MARYLAND GEOLOGICAL SURVEY

Kenneth N. Weaver, Director

GUIDEBOOK NO. 5

SELECTED EXAMPLES OF CARBONATE SEDIMENTATION, LOWER PALEOZOIC OF MARYLAND

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FIELD TRIP NO. 2
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Selected examples of carbonate sedimentation, lower Paleozoic of Maryland

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SELECTED EXAMPLES OF CARBONATE SEDIMENTATION, LOWER PALEOZOIC OF MARYLAND

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INTRODUCTION

The objectives of this two-day field trip are: 1) to visit localities representative of the Cambrian, Ordovician, and Silurian carbonate rocks in the central Appalachians; 2) to demonstrate similarity in depositional environments and patterns of sediment accumulation through a considerable period of geologic time, even though each stratigraphic unit poses unique problems of interpretation; and 3) to document a major carbonate facies change in Upper Cambrian rocks from west (Great Valley) to east (Frederick Valley). The first day we will focus on shallow-water sedimentation as portrayed in three temporally separate stratigraphic units in Washington County, Maryland; the second day we will concentrate on the evolution of a depositional basin at the edge of the Cambrian and Ordovician carbonate platform, Frederick County, Maryland.

The Great Valley section was an active area for research during the 40's and 50's. Numerous students from Johns Hopkins University (Neumann, 1950; Long, 1953; Sando, 1957) and Penn State University (Pelto, 1942; Folk, 1952; Rones, 1955; Donaldson, 1959) helped to develop a petrographic and biostratigraphic framework for these Cambrian and Ordovician rocks. This work together with the stratigraphic work of Stose, Bassler, Willard, and Butts, and the recent synthesis by Palmer (1971), has resulted in a well-established framework for this thick sequence of carbonate rocks. A somewhat schematic cross section (Fig. 1) adapted from Donaldson (1969) presents some of the stratigraphic nomenclature and the gross thicknesses of the Cambrian and Lower Ordovician sediments.

Recent developments in comparative sedimentology and new concerns with lithogenesis and weathering of carbonate rocks make it imperative that these rocks come under new scrutiny. Not only can we learn valuable lessons about sedimentation on carbonate platforms--epeiric seas, we can also investigate compaction, cementation, and diagenesis of various closely related lithologies. Preservation of both primary and secondary structures is superior in these rocks; our task is to unravel the early, intermediate or late lithogenesis. Some of these questions can be answered in the field and questions pertinent to further investigation can be formulated.

STRATIGRAPHIC FRAMEWORK (PREVIOUS STUDIES)

This field trip originates in the Coastal Plain, traverses the eastern and western Piedmont, crosses the Frederick Valley and skirts a thin Triassic Basin. The transition to the Valley and Ridge province occurs on the

Table 1. Stratigraphic section below Field Trip Stops

Group	Unit	Thickness (metres)	Lithology	Remarks
	Elbrook Formation (Middle Cambrian)	1000	Thinly bedded limestone and dolomite.	Gradational contact with Conococheague.
	Waynesboro Formation (Lower Cambrian)	100-200	Thin red shales and siltstones within thinly bedded calcarenite.	Limited knowledge of east-west variation due to poor outcrop and narrow outcrop belt.
	Tomstown Dolomite (Lower Cambrian)	150-300	Granular and mottled limestone; laminated and massive dolomite.	Onset of carbonate platform sedimentation. See Reinhardt and Wall (1975).
Chilhowee Group (Upper Precambrian and Lower Cambrian)	Antiem Sandstone	100-200	Cross-laminated to cross-bedded sandstone with *Skolithos* burrows; *Olenellus* at top.	Probably a fluvio-deltaic to shallow marine complex with considerable lateral and vertical variation. See Whitaker (1955), (Schwab 1970, 1971).
Chilhowee Group	Harpers Formation	600-1000	Shale-phyllite with sandy pods and lenses.	
Chilhowee Group	Weverton Formation	300	Coarse, cross-bedded quartzite interbedded with phyllite.	
Chilhowee Group	Loudoun Formation	0-50	Phyllitic to conglomeratic; poorly sorted.	
	unconformity			
Precambrian	Catoctin Formation		Interbedded (?) metabasalt (hornblende-chlorite schist and greenstone), metarhyolite (gray-purple slate and breccia).	
Precambrian	unconformity			
Precambrian	Swift Run Formation	0-10	Lithologically heterogeneous unit containing limestone (marble) poorly-sorted conglomerate and tuffaceous phyllite.	
Precambrian	unconformity			
Precambrian	Granite gneiss "Basement"			ca. 1100 MY old or older

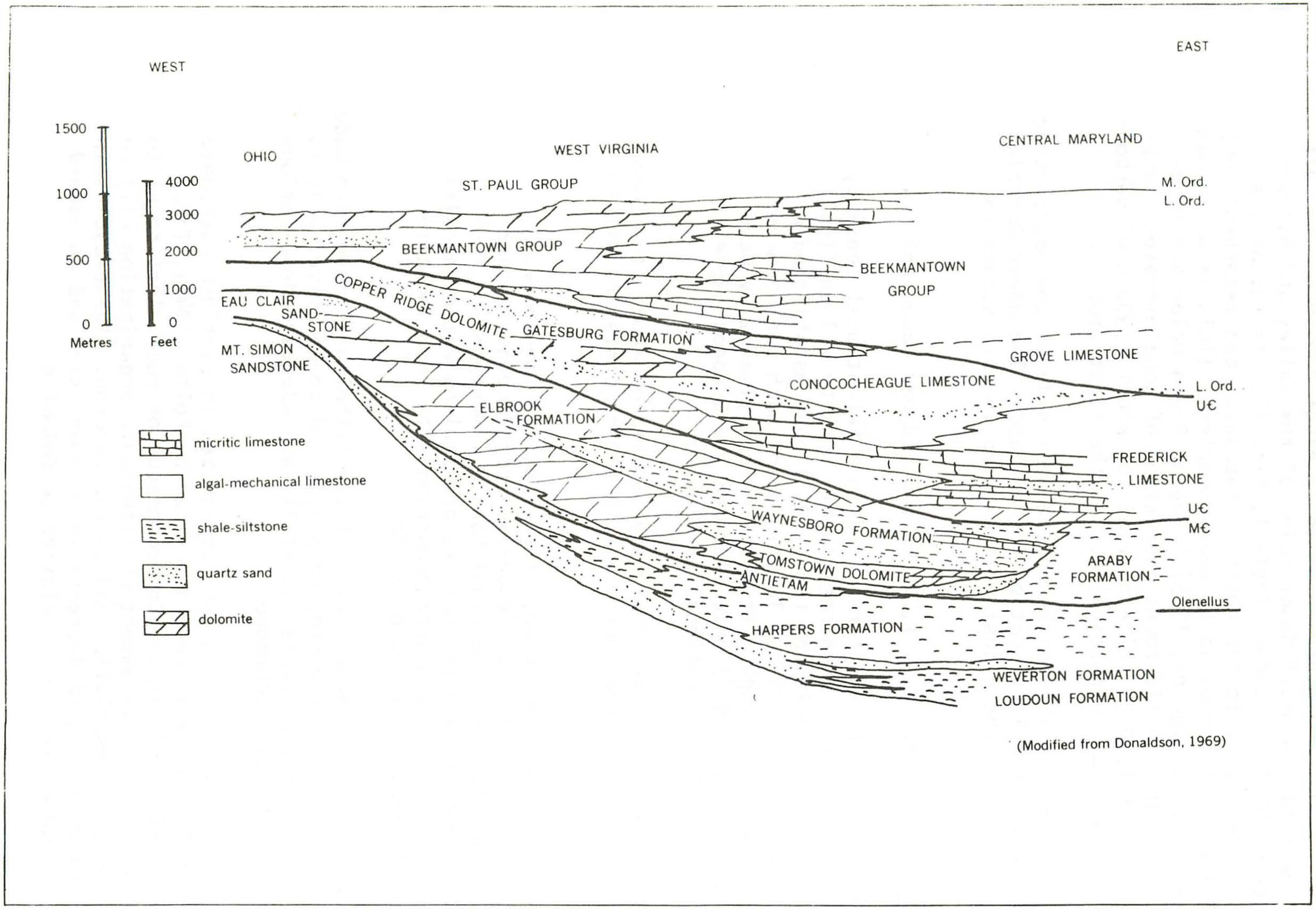

Figure 1. Schematic west-east cross-section from Ohio-West Virginia to area of this field trip. Time lines are approximate and the placement of stratigraphic unit names is partly a function of spacing.

western flank of the South Mountain fold. Blue Ridge province rocks are exposed within the fold. A brief description of the Valley and Ridge--Blue Ridge stratigraphy is included (Table 1; Fig. 1). In summary, a variably thick sequence of volcanic rocks (metabasalts and metarhyolites) overlies an 1,100-m.y.-old granitic basement complex. (This is a minimum age; [oral commun., M. W. Higgins, 1975].) Upper Precambrian and Lower Cambrian Chilhowee Group clastic rocks consisting of conglomerates, sandstones and shales about 1,000 m thick overlain by about 1,500 m of carbonate rocks complete the section exposed east of the first stop.

Our stops on day one will all be on the west side of the Massanutten synclinorium in the Great Valley section in Maryland. The Upper Cambrian Conococheague Limestone is the oldest unit exposed in this structural setting.

<u>Conococheague Limestone</u>: at least 1,000 m thick (Upper Cambrian)

This stratigraphic term was first used in a formational sense by Stose (1908) in Pennsylvania. Biostratigraphic work by Wilson (1952) and detailed petrographic studies by Long (1953) have established a basis for further work in Maryland. To this point such work remains to be done. Detailed stratigraphic studies in Pennsylvania by Geyer and others (1963) and Root (1968) have elevated the Conococheague to group status with differing formational terminology.

