Flaggy limestone; good lamination at base with wispy dolomitic horizons.	3.05	10.0
	Thinly bedded limestone with thin argillaceous interbeds; sparse burrow structures.	3.66	12.0
900.7	Thickly bedded, light gray limestone; granular with sparry patches, fossil hash?. Grades to thinly bedded, micritic calcite at top of section.	3.96	13.0
	Thinly bedded (2 cm. thick) limestone with argillaceous interbeds; thin beds show delicate laminations.	5.43	18.0
900.8	Flaggy granular limestone; contains fossil hash. Beds are 1-3 cm. thick.	4.57	15.0
	One bed 28 cm. thick; very granular with coarse peloids and fossil hash. Laminated, dark gray limestone.		
900.9	Light gray granular limestone, contains abundant fossil hash. Grades to laminated limestones which contain graphitic interbeds at top of interval.	4.27	14.0
900.10	Sparse carbonate peloids in thinly bedded limestone; a few argillaceous interbeds (1 cm. thick). Becomes less argillaceous toward top of interval.	2.74	9.0
	Irregularly bedded limestone with horizonal burrows; generally thin beds (1-3 cm. thick) with biogenic and mechanical sole marks.	7.32	24.0
	Very dark argillaceous limestone (1 cm. thick); some lamination may be largely tectonic (quite irregular and non-planar).	7.94	26.0
	Disturbed zone (close to kink fold); argillaceous and dolomitic interbeds and zones in limestone; good lamination.	9.15	30.0
900.11	Thinly bedded limestone (1-4 cm. thick) contains abundant fossil hash.	3.66	12.0
	Very thinly bedded (1-2 cm. thick) medium grained limestone; abundant lamination, sparse spar filled horizontal burrows, mechanical sole markings (E-W orientation).	9.46	31.0
900.12	Thickly bedded, highly stylolitic, granular limestone; sparse fossil hash and peloid patches.	1.22	4.0
	Thinly bedded granular limestone; irregular lamination.	1.83	6.0
900.13	Massive medium to light gray limestone; irregular dolomitic patches (oolitic?); sparry spherical splotches (oncolitic bodies).	1.83	6.0
	Thinly bedded limestone, contains dolomitic and argillaceous laminations. Beds composed of peloids show ripple cross-laminations; burrow structures.	3.36	11.0
	Laminated thin beds of limestone; beds thin from about 2 cm. at base to about 1 cm. at top of interval; becomes less argillaceous up section.	3.36	11.0
	Medium gray limestone with argillaceous interbeds. Good laminations at base and/or tops of thicker beds.	4.57	15.0
900.14	Thick beds of mechanical limestone; sparse fossil hash grades to thin beds (3-5 cm. thick) of wavy bedded limestone at top of interval.	3.36	11.0
	Lensoid, thinly bedded limestone; laminated interbeds of dolomite. Limestone is quite granular with abundant fossil hash and sparse oolites.	2.14	7.0
900.15	Erosional contact (up to 2 m. of relief). Channel fill consists of small clasts, oolites, fossil hash (sparry); massive bed of limestone. Irregular dolomite distribution at top with argillaceous interbeds.	3.36	11.0
	Thinly bedded (2-5 cm. thick), laminated limestone; dolomitic laminations and wispy dolomite along cleavage. Few burrows; starved ripples.	12.20	40.0
	"Ribbon rock" (predominantly dolomite). Beds are 2-3 cm. thick; calcite (1-2 cm. thick) at base, burrow zone of silty dolomite and dolomite-calcite laminate at top. Small scour structures and fewer burrows at base of interval.	13.11	43.0
	Flaggy limestone (1-3 cm. thick) separated by dolomitic partings; ripple cross-laminations, horizontal and inclined burrows, authigenic pyrite horizons. *Acidaspis ulrichi*, Bassler. Gritty at very top; quartz and dolomitic silt.	7.91	26.0
35	Thinly bedded (1-2 cm.), laminated limestones; sparse bedding plane burrows.	6.0	1.82
	Thinly bedded (2-4 cm.), laminated limestones; abundant bedding plane and inclined burrows.	3.36	11.0
	Thinly bedded (1-2 cm.) limestone with dolomitic laminations; sparse spar filled burrows. Gradational to medium gray, massive mottled limestone.	.91	3.0
	COVERED SECTION	6.05	20.0
BASE OF GROVE FORMATION:	TOTAL LIME KILN MEMBER	184.2	607.7

LOCALITY	DESCRIPTION	THICKNESS M.	FT.
236	Light gray calcarenite; contains abundant quartz sand which delineates shallow cross-beds.	9.08	30.0
	COVERED SECTION Est.	3.03	10.0
228	Poorly exposed light gray, massive limestone contains a few large dolomite patches without quartz sand. Transition to light gray limestone with well developed cross-beds and medium grain quartz sand in upper 2 m.	3.63	12.0
	COVERED	4.55	15.0
	Gray to buff massive dolomite; contains abundant quartz sand in lower 1 m.	3.03	10.0
229	Massive dolomite contains sparse quartz sand. Two dolomitic sandstone beds 0.2 nd 0.5 m. thick with well developed trough cross-beds about 8 m. from base of sequence.	14.6	48.0
	COVERED SECTION	4.55	15.0

LOCALITY	DESCRIPTION	THICKNESS M.	FT.
230	Massive dolomite		
231	Massive limestone contains large amounts of quartz sand in pods and horizons. Top of sequence is mottled, fossiliferous?	3.03	10.0
233	Thickly bedded limestone contains abundant coarse quartz sand and peloids.	1.51	5.0
232	Light gray, massivley bedded limestone; sparse to no quartz sand at base to abundant at top. Section is strongly jointed.	6.06	20.0
	COVERED SECTION	15.5	50.0
TOTAL GROVE FORMATION IN SECTION I		68.2	225
	TOTAL SECTION	612.8	2022.2

SECTION II

This cross-section runs west to east in the Rocky Springs Station Member of the Frederick Formation. The only exposures close to the Araby-Frederick contact in the western limb of the synclinorium are in the large window in the Triassic immediately west of Frederick.

The poor exposures of the Rocky Springs Station Member and the local structural complexity make the section the most tentative of the three presented. The lithologic descriptions and the overall organization of the stratigraphy are thought to be quite accurate as presented in Plate 2.

LOCALITY	DESCRIPTION	THICKNESS M.	FT.
512	Thinly bedded limestone with dolomite interbeds; dolomite also occurs in wisps along cleavage.	4.59	15.0
	COVERED SECTION Est.	30.5	100
523A	Massive to thickly bedded peloidal limestone contains abundant dolomitic peloids.	8.54	28
	COVERED SECTION	6.12	20

518	Massive dolomite; sugary, granular appearance; fractured and infilled by Triassic mudstone.	3.66	12.0
	COVERED SECTION	1.53	5.0
	Thickly bedded, light gray arenaceous limestone; quartz sand is coarse and well rounded.	1.22	4.0
	COVERED SECTION	4.59	15.0
523	Thickly to thinly bedded, medium-light gray peloidal limestone; sparse to abundant quartz sand.	1.53	5.0
	Light gray, granular limestone containing sparse quartz sand at base of section; abundant quartz sand at top (poorly exposed).	6.4	21.0
	COVERED SECTION Est.	21.8	75.0
522	Alternating thin beds of limestone and dolomite; irregular dolomite wisps and patches.	1.22	4.0
	Massive, arenaceous, light gray limestone; quartz sand and small dolomite patches are abundant.	1.53	5.0
	Poorly exposed medium gray, massive limestone.	3.03	10.0
	Irregularly bedded limestone (polymict breccia?) containing patches of arenaceous and non-arenaceous limestone.	1.53	5.0
	Buff, massive dolomite; coarsely crystalline.	1.83	6.0
	Medium gray, arenanceous-peloidal limestone contains irregular dolomite patches.	.91	3.0
	Subequal thinly bedded, medium gray limestone and tan granular dolomite interbeds.	1.22	4.0

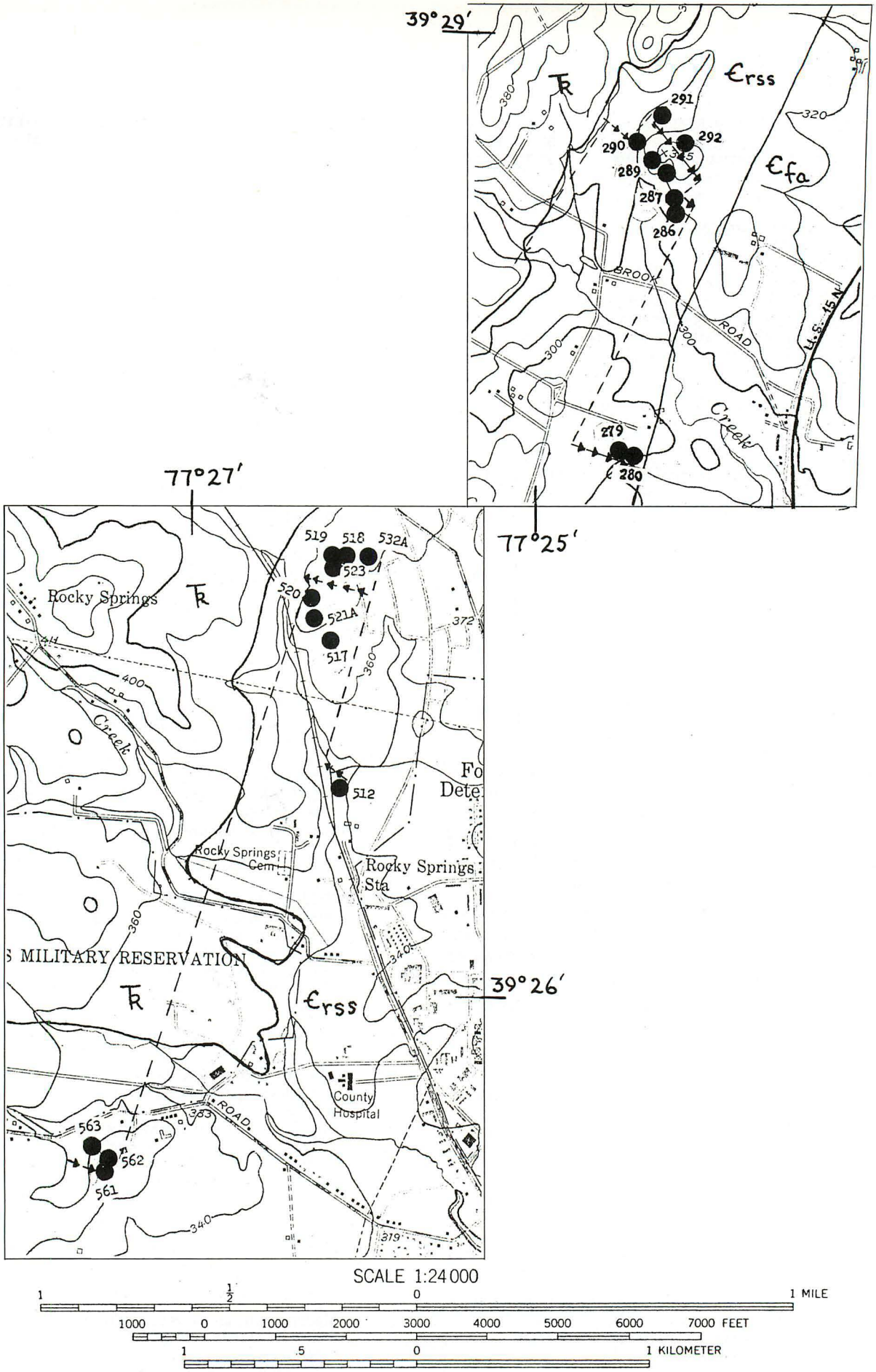


Figure 53.—Sketch maps showing the traverse and outcrop locations used in establishing the Rocky Springs Station Member type locality.