All of the workers who have previously studied or mapped the Conococheague have recognized various petrologic elements contained within the unit:

> "composed of massive, dark-blue, closely banded limestones. . . The most striking are beds of 'edgewise' conglomerates which alternate frequently with the usual banded limestone. . .The edgewise conglomerate and the oolites are shallow water deposits and the rounded grains of quartz occurring with them indicate nearby land." Bassler (1919, p. 77-78).

Although refinements in description of the lithologies have been made by later workers, until we have performed a detailed comparative analysis with modern sedimentary environments, we still lack adequate descriptions and understanding of the Conococheague.

One of the most important concepts recognized in platform carbonate rocks--CYCLIC SEDIMENTATION--has been described by Pelto (1942), Tasch (1951), and Root (1964, 1968) in the Conococheague or equivalent rocks to the west in Pennsylvania. This aspect of lithologic organization will be treated both in the stop description and on the outcrop. These cycles in general are defined by an upward decrease in sediment size and an upward decrease in percentage of limestone relative to dolomite.

Beekmantown Group: (Lower Ordovician) 1,300 m thick

Although several sections in the Beekmantown are quite well exposed, few continuous sections with diverse lithologic elements exist. For a detailed stratigraphic and biostratigraphic treatment we refer you to Sando (1957). Sando's memoir also includes the most up-to-date mapping on the west side of the Great Valley section in Maryland.

Generally the Beekmantown contains lithologic elements similar to both the underlying and overlying rocks. The unit contains less arenaceous and argillaceous material than the underlying Conocoheague; this decrease in siliceous components continues into the St. Paul Group.

St. Paul Group: Middle Ordovician (∿150 m thick)

The stratigraphy and faunas of this unit were described by Neumann (1951). The lower contact is defined by the siliceous-cherty Pinesburg Station Dolomite of the Beekmantown Group and may be gradational. The upper contact with the Chambersburg Limestone is rarely exposed. Two St. Paul units, the New Market Limestone (upper 110 m) and the Row Park Limestone (lower 40 m) have been defined primarily on the basis of topographic expression and style and absence of lamination. Both formations are characterized by alternations of light-gray limestone (stromatolites, intraformational conglomerates, and mottled zones) and white to buff dolomite (more or less distinct planar laminations).

Matter (1967) studied the St. Paul lithologies in considerable detail at Wilson Quarry and concluded that six rock types could be defined and that these represented various subenvironments within a tidal-flat complex.

Chambersburg Limestone: Middle Ordovician (30-60 m thick)

Dark-gray, fine-grained argillaceous limestone beds defined by thin interbeds to wispy lamination that are predominantly dolomite characterize this unit. Limestone beds are characterized by fossil debris from bryozoans, brachiopods, echinoderms, gastropods, and algae (*Nudulites pyriformis*, Bassler).

A thick interval of clastic flysch and molasse sediments (Table 2) fills the stratigraphic interval between Stops 2 and 3. Many of these units are more fully developed both in terms of thickness and degree of exposure in central and eastern Pennsylvania. The clastic sediments wane locally at the top of the Bloomsburg Red Beds.

Wills Creek Shale and Tonoloway Limestone: Upper Silurian (350 m thick)

The Wills Creek Shale and the Tonoloway Limestone were described in detailed measured sections by Swartz (1923) in Maryland. Tourek (1970) revised and summarized the stratigraphy: the Wills Creek was divided into four stratigraphic units and the Tonoloway was divided into three units. These units show considerable persistence laterally and are thought to represent seven sedimentation sheets with variable internal organization.

The dominant lithologies are: dolomitic and quartzitic mudstone, thinly bedded limestone, and thick-bedded dolomite.

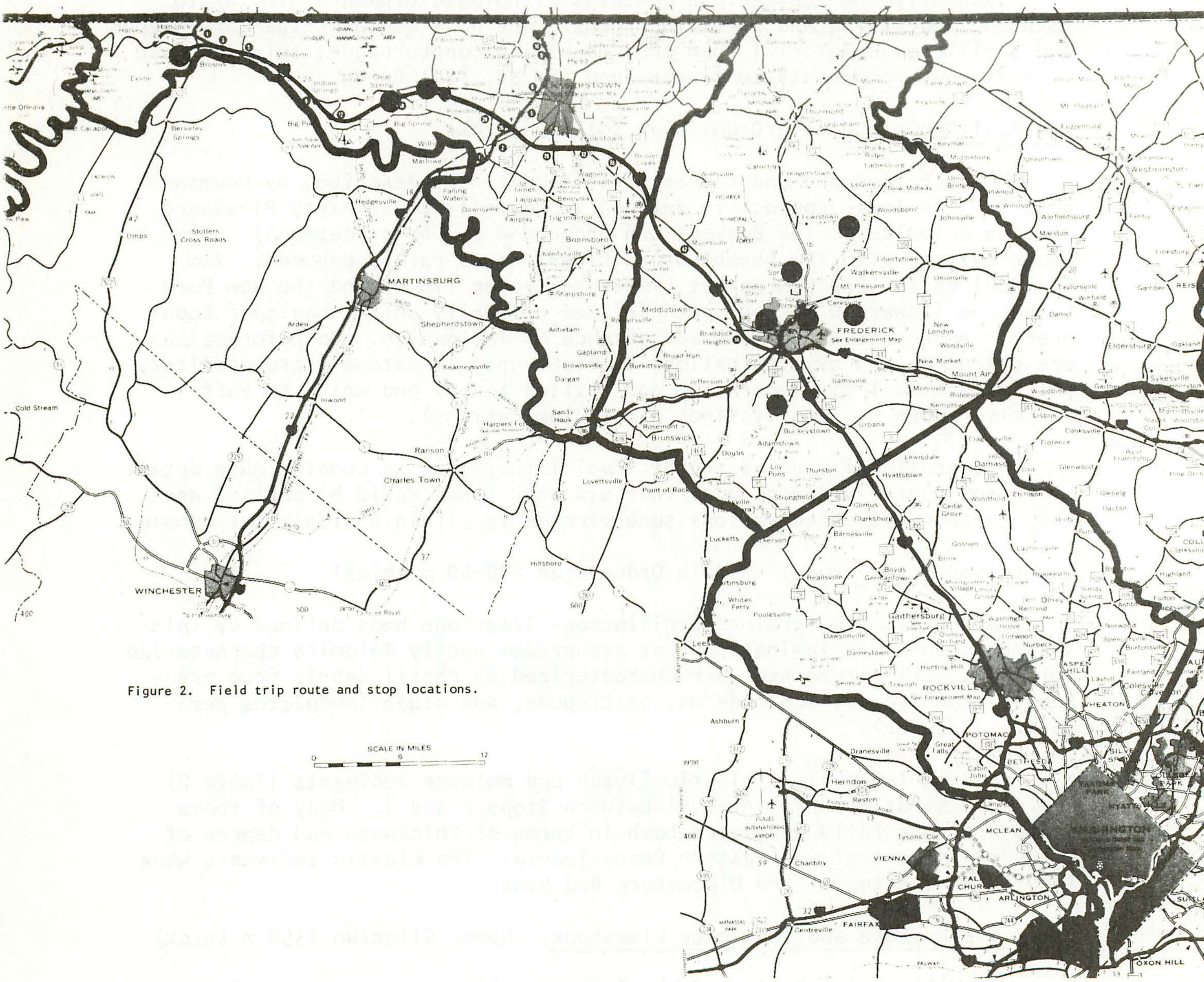

Figure 2. Field trip route and stop locations.

ROAD LOG: FIRST DAY

Mileage	
0.0	Leave at 7:30 A.M. from Stouffers Inn, Alexandria, Virginia, and proceed north on U.S. 1.
0.5	Turn right to George Washington Parkway west.
10.5	Exit for I-495 north.
10.9	Cross Potomac River to Maryland.
14.2	Exit to I-270 toward Frederick, Maryland.
15.1	Democracy Boulevard.
15.8	Junction I-270.
17.3	Junction Seven Locks Road and Montrose Road.
19.4	Junction Maryland Route 26.
21.1	Junction Shady Grove Road.
23.6	B & O Railroad.
23.7	Junction Maryland 118.
26.0	Junction Maryland 121.
29.4	Junction Maryland 109.
29.6	Montgomery County-Frederick County line.
32.7	Junction Maryland 80--cross into Frederick Valley section at "Martic Line."
36.1	Monocacy River.
37.2	Junction Maryland 85 (old U.S. 15).
37.9	Follow I-70 west toward Hagerstown (Frederick by-pass).
39.2	Junction U.S. 15-340.
42.5	Junction U.S. 40A.
44.0	Crest of Catoctin Mountain exposure of greenstone of Catoctin Formation--large quartz-epidosite knots.