LOCALITY	DESCRIPTION		THICKNESS M.	FT.
	COVERED SECTION	Est.	30.5	100
521	Massive limestone contains oolite particles; partial brecciation (proximity to Triassic Conglomerate.)		4.59	15.0
	COVERED SECTION	Est.	9.08	30
521A	Massive, light gray limestone contains sparse quartz sand and becomes dolomitic at top.		4.59	15.0
	COVERED SECTION	Est.	15.3	50
563	Light gray, massive, peloidal limestone; coarse peloids are both calcite and dolomite in a sparry calcite matrix. Peloids are well rounded and well sorted.		15.6	51.0
	Thinly bedded, medium gray limestone, containing some planar laminations; dolomitic partings and wisps along cleavage.		9.74	32.0
561	Massively bedded peloidal limestone.		2.14	7.0
	Medium gray, massively bedded limestone (breccia?).		.61	2.0
	Well bedded "ribbon rock"; limestone beds are 3-5 cm. thick.		1.83	6.0
	Light gray, peloidal limestone; small peloids, no internal structure.		0.61	2.0
	Distorted "ribbon rock", 3-5 cm. limestone beds separated by 1 cm. dolomite interbeds.		4.88	16.0
	COVERED SECTION	Est.	30.6	100
290	Medium gray, graded breccia; megaclasts to peloids in micritic matrix.		3.06	10.0
	Medium gray, massive peloidal limestone shows thick to massive bedding.		2.44	8.0

LOCALITY	DESCRIPTION	THICKNESS M.	FT.
	Thinly to thickly bedded, medium gray limestone contains laminated dolomitic interbeds.	2.14	7.0
	COVERED SECTION	0.61	2.0
	Scattered outcrops of medium gray massive limestone composed of peloids and small megaclasts.	4.88	16.0
	COVERED SECTION	7.63	25.0
289	Coarse arenaceous, massive limestone; abundant quartz sand and peloids with a few irregular dolomite patches.	6.12	20.0
	Polymict breccia composed primarily of arenaceous clasts, oolites and quartz sand in the matrix.	4.59	15.0
	COVERED SECTION	9.18	30.0
	Granular, medium gray limestone becomes highly arenaceous at the top; thin breccia layer tops the sequence.	8.24	27.0
	COVERED SECTION (Thought to be mostly flaggy limestone.)	10.67	35.0
	Thinly bedded (3-6 cm. thick) micritic limestone with dolomitic interbeds about 1 cm. thick.	1.22	4.0
279-280	Massive peloidal limestone at base grades to light gray, massive oolitic limestone containing sparse dolomite clasts about 3 cm. across; massive, planar laminated, arenaceous limestone at top.	9.18	30
	Massive arenaceous limestone contains sparse oolites and abundant coarse quartz sand.	3.06	10
TOTAL ROCKY SPRINGS STATION MEMBER:		300.4	993.0

SECTION III

Measured sections in the Woodsboro Quadrangle are presented as representative of the Grove Formation. West and north of the measured sections are Triassic sediments which cover most of Frederick Formation carbonates. The section was measured west to east beginning in sparse outcrops of the Lime Kiln Member:

LOCALITY	DESCRIPTION	LOCALITY M.	FT.
1078	Thinly bedded limestone with laminated dolomitic interbeds; beds are slightly boudined.	5.60	18.5
	Thinly bedded (2 cm. thick) limestone; less deformed with Triassic mud infill at top of sequence.	6.06	20.0
	Flaggy limestones (3 cm. thick); very planar with no burrows or laminations.	6.66	22.0
	SMALL COVERED SECTION	?	?
12	Thinly bedded, laminated limestone; sparse to abundant burrows and fossil debris.	3.64	12.0
12A	1-2 cm. thick beds of flaggy limestone thicken to about 3 cm. at top of section.	2.58	8.5

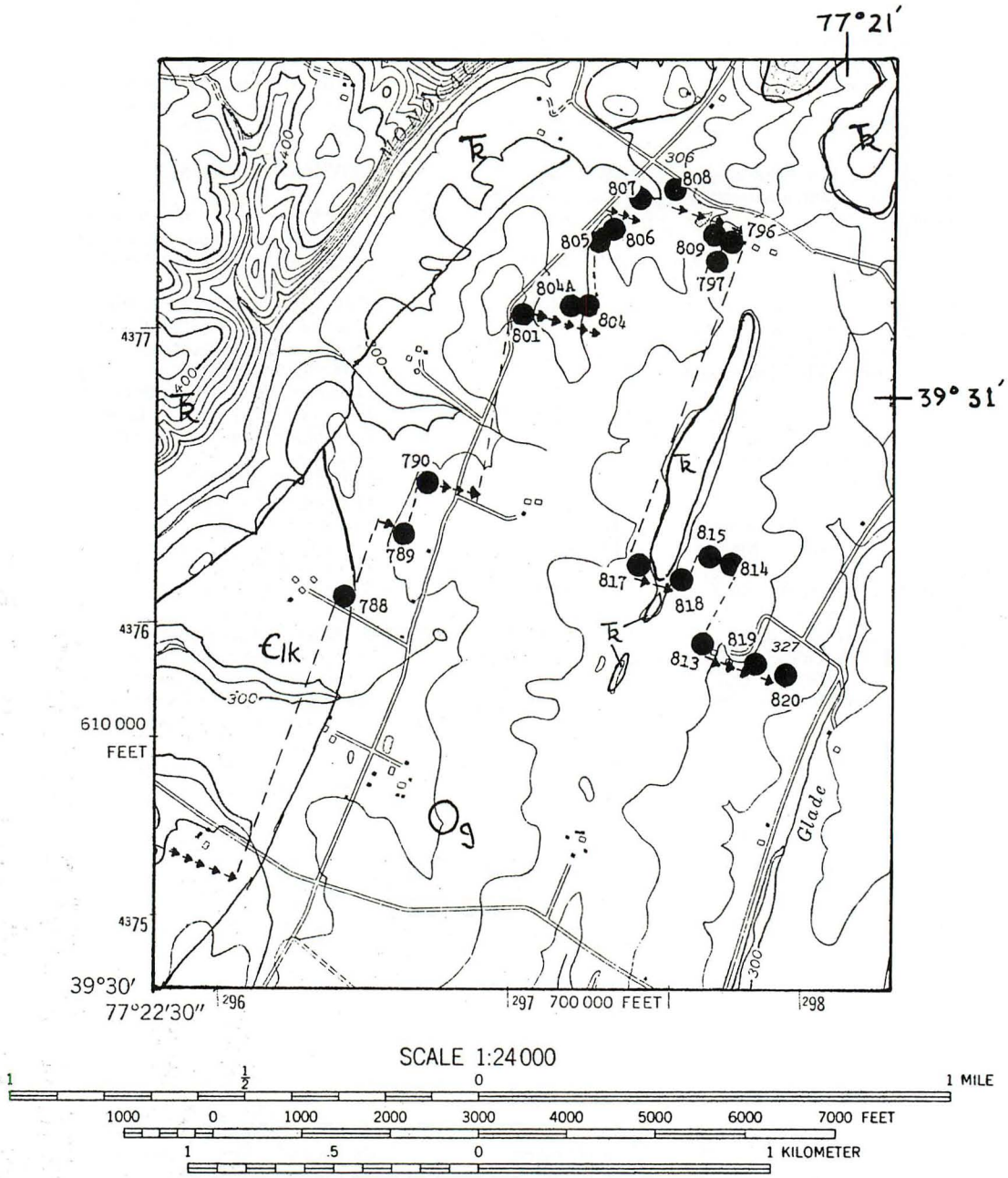


Figure 54.—Sketch map for section III. This measured section indicates outcrops used in establishing a reference section for the Grove Formation.