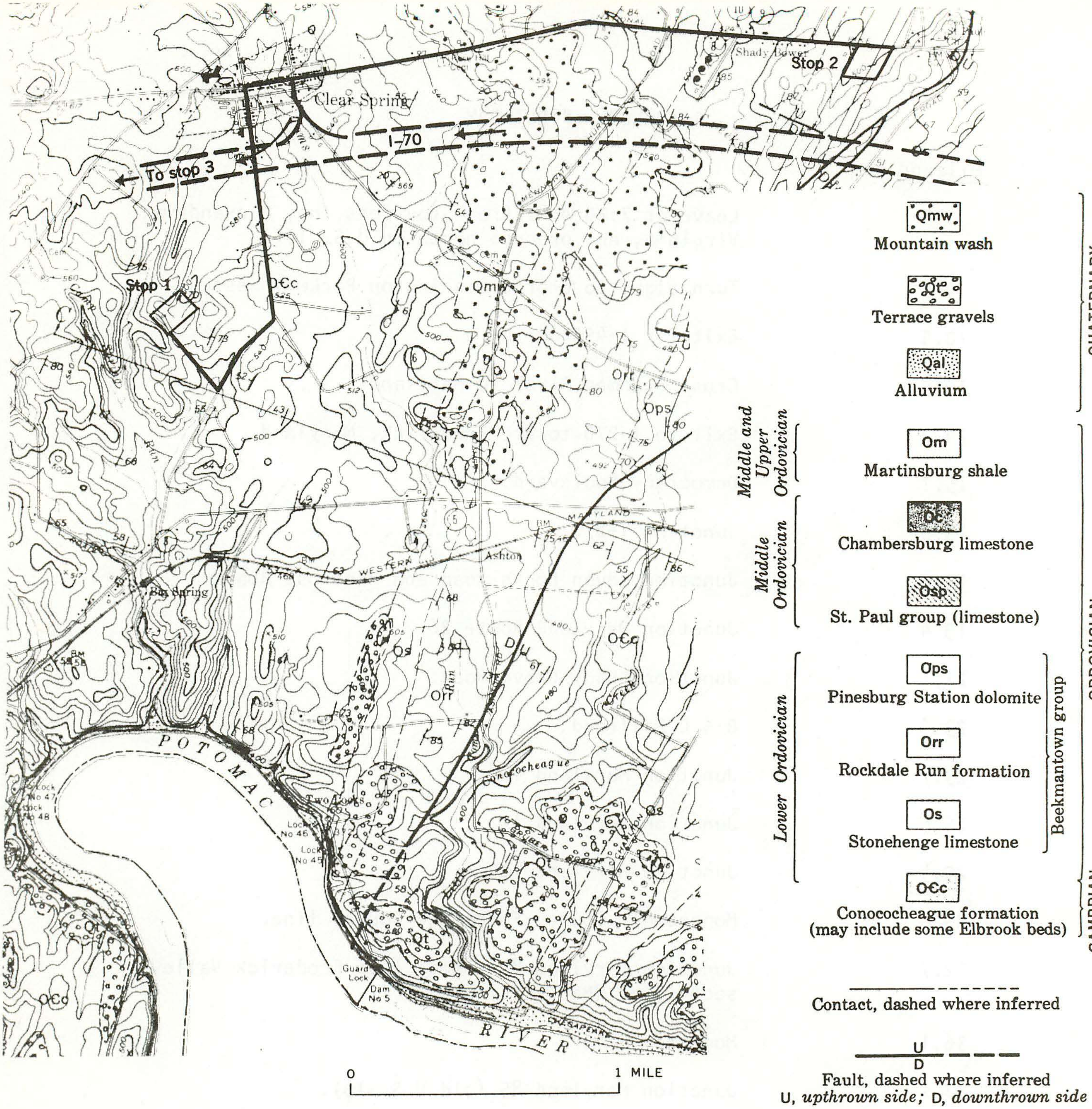

Figure 3. Detail of routes between Stops 1 and 2 on geologic base map prepared by W. J. Sando (1957).

Mileage	
45.0	Descend to floor of Middletown Valley.
49.5	Roadcut in Catoctin metabasalt.
50.6	Junction Myersville exit.
51.5	Appalachian trail at South Mountain crest up section through Chilhowee Group--much is covered by Quaternary mountain wash especially toward toe of slope.
54.3	End Quaternary mountain wash--first exposures of Cambrian limestone on north side of road.
54.9	Junction Maryland Route 66 to Boonesboro.
57.4	Junction U.S. Route 40 to Hagerstown.
64.2	Junction Maryland Route 65 to Sharpsburg--Antietam Battlefield.
64.4	Roadcut in Martinsburg Shale.
66.9	Roadcut in St. Paul Group-Beekmantown Group.
70.0	Exit Maryland 68 to Clear Spring.
70.3	Turn LEFT at U.S. 40, Clear Spring and proceed through town.
70.5	Turn LEFT on Big Spring Road.
70.9	Cross I-70.
71.7	Turn RIGHT into driveway of Jack Corwell Farm (Box 26 on mailbox).
72.0	STOP 1: Jack Corwell's Farm, Clear Spring, Maryland

Please note: If you wish to collect rock samples, please look first in the rock piles around the outcrop area. If nothing there is adequate for your needs, be judicious about what you remove from the outcrop. Please do not leave rock chips lying around--these can be a hazard to the cows!

This stop is (1) to familiarize you with the basic lithologies in the platform carbonate rocks, (2) to demonstrate cyclic sedimentation patterns, and (3) to show superb exposures of the Conococheague Limestone. Several unpublished measured sections at this locality by L. A. Hardie and D. M. Hepp (see section on Conocoheague sedimentation for specific portions of the section) indicate that the Conococheague is more than 1,000 m thick.

The major emphasis in the first area will be on the recognition of the major lithologies and their vertical arrangement. The three major lithologies and variations of these are: (1) GRANULAR CRYPTALGAL LIMESTONE: a coarse, sandy carbonate, containing rounded lithoclasts, peloids, coated grains, oolites, and quartz sand (crossbedding) and algal structures (SH stromatolites and thrombolites); (2) RIBBON ROCK: thinly bedded limestones with dolomitic lamination to interbeds; containing predominantly fine sand to silt-size carbonate grains and lenses to thin beds of flat-pebble conglomerate (ripple cross lamination, wavy bedding, clast imbrication); and (3) LAMINATED CARBONATE ROCK: closely spaced dolomite and limestone showing parallel to low-angle cross laminae composed of fine-grained sediment; laminae are disturbed by vertical disruptions (mud cracks) or sparse spar-filled knots (record of evaporite nodules?). Rare pods of crossbedded quartz sand accompany these dolomitic laminae.

The three major lithotypes are arranged in a systematic way from a sharp, erosive base that records the removal of either a little or a great deal of sediment, overlain by the granular-cryptalgal limestone, a relatively sharp transition to ribbon rocks, which become more thinly bedded (also more dolomitic), and finally laminated toward the top of the cycle. For a detailed explanation of our interpretation of these shallow-water carbonate rocks and their cyclicity, see the section on Conococheague sedimentation.

<u>Mileage</u>

72.0	Return to Big Spring Road.
	Note Wilson's Big Spring Station section is about 1.5 miles to the south.
72.3	Turn LEFT and retrace through Clear Spring to junction Maryland 68.
73.7	Continue east on U.S. 40 to Boward's Pasture. Park on south shoulder of road.
75.7	<u>STOP 2</u>: James E. Kenney Farm (Boward's Pasture), Clear Spring, Maryland.

This is the type locality for the St. Paul Group (Middle Ordovician) (Neumann, 1951), and has been included on numerous previous field trips (AAPG-SEPM, 1960). This stop is included primarily as a comparison and contrast to the Conococheague stop. We have no new insights into the sedimentation story here; rather we think there are some interesting lithogenesis problems in these rocks which are worthy of attention. Matter (1967) developed his analysis of these tidal-flat deposits by focusing on the abundant desiccation features. There are, however, sedimentary structures and patterns of sedimentation that are not adequately treated by Matter's paper. The biostratigraphic framework of Neumann plus the detailed study by Matter provide excellent starting points for further work.

Our approach in viewing these rocks will be to start in the Chambersburg Limestone (the overlying unit) and work down across a covered interval into the New Market Limestone. The Chambersburg was deposited in somewhat deeper water and contains sedimentary structures similar to portions of the Frederick Valley section which will be seen tomorrow. The salient features in this unit are summarized in the schematic Figure 4, that is meant to represent a typical Chambersburg bed. Most of the Chambersburg is composed of dark-gray, argillaceous beds of this kind.

The striking contrast between the Chambersburg and the light-gray, thick-bedded New Market beds suggests different modes of sedimentation. Similarities with the three major rock types defined in the Conococheague will be seen. The granular, sandy limestone unit is much less conspicuous and more variable here; it may contain shelly muds, birdseye structures, and thin beds. The cryptalgal components are interbedded with "ribbon rocks," as well as granular limestones. The "ribbon rocks" have a somewhat different aspect containing much more finely laminated dolomite coupled with thin, commonly structureless, limestone beds. Burrows and clotted thombolites are typically found in this lithotype. The laminated dolomites, which represent the third major lithotype, contain pockets of flat pebbles and are extensively mud cracked. The vertical arrangement of these lithologies is much less regular than in the Conococheague, and a simple alteration of only two lithologies persists locally over considerable intervals.

Pressure solution phenomena are extremely well exposed in this package of sediments as abundant solution seams along bedding planes in the Chambersburg and large amplitude stylolites in the New Market. The relative age of these features and other post-depositional structures are all relevant to the lithogenesis of carbonate rocks. Few of the problems have even been adequately defined for these rocks.

Mileage	
75.7	Retrace to Clear Spring (west on U.S. 40) to Maryland 68.
77.7	Turn LEFT.
78.0	Exit RIGHT to I-70 west toward Hancock.
80.5	Transition from Cambrian and Ordovician carbonate rocks to Silurian clastic rocks; note changes in topography and vegetation.
83.2	Junction Maryland 56 to Big Pool and Indian Springs.
86.4	Long roadcut in Devonian clastic rocks. This section shows a transition from predominant fluvial to deltaic (marine fossils).

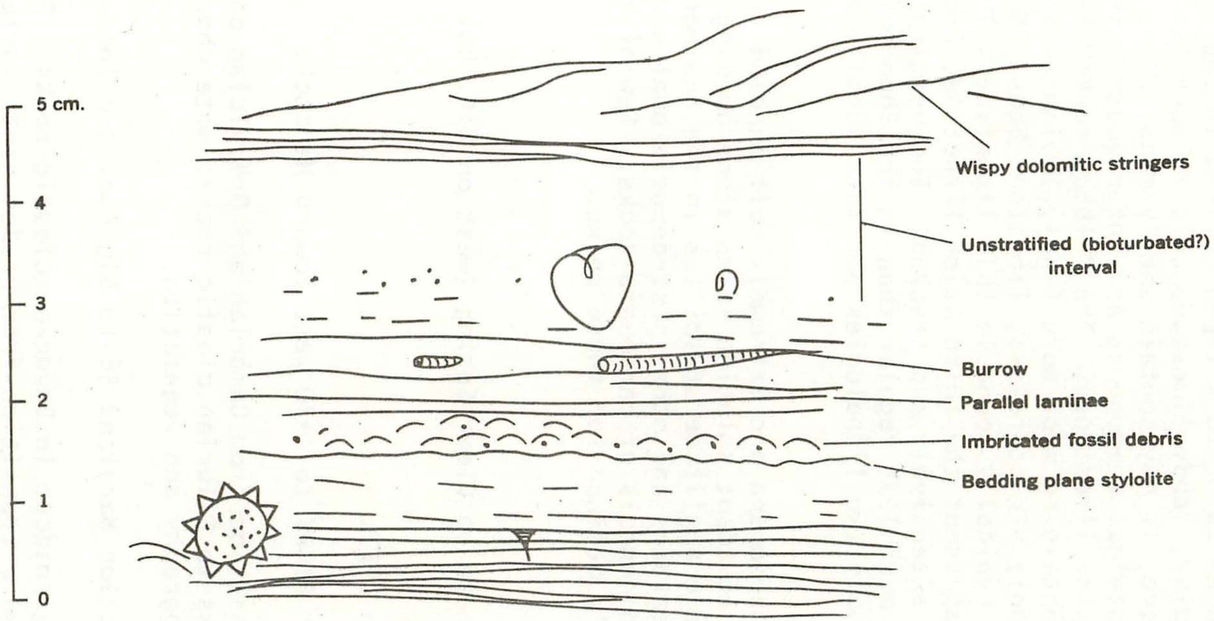

Figure 4. Sketch of a "typical" bed in the Chambersburg Limestone (Middle Ordovician). This represents a composite of several thin beds each containing one or more of the elements shown in this figure.

Table 2. Stratigraphic units between Stops 2 and 3

Unit	Thickness (metres)	Lithology	Remarks
			STOP 3
Bloomsburg Red Beds (Upper Silurian)	10-60 10-60	Red shale with thin sandstone interbeds.	Fluvial to restricted marine.
McKenzie Formation (Middle Silurian)	75	Interbedded shale and argillaceous limestone.	Shallow marine.
Rochester Shale (of Clinton Group) (Middle Silurian)	10	Upper calcareous shale and limestone and lower massive sandstone (Keefer Sandstone equivalent).	See Folk, 1962; Hunter, 1970.
Rosehill Formation (Middle Silurian)	100-150	Heterogeneous mix of drab olive to red shale, sandstone and limestone.	
Tuscaraora Sandstone (Lower Silurian)	20-100	Thick beds of coarse sandstone with thin shale interbeds.	Fluvial to shallow marine (see Folk, 1960; Yeakel, 1962).
Juniata Formation (Upper Ordovician)	75-200	Red sandstone and mudstone.	Fluvio-deltaic sediments.
Martinsburg Shale (Middle and Upper Ordovician)	1000	Dark bluish to black shale with tan sandstone intervals.	Shallow to deep basinal flysch sediments.
			STOP 2

Mileage

88.3	Junction Maryland Route 615.
91.0	Exit from LEFT LANE to Maryland Route 144 (Pennsylvania Avenue) HANCOCK.
91.4	Tonoloway Creek.
92.6	Turn LEFT to Main Street.
92.7	Cross Western Maryland Railroad then TURN RIGHT-- road parallels C&O Canal. Cross RR and turn to left.
94.6	Cross RR and turn LEFT.
95.0	Park at end of paved road.

STOP 3: Roundtop section along Western Maryland Railroad west of Hancock, Maryland.

This is a recently deactivated section of tract that has been visited by many previous field trips, most led by the late Dr. Ernst Cloos. The structures of interest on this trip are primary sedimentary structures rather than folds, wedges, and cleavage, which are also well exposed. The first cut in an anticline of Bloomsburg Red Beds is pictured in Billings' (1954) *Structural Geology*. For a discussion of the tectonic structures see Cloos (1958); Geiser (1974) has presented an in depth treatment of deformation in the Bloomsburg at this location.

In the second cut the sequence is: (1) Bloomsburg shale in an anticline at the east end overlain by (2) the Wills Creek in an anticline and a syncline to the west. We will concentrate our efforts in this area and if time remains we can walk around the bend into the Tonoloway.

The lithologies and their organization, as discussed by Tourek (1970), are similar to those in the previous sections but the vertical scale is reduced. Most beds are thin to very thin and(or) laminated, and the granular limestones are even less abundant than in the St. Paul. The amount of fine-grained clastic material (red shale) is considerably greater than in the other platform carbonate units, because of stratigraphic and geographic proximity to clastic sedimentary rocks.

The sedimentary structures: scour and fill, graded beds, parallel and ripple cross-lamination, mudcracks, salt casts, and roll-ups, are not unique to these platform carbonate rocks, but the lateral and vertical regularity of lithologies has not been documented in other units. An on-lap and off-lap model on a deflated surface explains the sediments and their cyclicity better here than for any other carbonate sequence in the Appalachians.

Mileage

95.0	Retrace to Md. Rt. 144.
97.4	Turn LEFT on Pennsylvania Avenue.

Mileage

97.5	TURN RIGHT to U.S. 522 (signs for I-70).
97.8	BEAR RIGHT for I-70 east.
130.9	Return via I-70 to Frederick County Appalachian Trail.
138.8	Crest of Catoctin Mountain--cut in Catoctin greenstone with large quartz and epidosite knots.
139.7	Exit RIGHT to U.S. 40 Frederick. Small cuts are in Chilhowee rocks, mostly Harpers Formation.
140.7	Transition to Frederick Valley. The carbonate rocks here have a thin cover of Quaternary mountain wash. Triassic redbeds to the north and south also overlie the carbonate rocks.
141.8	Triassic limestone conglomerate in roadcuts along south side of U.S. 40. The closely associated shales have been used as fill for shopping centers on the north side of the highway.
142.8	Turn LEFT to Holiday Inn Motel, U.S. 40 at Linden Street, Frederick, Maryland.
	END FIRST DAY.

SHALLOW PLATFORM CARBONATE SEDIMENTATION PATTERNS IN THE LOWER PALEOZOIC OF THE CENTRAL APPALACHIANS

Our Approach

The interpretation of depositional environments and sediment-accumulation patterns in space and time is based on sedimentary structures, textures, fossils, mineralogy, paleocurrents, vertical sequence of interbedded lithologies, lateral continuity of lithologies, and deposit geometry. However, of all these attributes we place heaviest reliance on the assemblages of sedimentary structures because they record with most clarity the depositional and other syngenetic processes that operated in the depositional environment.

Our approach is to try to identify small-scale units of rock that carry distinctive assemblages of sedimentary structures, textures, and fossils that delineate distinctive depositional subenvironments.[1/] By subenvironments we mean distinctive physiographic domains in which distinctive sets of physical, chemical, and biological processes operate. A group of genetically related subenvironments makes up an environment, whereas a mosaic of interfingering environments makes up an environmental complex. For example, the Great Bahama Banks is an environmental complex made up of a group of environments such as the open-bank environment, the tidal-flat environment, the reef environment, and so on. In turn the open-bank environment is made up of a leeward lagoon subenvironment and scattered ooid shoal subenvironments; the tidal-flat environment consists of levee, pond, marsh, channel, beach-ridge, and beach subenvironments; while the reef environment can be divided into windward (backreef) lagoon, reef flat, reef front, etc., subenvironments. The rock equivalents of these environmental terms are facies complex, facies and subfacies, so, for example, we speak of the marsh subfacies of the tidal-flat facies, etc.

Our ability to properly interpret rocks on the subfacies level depends almost entirely on our understanding of processes and their sedimentary record in modern depositional environments, the approach that Ginsburg (1974) calls comparative sedimentology. Our criteria were drawn from studies such as those of Logan and others (1970, 1974b), Shinn and others (1969), Hardie (in press), Purser (1973), Reineck and Singh (1973), and Ginsburg (1975), among many others.

The sensitivity of the record

One of the most significant findings of studies of modern shallow carbonate deposits is the remarkable ability of the sediments, particularly in the tidal zone, to record small differences in environmental conditions (Hardie, in press). For example, Fig.5 shows that small surface elevation differences (measured in cms) across a levee on the modern tidal flats of Andros Island, Bahamas, produces large differences in degree of exposure and hence in sedimentary structures like layering, mudcracks, and burrows. Such sensitivity implies that (1) it is unlikely that any two marginal

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1/ With this approach we run into nomenclature difficulties because, if the rock names are to reflect the sedimentary structure criteria, then the present classifications of carbonate rocks (e.g. Folk, 1959; Dunham, 1962) are inadequate because they are based primarily on granular textures. In the Appalachian sequences (as elsewhere) Tidal-flat sediments are made up primarily of micrite and peloids (ooids and skeletal gtains are minor) or their recrystallized equivalents and so the classifications would lump rocks that were actually deposited in significantly different subenvironments. This we found to be frustratingly true of the modern Bahama sediments where subtidal lagoon, intertidal pond, supratidal levee, and freshwater marsh subenvironments all collect the same range and tupe of peloidal sand, silts, and mud grains (see Hardie, in press). An added difficulty is that these classifications cannot handle even the most common of laminated carbonate sediment in which well-sorted peloid sand laminae alternate with mud laminae on a submillimeter scale. Our terminology, therefore, is makeshift and does not follow any established classification.