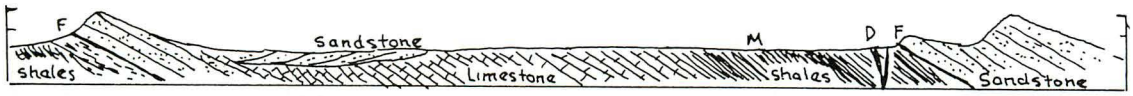
	COVERED SECTION	6.06	20.0
753	Thick sequence of thinly bedded limestone; beds are 3-4 cm. thick at base of sequence and contain abundant peloids; fines to 1 cm. thick limestone beds containing abundant horizontal burrows.	21.75	75.0
752	Thinly bedded argillaceous limestone; horizontal burrows.	2.54	8.0
	COVERED SECTION	75.8	250.0
TOTAL LIME KILN MEMBER		131.5	434.0

BASE OF GROVE FORMATION			
789	Light gray, peloidal limestone containing quartz grains, shallow cross-beds. Becomes highly mottled with irregular dolomite patches; small irregular, pustular algal heads.	1.21	4.0
	COVERED SECTION	1.52	5.0
	Medium gray limestone; highly mottled with dolomite patches becoming less abundant at top of section; abundant fossil hash.	1.82	6.0
	COVERED SECTION	3.03	10.0

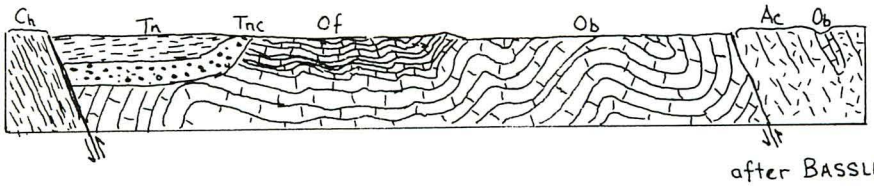
LOCALITY	DESCRIPTION	THICKNESS M.	THICKNESS FT.
790	Medium gray limestone contains abundant medium grain quartz sand; small scale herringbone cross-beds; quartz sand becomes more abundant and coarser at top.	3.64	12.0
	Sharp contact with mottled limestone containing SH algal heads up to 30 cm. across; embedding matrix is massive micrite with sparse fossil hash.	1.21	4.0
	Dolomitic laminates; basal scours; flat pebbles.	.91	3.0
	COVERED SECTION	2.28	7.5
	Coarse peloidal limestone containing sparse quartz sand, abundant dolomite clots.	.61	2.0
	Mottled irregular patches containing abundant stylolites (thrombolites?) become well developed SH algal heads topped by a variably thick dolomite beds.	1.67	5.5
	Light gray limestone, granular with abundant quartz sand; herringbone cross-beds.	2.13	7.0
	Well developed stromatolites (SH heads) becomes irregular mottled zones containing isolated thrombolites and digitate stromatolites.	3.03	10.0
	Well defined SH heads in granular limestone; abundant clasts, peloid and fossil hash in channels.	2.42	8.0
	Massively bedded granular dolomite.	3.03	10.0
804B	Massive granular dolomite; no good bedding criteria in absence of quartz sand. Strong fracture cleavage.	4.55	15
804A	Poorly developed stromatolites at base grades to massive white to buff granular dolomite.	4.55	15
804	Poorly exposed carbonate cycles; buff massive dolomite overlain by thick sequence of medium granular limestone; massively bedded with no apparent internal structures. Coarse granular peloids with dolomite coatings and quartz sand; massively bedded and overlain by massive buff dolomite at top of interval.	15.2	50
805	Medium gray granular limestone containing abundant fine quartz sand.	1.51	5.0
	COVERED SECTION	3.03	10.0
	Stromatolite head structures poorly preserved in massive light gray limestone; delineated by very coarse quartz sand; dolomitic sandstone at top of section.	2.43	8.0
806	Medium gray granular limestone; massively bedded.	2.12	7.0
	COVERED SECTION	9.10	30.0
807	Thinly bedded dolomite (very stylolitic) contains abundant peloids and small clasts. Thick section containing abundant quartz is light gray, granular limestone becomes very stylolitic with stromatolites? at top.	3.03	10.0

LOCALITY	DESCRIPTION	THICKNESS M.	THICKNESS FT.
	COVERED SECTION	4.55	15
	Granular massive limestone containing small irregular thrombolites; highly mottled calcite with abundant fossil hash at top of interval.	6.97	23
	Predominantly massive granular dolomite; scattered thinly bedded limestone-dolomite alterations.	7.72	25.5
	COVERED SECTION Est.	90.8	300
808	Poorly bedded, medium gray limestone; breccia (?) at base topped by thin alterations of mottled and structureless limestone.	.91	3.0
	COVERED SECTION Est.	75.6	250
809	Thickly bedded, medium gray limestone becomes thinly bedded with argillaceous interbeds; tops of beds become very irregular at top of section.	2.12	7
	Mostly covered; small outcrop of medium gray limestone with irregular dolomite pods.	4.84	16
	Thickly bedded, medium gray, stylolitic limestone; dolomite pods and sparry fossil debris in lower half; upper half is thinly to irregularly bedded, medium gray limestone containing abundant mottles.	3.64	12
	Thickly bedded limestone with a few thin beds; abundant mottles, sparse fossil debris.	4.84	16
	COVERED SECTION Est.	45.4	150
797	Thinly bedded, medium to light gray limestone, abundant fossil hash; very granular contains some fine quartz sand.	1.82	6
	Mostly covered; some granular limestone float.	2.73	9
	Medium gray limestone; thin to medium beds contain peloids, quartz sand.	3.03	10.0
	COVERED SECTION	4.54	15
796	Poorly exposed section; medium gray limestone hemispheroids (thrombolites?) separated by dolomite patches.	4.84	16
	Limestone patches (low stromatolitic heads?) enveloped by dolomites and laminated dolomitic limestones.	7.11	23.5
817	Massive, light gray limestone; irregular dolomite horizons and patches throughout. Becomes thinly bedded limestone with abundant pods of fossil debris.	3.64	12
	Granular limestone; dolomite partings define thin beds of limestone. Fossil hash (pelmatozoan columnals) and peloids at base of beds.		
	COVERED SECTION	1.21	4.0
	Thinly bedded limestone; carbonate is less granular than below.	.61	2.0
	COVERED SECTION Est.	15.1	50