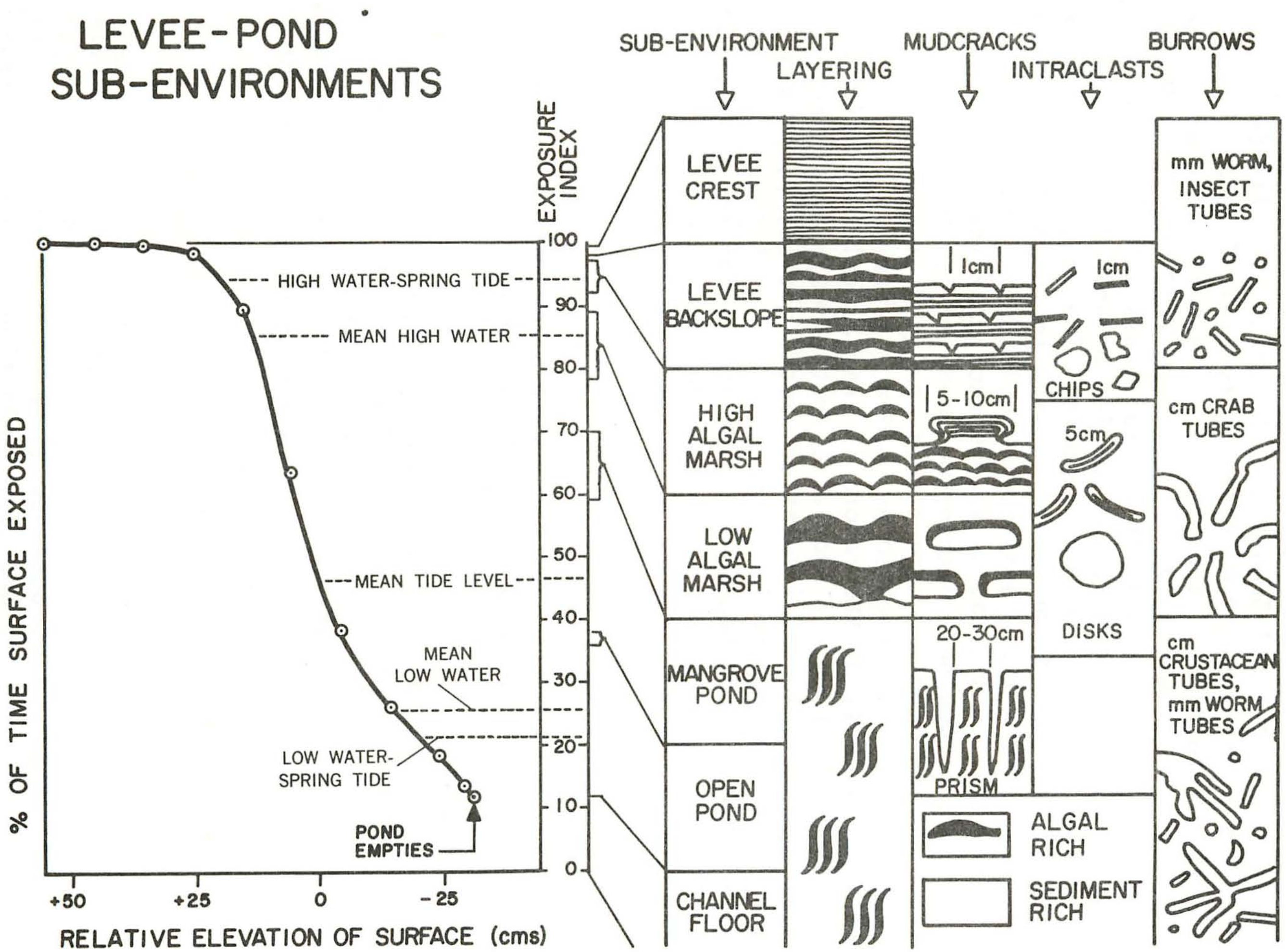


Figure 5. Diagram of exposure index calibrated from studies of the modern tidal flats of Andros Island, Bahamas. From Ginsburg and Hardie (1975).

marine deposits will ever be quite the same, and hence (2) there exist no precise modern analogs for ancient deposits. The first point is amply demonstrated by published descriptions of ancient tidal-flat carbonate rocks (compare, for example, Fischer, 1964; Bosellini, 1967; Laporte, 1967; Matter, 1967; Roehl, 1967; Schenk, 1967; Bosellini and Hardie, 1973) as well as modern tidal flats (compare Shinn and others, 1969; Logan and others, 1970; and Kendall and Skipwith, 1969; for example). It is also demonstrated by comparison of the three Appalachian sections we will visit on this field excursion. All three sequences, the Cambrian Conococheague Limestone, the Ordovician St. Paul Group, and the Silurian Wills Creek Shale exhibit basically the same set of features typical of lagoon-tidal flat complexes, i.e. stromatolites, thrombolites, flat and wavy lamination, thin bedding, mudcracks, burrows, sheet cracks, fenestral pores, pelleted mud, flat-pebble conglomerates, evaporite mineral casts and molds, oolites, and so forth, but the type, abundance, and spatial organization of these features are strikingly different in each deposit. The second point is to be taken as a "cautionary tale." We should not try to force ancient tidal-flat deposits into one of the three available models, the Bahama-, Shark Bay-, or Persian Gulf-model. Instead we should recognize the individuality of each deposit and piece together whatever we need to interpret each subfacies, facies, and facies complex, some pieces coming from one modern example, some from another, as suggested by Hardie (in press). A third consequence of the sensitivity of the record is that a wealth of information on the environmental parameters such as climate, weather patterns, tidal regime, wave activity, water circulation, water chemistry, physiography, etc., must be stored in marginal marine rocks. Unfortunately, at the present time we have far too few correlative studies of the sedimentary record of environmental parameters to be able to do much more than draw broad interpretations.

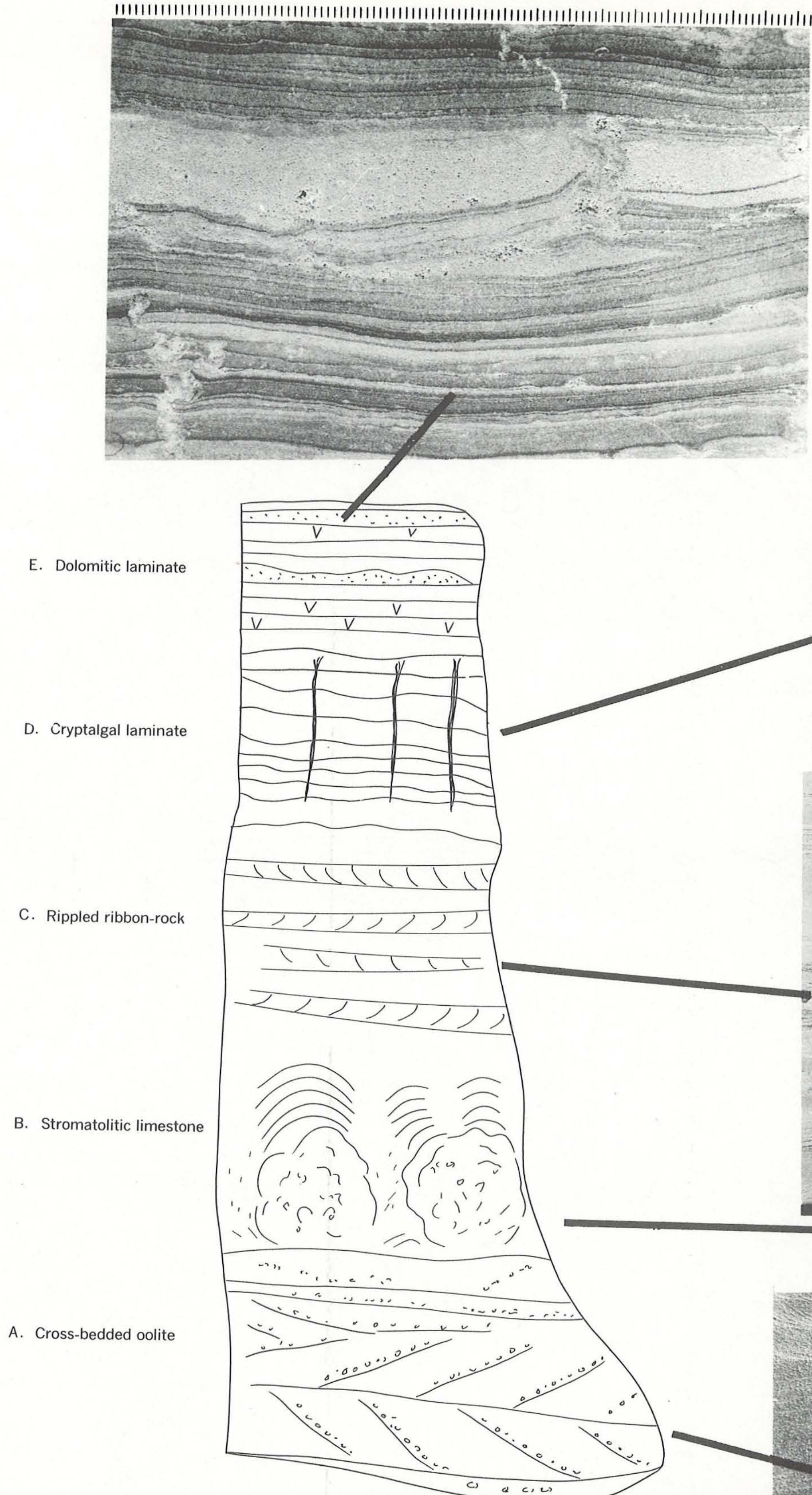
Cycles

Most marginal marine deposits show some systematic vertical arrangement of subfacies, a repetitive packaging of the sediments of adjacent subenvironments as regression of the shoreline progresses with time. This, of course, is the essence of Walther's Law (Walther, 1893, 1894), perhaps the most fundamental tenet of sedimentology (see Middleton, 1973, for a review). In the Appalachian sequences we will visit, the recognition of cycles is the single most illuminating factor in making sense of the seemingly bewildering vertical parade of subfacies. We have, therefore, used the cycle theme to present our brief descriptions and interpretations of the rocks of each sequence.