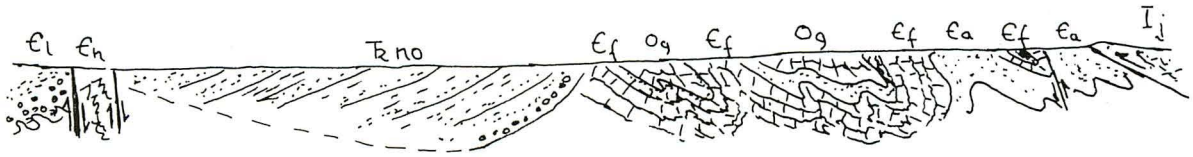
LOCALITY	DESCRIPTION	THICKNESS M.	THICKNESS FT.
818	Mostly covered section; light gray massive limestone with abundant dolomite mottles and pods.	10.6	3.4
	Light to medium gray massive limestone; very granular, interrupted by thin dolomite interbeds.	2.43	8.0
	COVERED SECTION Est.	6.06	20
815	Light gray cross-bedded limestone; abundant medium quartz sand becomes coarse at top of interval. Occasional dolomite beds and laminates contain abundant quartz.	3.64	12
	Medium gray granular limestone; quartz sand is absent.	1.21	4.0
	Massive limestone with irregular dolomite patches and splotches (3-10 cm. long).	3.03	10.0
	Mechanical limestone; poorly developed algal heads between erosive channel fills.	.61	2.0
	Small to medium algal heads (up to 50 cm. in diameter) immediately above cross-bedded limestones. Mostly covered; patches of granular dolomite.	4.54	15.0
816	Light gray cross-bedded limestone; abundant medium to coarse grained quartz sand.	4.54	15.0
	Medium gray limestone; small dolomitic spheroids at base; good laminated SH algal heads toward top of interval. Thin irregular limestone beds at top.	4.54	15.0
	COVERED SECTION Est.	60.6	200
819	Mechanical limestone; large peloids, flat pebbles and very coarse quartz sand.	2.43	8.0
	COVERED SECTION	3.03	10.0
	Peloidal granular limestone; massively bedded with elipsoidal clasts (up to 10 cm. long) at base.	1.51	5.0
	COVERED SECTION	.91	3.0
	Irregularly bedded medium gray limestone; contains geopetal structures and small algal clots.	2.43	8.0
	COVERED SECTION	6.06	20.0
END OF SECTION:			
	GROVE FORMATION TOTAL	477.5	1576.0
	TOTAL SECTION III	619.0	1619.4



after KEYES (1890)



after BASSLER (1919)



after JONAS & STOSE (1938)

Figure 55.—Cross-sections of previous workers. All sections are west to east; not to same scale.

Symbols used in the cross-sections are:

Keyes (1890)
- F = fault
- M = Monocacy River
- D = diabase dike

Bassler (1919)
- Td = Triassic Diabase
- Tn = Newark sandstone and shale
- Tnc = Newark Conglomerate
- Ob = Beekmantown Limestone
- Of = Frederick Limestone
- Ac = Catoctin Schist
- Ch = Harpers Shale

Jonas and Stose (1938)
- Trno = New Oxford Formation
- Og = Grove Limestone
- Cf = Frederick Limestone
- Ca = Antietam Quartzite
- Ch = Harpers Phyllite
- Cl = Loudon Formation

APPENDIX B: FREDERICK VALLEY FAUNAS

The relationship of various stratigraphic intervals in the Frederick Valley to the Great Valley section was reasonably clear prior to this study. Additional faunas have been collected primarily to solidify the stratigraphic framework within the Valley and to add new biostratigraphic information for the Appalachians. The rather conspicuous increase in the abundance and diversity of faunas and fossil debris from the base to the top of the carbonate section is one of the important pieces of evidence in documenting the shallowing upward of the depositional environment. The absence of a bottom community in the relatively deep water basin (estimated at 600 m.) represented by much of the Rocky Springs Station Member has interesting evolutionary implications. Especially since this niche was exploited by the Late Ordovician judging by fossil content (trilobites) in portions of the Martinsburg Formation representing basinal conditions and similar order of magnitude depths.

The first faunas described from the Araby Formation are obviously important as the oldest Piedmont fossils in Maryland. Important new, coarsely silicified Franconian-Trempealeauan fossils, especially trilobites, have already added new information on the morphology of some Late Cambrian taxa (M. Taylor, personal communication; 1973). The biofacies for these faunas is thought to be shelf-edge to basin-facing from work done in the Great Basin (A. R. Palmer, 1971).

The first Trempealeauan nautiloid cephalopod material from the Appalachians is present at the top of the Lime Kiln Member. Also, the first work on conodonts in the Frederick Valley has been initiated during this study to add biostratigraphic control within the Grove Formation. To this point only fibrous forms which have little biostratigraphic usefulness have been found (A. Epstein, personal communication; 1973).

Previous work and new data will be presented by stratigraphic unit beginning at the base of the section. Longitudinal and latitudinal coordinates will be given for each new fossil locality and for literature references where possible. Locality numbers are given preceded by the first two letters of the 7½ minute quadrangle in which they are located.

ARABY FORMATION

Previous work: Mention of trilobite spines and fossil molds at several poorly described localities (Stose and Jonas, 1946).

NEW DATA:

Fauna	Assigned Age	Locality	Coordinates
Trilobites	Late Lower Cambrian	Wo 1050	39 31' 77 17' 30''
Olenellus sp.			
Ecinoderm columnals	Latest Middle Cambrian	Bu 1051	39 21' 15'' 77 23' 40''

FREDERICK FORMATION
ROCKY SPRINGS STATION MEMBER

Previous work: (Rasetti, 1961)

Trilobites	Upper Cambrian Dresbachian stage	Fr 293	39 28' 13'' 77 24' 57''

Acmarhachis acuata (Kobayashi)
Bathyholcus gaspensis Rasetti, n. gen., n. sp.
Dunderbergia simplex Rasetti, n. sp.
Dunderbergia cf. variagranula Palmer
Glyptometopsistumida Rasetti, n. gen., n. sp.
Glyptometopsis? marginatea Rasetti, n. sp.
Homagnostus, sp. undet.
Pseudagnostus communis (Hall and Whitfield)
Ptrocephalops acrophthalma Rasetti
Quebecaspis marylandia Rasetti, n. sp.
Quebecaspis conifrons Rasetti, n. sp.
Taenicephalites macrops Rasetti, n. gen., n. sp.
Undetermined cranida and pygidia

NO NEW DATA

ADAMSTOWN MEMBER

Previus work: (Rasetti, 1959)

Trilobites	Upper Cambrian Trempealeauan	Fr 17	39 26' 77 24'

Trilobites
Apatokephaloides macrops Rasetti, n. sp.
Aposolen opleura plicata Rasetti, n. sp.
Geragnostus, sp. undet.
Glyptometopus laflammei (Clark)
Keithia intermedia Rasetti n. sp.
Keithiella cylindrica (Billings)
Loganellus cf. L. similis Rasetti
Pseudagnostus gyps (Clark)
Richardsonella unisulcata Rasetti
Theodenisia communis Rasetti

Note: This locality is a stone wall (Rasetti loc. ccb/2) thought to represent Grove limestone. From the locality description it is probably Adamstown member of the Frederick formation.

Trilobites
Apatokephaloides minor Rasetti, n. sp.
Geragnostus, sp. undet.
Hungaia magnifica (Billings)
Leiocoryphe cf. l. occipitalis Rasetti

Fauna	Assigned Age	Locality	Coordinates

Levisella nasuta Rasetti, n. sp.
Lotagnostus cf. L. trisectus (Salter)
Onchonotus richardsoni (Walcott)
Richardsonella megalops (Billings)
Richardsonella subcristata Rasetti, n. sp.
Theodenisia, sp. undet.

NEW DATA:

Upper Cambrian	Bu 323	39 17' 12''
Trempealeauan (early part)		77 28' 43''
(Saukiella pyrene subzone)		

Trilobites
Apatokephaloides sp.
Eurekia sp.
Idiomesus sp.
Leiocoryphe sp.
cf. Rasetti sp.
Richardsonella sp.
agnostid, gen and sp. undet.
? catillicephalid, gen. and sp. undet.
ptychaspidinid, new genus
ptychopariid, gen. and sp. undet.

Brachiopods
linguloid, gen. and sp. undet.

LIME KILN MEMBER

Previous work: (Bassler, 1919)
Trilobites
Acidaspis ulrichi Bassler

(Rasetti, 1959)

Trilobites	Upper Cambrian	Rasetti loc. ccm/l
	Trempealeauan	

Apatokephaloides, sp. undet.
? Bowmanica pennsylvanica Rasetti, n. sp.
? Entomaspis radiatus Ulrich
Leiocoryphe cf. L. brevis
Litagnostus sp. undet.
Plethometopus sp. undet.
Stenopilus pronus Raymond

Brachiopods (Ulrich and Cooper, 1938) loc. ccm/1
Xenorthis stosei

Xenorthis aequicostella	Wa 2	39 27'
Xenorthis jonasae		77 21' 56''

NEW DATA:

Upper Cambrian	Bu 79	39 20' 43''
Trempealeauan		77 26' 20''

(Saukiella junia or Saukiella serotina subzone of Saukiella zone)

Trilobites
''Acidaspis'' ulrichi Bassler
Leiocoryphe sp.
Stenopilus cf. L. pronus Raymond

Brachiopods
Xenorthis sp.

Fauna	Assigned Age	Locality	Coordinates
	Upper Cambrian	Fr 189	39 23' 50''
	Trempealeauan		77 24' 25''
	(probably upper part)		

Trilobites
cf. Geragnostus sp.
plethopeltid? gen. and sp. undet.
meraspid? cranidium, gen. and sp. undet.

Brachiopods
Xenorthis sp.

Ecinoderms
six-rayed echinodermal thecal plates
pelmatozoan columnals

Cephalopods
nautiloid cephalopod, gen. and sp. undet.

Upper Cambrian	Bu 35	39 21' 45''
Trempealeauan Stage		77 26' 20''

(*Saukiella junia* or *S. serotina* subzone of *Saukia* zone)

Trilobites
''Acidaspis'' ulrichi Bassler

Note: The Lime Kiln member is quite fossiliferous and should be systematically studied at the type area (Alpha Portland quarry, Lime Kiln, Maryland) for variation from base to top. Some faunas show partial silicification.

GROVE FORMATION

Previous work: (Ulrich and Foerste, 1935)

Lower Ordovician	Wo 7	39 33'
(Canadian Stage)		77 18' 50''

Cephalopods
Clarkoceras
Ectenolites n. sp.
Lewisoceras sp.
Walcottoceras

(Ulrich and Cooper, 1938)

Lower Ordovician	Fr 18	77 23' 30''

Brachiopods
Acrotreta sp.
Nanorthis difficilis Ulrich and Cooper
?Syntrophina impressa Ulrich and Cooper

NEW DATA:

Trilobites	Lower Ordovician	Fr 463	39 22' 21''
	(Canadian Stage)		77 23' 55''

Symphysurina sp.
cf. Xenostegium sp.
agnostid, gen. and sp. undet.
asaphid librigena
asaphid gen and sp. undet.

Porifera
sponge spicules.

SYMBOLS

Contact
Long-dashed where approximately located.

Fossil localities
Predominantly echinodermal debris is indicated by columnals.

No major faults have been mapped; many small scale NW-SE offsets can be seen in the field.