The rocks

(1) The Upper Cambrian Conococheague Limestone at Corwell's Pasture: A quick look at almost any exposure of the Conocheague Limestone in Maryland will provide convincing evidence of deposition in a shallow-platform lagoon-tidal flat environment complex. As outlined above, this evidence is simply the overwhelming occurrence of flat and wavy lamination, thin beds, stromatolites, thrombolites, oncolites, "herring-bone" crossbedded ooid and peloid sand, rippled peloid sand, flat-pebble conglomerates, burrows and bioturbated

Figure 6. Complete and consequently idealized Conococheague Limestone cycle. The illustrated subfacies indicated by circled letters correspond to descriptions in Table 3. The illustrations are to approximately the same scale (centimeter divisions on the calibrated rule).



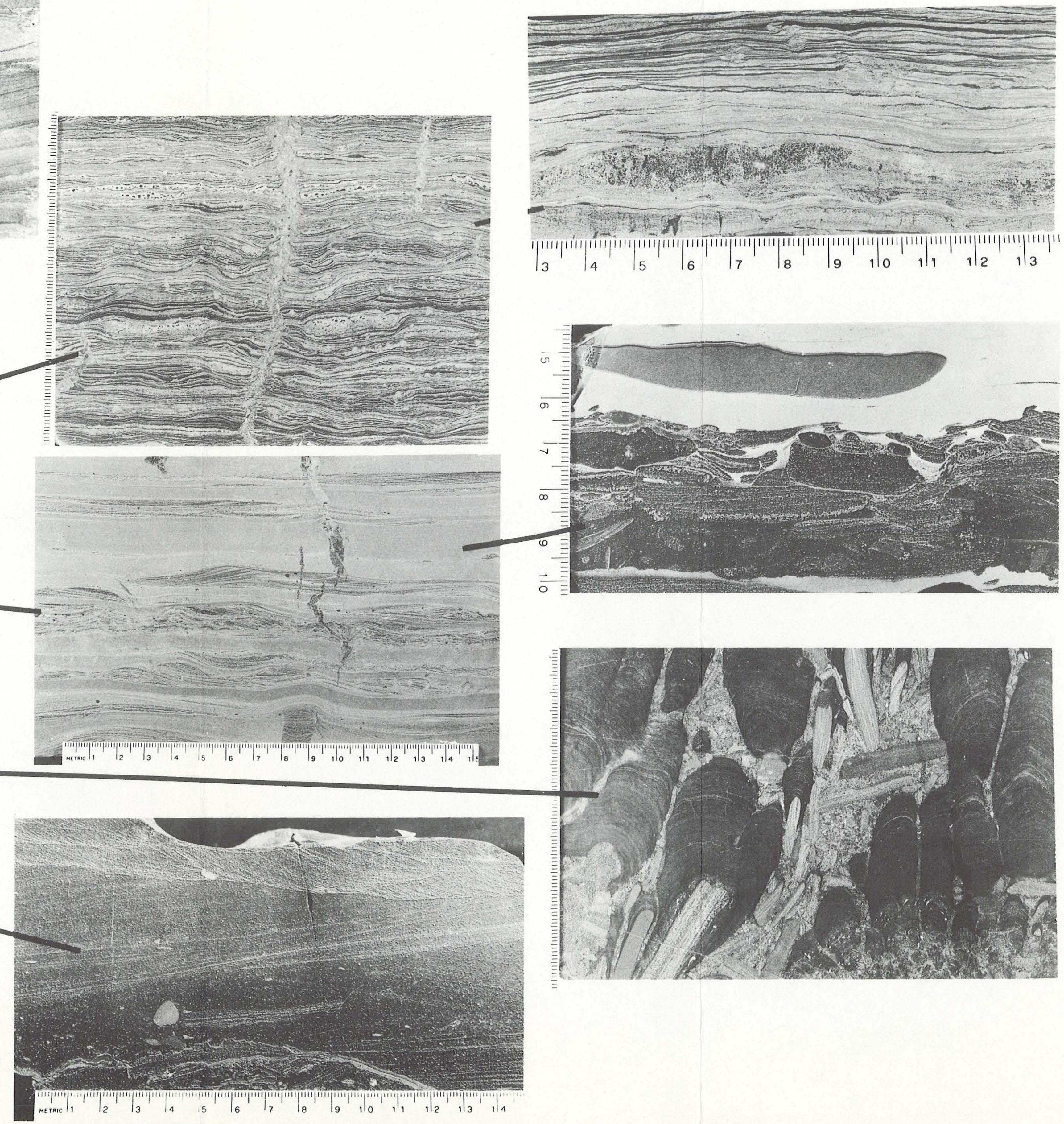


Table 3: The Conococheague Cycle

Typical Thickness	Subfacies	Characteristic features	Depositional subenvironment
0.5 m	Mud cracked dolomitic laminite (E) Grades to	Flat lamination in planar to lenticular beds; shallow mudcracks; thick lenses of carbonate sand and rare pods of cross-bedded quartz sand; gypsum nodules and calcite-lined vugs.	Dry supratidal coastal plain reached by seawater only during major storms; wind transport of both carbonate and quartz sand; evaporitic enough to allow nodular anhydrite growth and discourage algae.
1 m	Prism-cracked cryptalgal laminite (D) Grades to	Wavy lamination composed of alternating peloidal to micritic calcite and dolomite laminae; deep (up to 2m) prism cracks; laminae may drape prism cracks and ripples or oversteepen to LLH heads; uncommon lenses of peloidal sand.	Upper intertidal algal-mud flat; barely covered by water at MHT, exposed enough at low tide to allow pore water drainage to generate the prism cracks. Occasional storm flooding covered the surface with isolated sand ripples; algal mats draping these sand ripples may make small LLH heads.
2 m	(C) Irregularly bounded by	Thin beds of sand and silt-size carbonate (dolomite-rich layers alternating with calcite-rich layers); isolated sheets to pods of flat pebble (intraclast) conglomerate. Ripple cross-laminated sediments are typically distorted by compaction and pressure solution. Burrows are common; mudcracks present but rare.	Lower intertidal sand flat; rippled by waves and burrowed and browsed at high tide, exposed (partially desiccated) at low tide; cohesive algal mat growth discouraged by sediment movement, browsing and burrowing. Flat pebble conglomerates are storm (rip-up) features. Sand mainly pellets or "soft" intraclasts.
1 m	Algal limestone (B)	Large (up to 2 m across) to small (5 m across) SH club- and mound-shaped stromatolites (commonly digitate internally) or thrombolite (unlaminated to very poorly laminated) heads bounded by coarse peloidal, oolitic and skeletal sand with sparse to abundant flat pebbles.	Lower intertidal to upper subtidal wave-swept platform with mobile sand and gravel sheets. Development of algal heads on highs (cemented pavements or stable clasts). Clasts and sand are generated by mechanical erosion of cemented material (pavements, algal heads, etc.)
0.5 m	Crossbedded oolite or calcarenite (A) Erosive base	Well-sorted, "herring-bone" crossbedded oolitic, peloidal and skeletal sand.	Subtidal sand shoals (bars), or in some cases tidal channel fills.

Units are illustrated in Figure 6.

mud, mudcracks, gypsum nodules. However, it is the presence of cycles of subtidal through intertidal to supratidal subfacies that provides the most enlightening picture of Conococheague sedimentation. The most complete cycle in the sequence, though rarely found, nicely summarizes the basic constituent subfacies and their temporal relations. This complete cycle is described and interpreted in Table 3 and illustrated in Figure 6. The cycle is interpreted as a regressive one produced by progradation of an indented strandline of a tropical tidal flat-coastal plain complex over a shallow bank (bar) isolated from the mainland. The entire carbonate sediment production was *in situ* (skeletal debris, mainly mud, from both algae and invertebrates). Sediment production always exceeded bank subsidence (as on Bahama Banks from Cretaceous to present) so that deep-water conditions, which would have prohibited mud production and so stopped the bank accretion "machine," never prevailed. The overall physiography must have been a bank on the continental shelf somewhat like that of the Bahama platform but considerably longer, paralleling the Cambrian and Ordovician mainland for several thousand miles from tropic to tropic. The weather, climate, and wave regime, however, must have been more like that of the dry Shark Bay area of western Australia (Logan and others, 1970). The abundance of club- and large round-shaped stromatolites and thrombolites in a coarse sand and gravel matrix points to significant wave agitation (prevailing onshore winds? i.e.--a windward lagoon?) such as occurs in Shark Bay (the low-wave energies in the Persian Gulf lagoons and the leeward shelf lagoons of the Bahamas do not favor the establishment of large stromatolitic heads in the tidal zone). A moderately arid climate, not as dry as the Persian Gulf (zero rainfall) or as wet as the Bahamas (45-inches rainfall annual average), is suggested by the presence of sparse gypsum nodules and calcite-lined vugs (once anhydrite nodules?) and laminated surface caliche crusts, and by the absence of freshwater marsh tufa. The laminated caliche is very rarely found, but in Corwell's pasture an example, associated with pisolites, is seen at the base of a cycle acting as template on which stromatolite heads developed (see Fig.7).1/ These undulating crusts likely represent vadose diagenetic carbonate encrustation of an emergent sediment surface in a fairly arid setting (compare with similar crusts described by Purser and Loreau (1973) from the Persian Gulf). On submergence during the next transgression of the sea, the local highs of this crusted surface made an excellent stable foundation on which the basal stromatolites of the next cycle could grow.