PLANAR FEATURES

Bedding, strike and dip

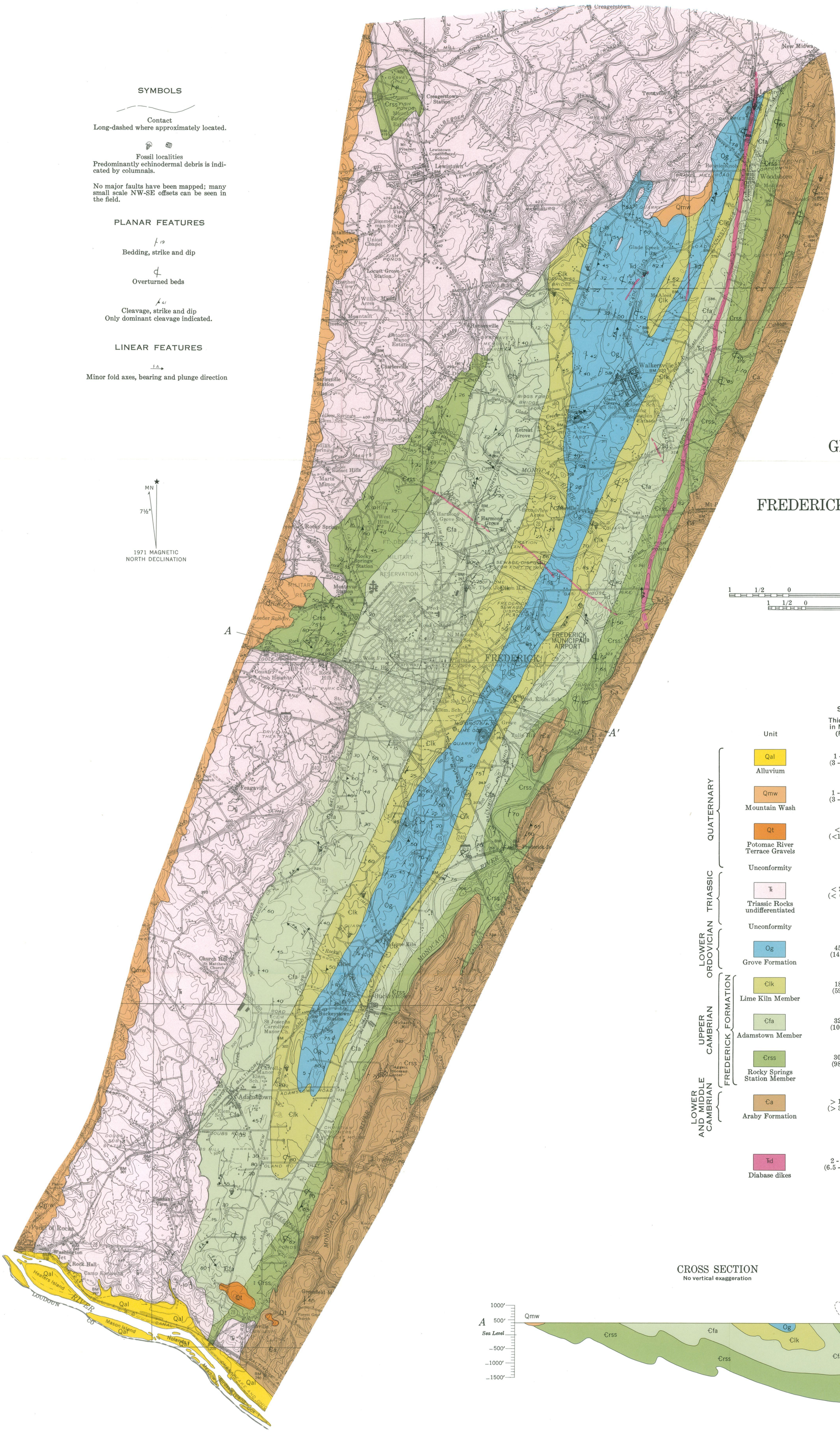
Overturned beds

Cleavage, strike and dip
Only dominant cleavage indicated.

LINEAR FEATURES

Minor fold axes, bearing and plunge direction

MN
7½°
1971 MAGNETIC NORTH DECLINATION



GEOLOGIC MAP OF THE FREDERICK VALLEY, MARYLAND

By
Juergen Reinhardt
1974

Scale 1:62500

1 1/2 0 1 2 3 4 Miles

1 1/2 0 1 2 3 4 5 Kilometers

Contour interval 20 feet
Datum is mean sea level

EXPLANATION

SEDIMENTARY ROCKS

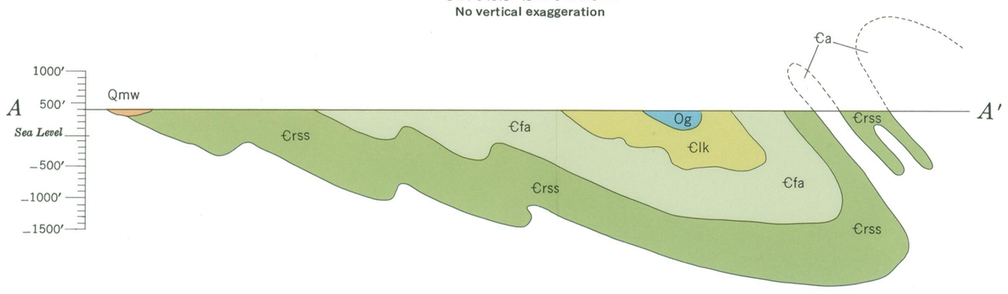
	Unit	Thickness in Meters (Feet)	Description
QUATERNARY	Qal — Alluvium	1 - 3 m (3 - 12 ft)	Interbedded sand, silt, clay and sparse gravels of the Potomac River floodplain.
QUATERNARY	Qmw — Mountain Wash	1 - 10 m (3 - 33 ft)	Poorly sorted, angular sandy, silty and granular colluvium and alluvium(?).
QUATERNARY	Qt — Potomac River Terrace Gravels	< 5 m (<16.5 ft)	Well rounded, spherical to discoid quartz and quartzite cobbles.
	Unconformity		
TRIASSIC	Ꞧ — Triassic Rocks undifferentiated	< 200 m (< 655 ft)	Limestone and quartz pebble conglomerates, red siltstones and mudstones.
	Unconformity		
LOWER ORDOVICIAN	Og — Grove Formation	450 m (1475 ft)	Interbedded, cross-bedded peloidal to arenaceous limestones, stromatolitic, fossiliferous limestones and laminated to massive dolomites.
UPPER CAMBRIAN, FREDERICK FORMATION	Ꞓlk — Lime Kiln Member	180 m (590 ft)	Fine grained, thin bedded and laminated limestones and dolomites; highly burrowed, containing abundant fossil debris, stromatolitic at very top. Sparse quartz sand and silt.
UPPER CAMBRIAN, FREDERICK FORMATION	Ꞓfa — Adamstown Member	325 m (1095 ft)	Uniformly fine grained, laminated and thin bedded, dark gray limestones, sparse burrows and fauna. Unit contains several traceable breccia zones.
UPPER CAMBRIAN, FREDERICK FORMATION	Ꞓrss — Rocky Springs Station Member	300 m (985 ft)	Interbedded light gray peloidal and dark gray thin bedded limestones and dolomites with sparse limestone breccias and locally abundant coarse quartz sand. Very sparse fauna, no burrows. Laminated calcareous shale and dolomite at the base.
LOWER AND MIDDLE CAMBRIAN	Ꞓa — Araby Formation	> 100 m (> 330 ft)	Tan to buff metasiltstone and phyllite, typically highly cleaved and mottled. Top of unit contains echinoderm columnals; *Olenellus* sp. in lower portion of unit.

INTRUSIVE ROCKS

Ꞧd — Diabase dikes	2 - 78 m (6.5 - 255 ft)	Dark green to black, medium to coarse grained augite diabase.

CROSS SECTION

No vertical exaggeration



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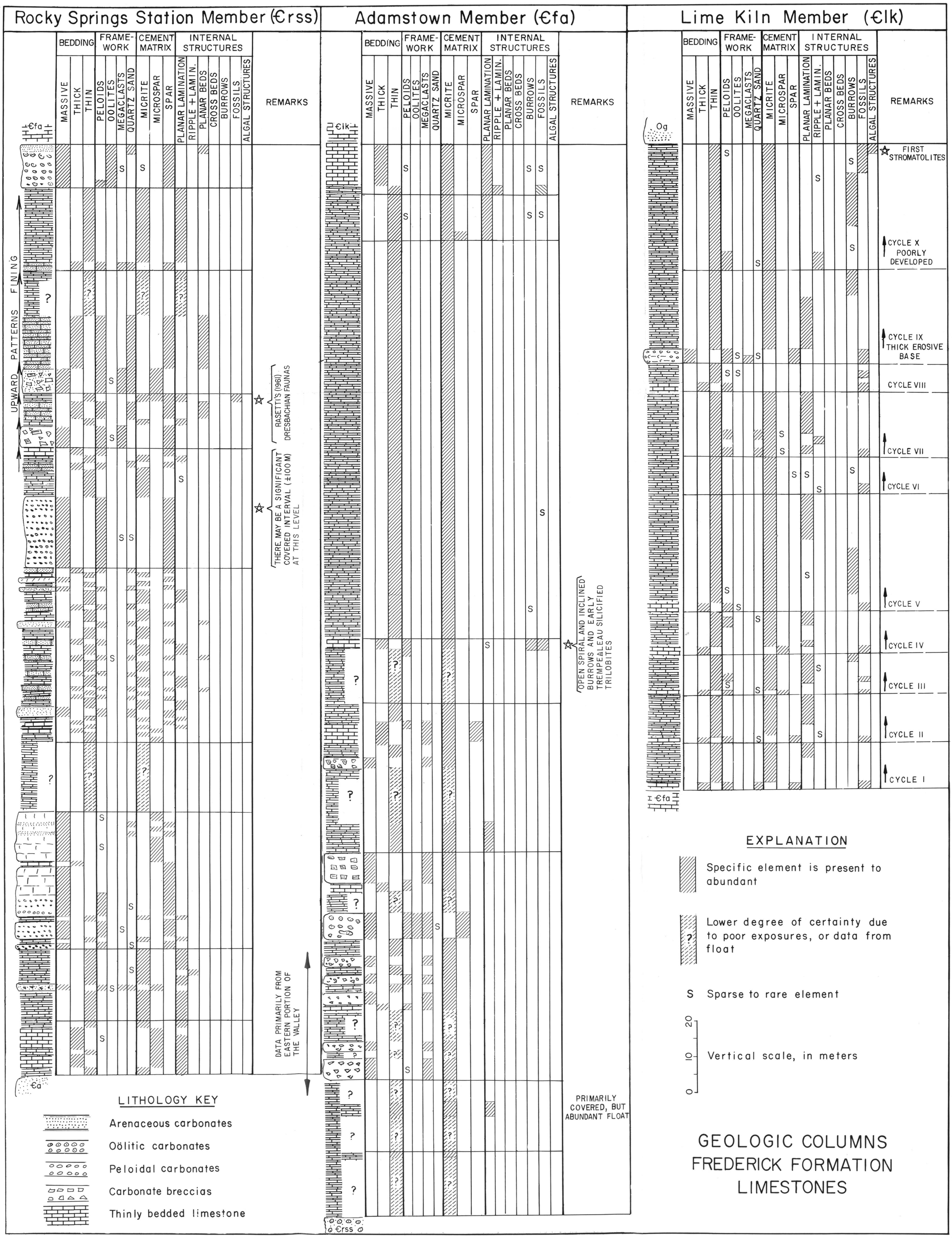
Rocky Springs Station Member (Ꞓrss)
Adamstown Member (Ꞓfa)
Lime Kiln Member (Ꞓlk)
BEDDING
FRAME-WORK
CEMENT MATRIX
INTERNAL STRUCTURES
MASSIVE
THICK
THIN
PELOIDS
OOLITES
MEGACLASTS
QUARTZ SAND
MICRITE
MICROSPAR
SPAR
PLANAR LAMINATION
RIPPLE + LAMIN.
PLANAR BEDS
CROSS BEDS
BURROWS
FOSSILS
ALGAL STRUCTURES
REMARKS
UPWARD FINING PATTERNS
RASETTI'S (1961) DRESBACHIAN FAUNAS
THERE MAY BE A SIGNIFICANT COVERED INTERVAL (±100 M) AT THIS LEVEL
DATA PRIMARILY FROM EASTERN PORTION OF THE VALLEY
OPEN SPIRAL AND INCLINED BURROWS AND EARLY TREMPEALEAU SILICIFIED TRILOBITES
PRIMARILY COVERED, BUT ABUNDANT FLOAT
FIRST STROMATOLITES
CYCLE X POORLY DEVELOPED
CYCLE IX THICK EROSIVE BASE
CYCLE VIII
CYCLE VII
CYCLE VI
CYCLE V
CYCLE IV
CYCLE III
CYCLE II
CYCLE I
LITHOLOGY KEY
Arenaceous carbonates
Oölitic carbonates
Peloidal carbonates
Carbonate breccias
Thinly bedded limestone
EXPLANATION
Specific element is present to abundant
Lower degree of certainty due to poor exposures, or data from float
S Sparse to rare element
Vertical scale, in meters
0
10
20
GEOLOGIC COLUMNS
FREDERICK FORMATION
LIMESTONES

MARYLAND GEOLOGICAL SURVEY

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