There is a strong bias in the sequence toward incomplete cycles in which the upper two units, D and E, are missing. At least part of the explanation for this is erosional ingress of the transgressing sea (ravinement) because deeply scoured erosional contacts can be found along cycle boundaries. Another factor is the prevalence of bedding-plane pressure solution within the entire sequence. Parallel, closely spaced stylolites have in places cut out almost entire beds and disrupted the internal organization of beds almost beyond recognition. A conservative estimate would put section loss at about 20 percent but in some places an argument can be made for losses as high as 40 percent. And, of course,

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1/ These caliches were brought to our attention by Joseph Smoot of The Johns Hopkins University.

Figure 7. Polished slab of a stromatolite head. Sample is from the upper part of the Conococheague exposures at Corwell's pasture. The continuous micritic laminae at the base of the head (below arrow) are interpreted as a caliche crust (chemically precipitated), while the discontinuous sandy laminae (above arrow) are interpreted as algal stromatolites (produced by sediment trapping). Scale is in centimeters.

Table 4: The Wills Creek Cycle

Thickness range	Subfacies	Characteristic features	Depositional subenvironment
0.2 - 2.0 m	Highly disrupted massive dolomitic mudstones (C) Grades to	Yellow, massive, concoidal fracturing with vague layering in field; highly disrupted lamination; multiple mudcracks; celestite(?) - gypsum(?) pseudomorphs and calcite lined vugs common in slabs. Rare ostracods; scattered, well-rounded quartz sand grains.	Wind blown sabkha (very arid supratidal flat where extensive mudcracking, intrasediment mineral growth, and efflorescent halite crusts disrupt and destroy sedimentary lamination. Sediment deposition during catastrophic storm flooding and by wind transport.
0.5 - 1.0 m	Mudcracked, laminated calcisiltite to calcilutite (B) Grades to	Planar laminated (mean lamina thickness = 0.17 mm.) continuous mud laminae and discontinuous silt laminae (commonly graded) disrupted by small V-shaped multiple mudcrack fillings. Sheet cracks; pods of intraclasts (thin chips); fenestral pores; halite casts; current-oriented ostracod shells. Rare "jelly roll" structures, wavy (algal?) lamination.	High intertidal mudflat subject mainly to sheet wash (wetted daily); planar surface covered and bound by algal films. Depositional events were sporadic storms producing silty mechanical laminae and flat muddy algal "stick-on" layers. Ponding and evaporation of flood waters produced halite hopper crystals.
0.5 - 3.0 m	Thinly bedded limestone (A)	Lenticular thin beds of calcisiltite and calcilutite with argillaceous partings; ripple cross-laminated sand and silt composed of peloids, skeletal grains (ostracods, brachiopods, echinoderms), ooids and quartz sand. Scours filled with flat pebbles; load casts; convolute bedding; halite casts; stromatolites and thrombolite mounds locally.	Shallow, restricted saline lagoon protected from intense wave and current energy. Periodic evaporative conditions (and even exposure?) during particularly dry periods when halite hopper crystals formed at the air-water interface and foundered into the bottom sediment. Algal mats covered the bottom producing a few LLH-SH stromatolites and thrombolites where conditions were favorable.

Lettered units are illustrated in Figure 8.

as with all natural exposures, crucial parts of the section are covered making it difficult to read the succession of subfacies. Stromatolites and thrombolites may also be missing from unit B but this is to be expected because large SH-stromatolites require particular niches to develop into large mounds (see Logan, 1961; Logan and others 1974a). Ooid shoals, too, are not always present because of their need for a particular current regime.

(2) The Upper Silurian Wills Creek Shale at Roundtop: The sedimentology of the Wills Creek Shale of western Maryland has been studied in considerable detail by Tourek (1970) and much of the information presented here is taken from Tourek's work.

Structures such as flat and wavy lamination, lenticular thin beds, stromatolites, thromobolites, flat-pebble conglomerates, burrows, algal filament molds, mudcracks, sheet cracks, fenestral pores, halite, and other evaporite mineral casts, all show the essential marginal marine nature of the whole Wills Creek sequence, but the abundance of halite casts and mudcracks and desiccation structures call for a very dry evaporative climate. The latter is not too surprising because the Wills Creek is a correlative of the Salina Formation of Michigan (Alling and Briggs, 1961) which contains thick masses of bedded halite.

Tourek (1970) recognized four kinds of cycles in the Wills Creek Shale but they are all variations on the theme of a gradual upward decrease in bedding thickness and increase in desiccation and evaporite features. Sharp (erosional) contacts between subfacies are characteristically found only at boundaries between cycles. The cycle repeated many times at Roundtop is an excellent type example. The basic features are described and interpreted in Table 4 and illustrated in Figure 8.

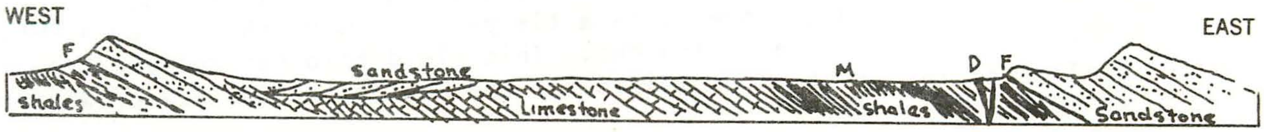
ROAD LOG: SECOND DAY

The Frederick Valley

Introduction

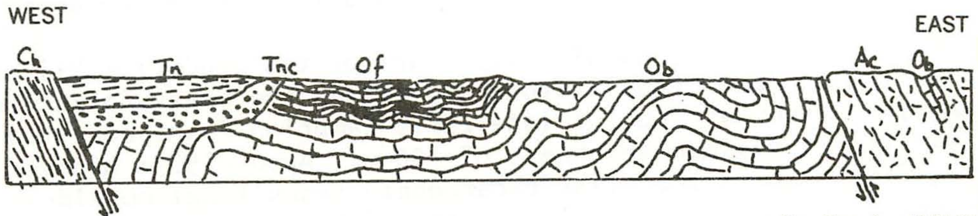
In contrast to the approach yesterday when we compared three temporally distinct, sedimentologically similar carbonate units, today we begin at the base of a shallowing-upward sequence and trace the evolution of a depositional basin situated at the eastern margin of the Cambrian and Ordovician carbonate platform. On the way to the Frederick Valley we have crossed the Blue Ridge province and are therefore in a distinctly different structural and physiographic province. The rocks have been affected by at least two major deformations and the overall structure is an eastward continuation of the South Mountain fold.

The Frederick Valley section has received considerably less attention than the rocks seen on the first day, mainly because of poor exposures. Previous work was done by Keyes (1890), Bassler (1919), Jonas and Stose (1936, 1938), Stose and Stose (1946), Rasetti (1959, 1961), and Reinhardt (1974). The stratigraphic framework has evolved to the point where more than 1,000 m of carbonate rocks are recognized and have been subdivided



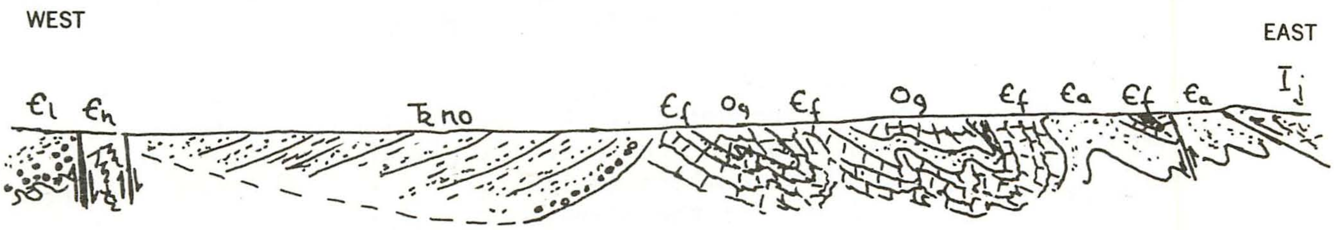
after Keyes (1890)

scale ~1:1000,000
vertical exaggeration ~ 10×



after Bassler (1919)

scale~ 1:62,500
no vertical exaggeration



after Jonas and Stose (1938)

scale 1:62,500
no vertical exaggeration

Keyes (1890) Section from Catoctin Mountain to Sugarloaf Mountain

F=fault
M=Monocacy River
D= diabase dike

Bassler (1919) West to east section about 3 km north of Frederick, Md.

Td=Triassic Diabase
Tn=Newark sandstone and shale
Tnc=Newark Conglomerate
Ob=Beekmantown Limestone
Of=Frederick Limestone
Ac=Catoctin Schist
Ꞓh=Harpers Shale

Jonas and Stose (1938) Portion of C-C′ section about 8 km north of Frederick, Md.

TRno=New Oxford Formation
Og=Grove Limestone (~200 m thick)
Ꞓf=Frederick Limestone (~200 m thick)
Ꞓa=Antietam Quartzite
Ꞓh=Harpers Phyllite
Ꞓl=Loudoun Formation
Ij=Ijamsville Phyllite

Figure 9. Sketch of cross-sections of the Frederick Valley.

into four stratigraphic units (see Figs. 9,10, 11). This area is especially important since it is a tie point between the Valley and Ridge province and the western Piedmont. This field trip has evolved from a similar series of stops organized for the Geological Society of Washington in 1973.

Stratigraphic and Lithologic Framework

The stratigraphic nomenclature of the Frederick Valley has developed along with the gross structural interpretation of the area (Figs. 9, 10) The recognition of the Frederick Valley as a major synclinorium presents interesting geometric aspects to the platform or shelf-basin transition.

The oldest unit considered a part of the Frederick Valley sequence is a fine-grained metasiltstone-argillite, the Araby Formation[1/], which contains *Olenellus* sp., a late Early Cambrian fauna near the middle of an estimated minimum thickness of 100 m. About 150 m higher in the section (100 m above the clastic-carbonate transition) considerable collections of Dresbachian (earliest stage of Late Cambrian) faunas were gathered by Rasetti (1959). This lowermost interval is where the greatest uncertainty and lack of biostratigraphic control exists. These rocks are temporally equivalent to the Antietam, Tomstown, Waynesboro, and Elbrook Formations. While the clastic-carbonate transition occurs below the Lower-Middle Cambrian boundary in the Great Valley section, it occurs close to the Middle-Upper Cambrian boundary in the Frederick Valley section. This temporal shift in gross lithologic boundaries has important paleogeographic consequences: it indicates that the Frederick Valley was a starved clastic basin during the Early and Middle Cambrian.

The Upper Cambrian rocks are thick packages of thinly bedded "dark and dirty" limestone interrupted by thick beds of coarse-grained "clean" limestone collectively called the Frederick Limestone. This unit has been subdivided into three members (Reinhardt, 1974): the Rocky Springs Station[2/] (Stops 4, 5, and 9); the Adamstown[2/] (Stops 6 and 7); and the Lime Kiln[2/] (Stop 7) on the basis of lithology and sedimentary structures with some biostratigraphic aid. A detailed stratigtaphic section is presented for the Frederick Limestone in Figure 11.

The transition from the Frederick Limestone to the Grove Limestone is nearly coincident with the Upper Cambrian-Lower Ordovician boundary, based on conodont and cephalopod data (A. G. Epstein and R. Flower, oral commun., 1974). The Grove consists of coarse-grained, arenaceous limestones comparable in lithologies and lithologic packaging to the Conococheague Limestone and Beekmantown Group.

1/ Araby Formation of Reinhardt (1974) is herein adopted for usage by the U.S. Geological Survey.

2/ Three new members of the Frederick Limestone (in ascending order): the Rocky Springs Station, the Adamstown, and the Lime Kiln of Reinhardt (1974) are herein adopted for usage by the U.S. Geological Survey.

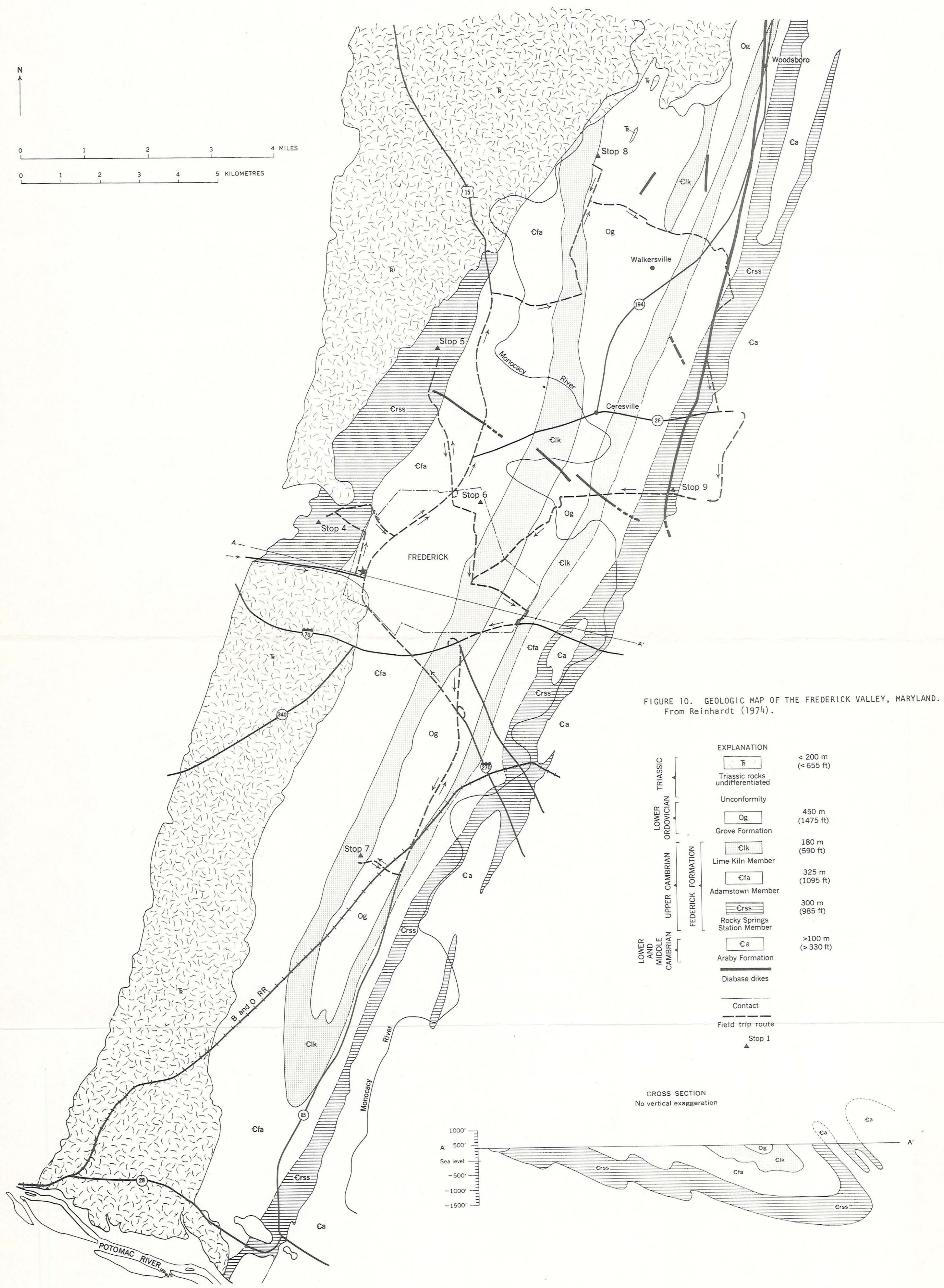


FIGURE 10. GEOLOGIC MAP OF THE FREDERICK VALLEY, MARYLAND. From Reinhardt (1974).

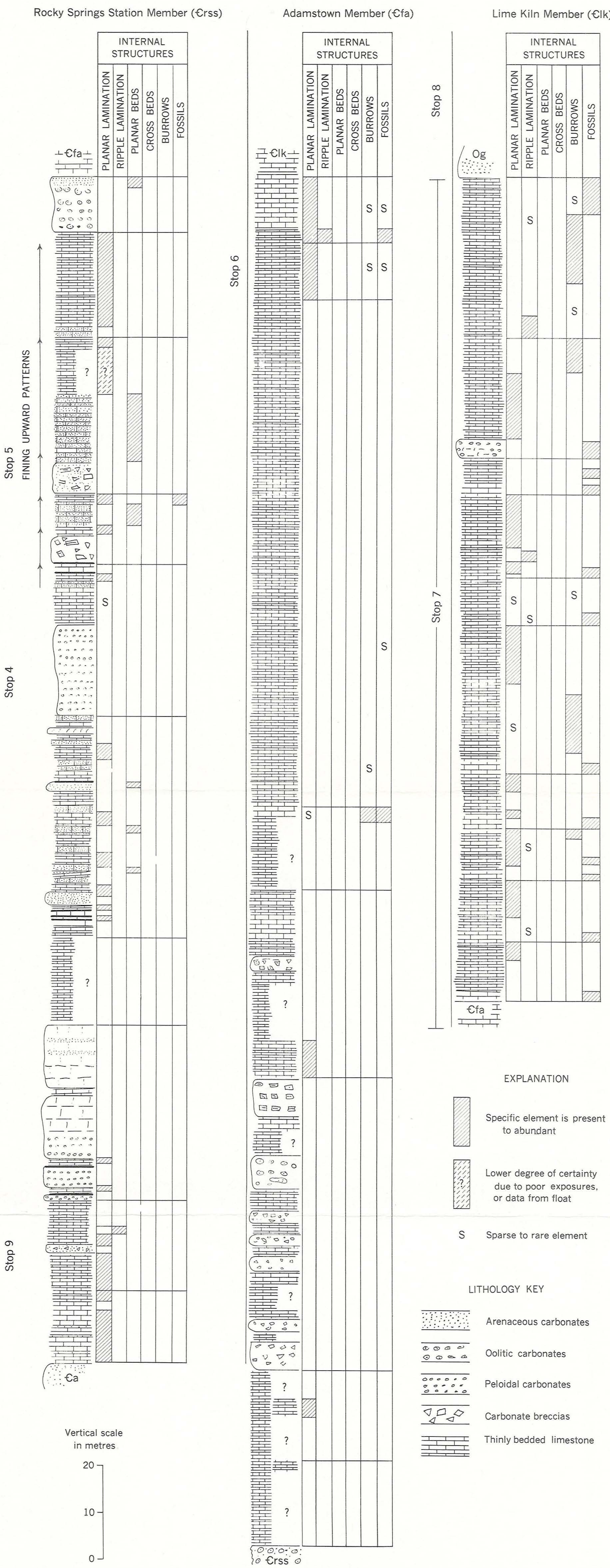


FIGURE 11. DIAGRAM OF GEOLOGIC COLUMNS OF FREDERICK LIMESTONE MEMBERS.

Departure from Holiday Inn, Linden Street at U.S. 40, Frederick, Maryland, at 8:00 A.M. Field trip will follow routes shown on the Frederick Valley geologic map (Fig. 10).

Mileage

0.0	Leave motel parking lot and proceed north on Linden Street.
0.5	LEFT turn on Shookstown Road.
1.3	Park on right shoulder and walk into Brosius Quarry.
	STOP 4: Abandoned limestone quarry in Rocky Springs Station Member, Frederick Limestone.

Tops of beds are to the east-southeast at a high angle and two distinct lithotypes are exposed (measured section, Fig. 12). Basic to understanding the relationship of these two lithologies is knowing the bulk composition of the stratigraphic column. A high percentage, probably about 80 percent of the Frederick Limestone, is composed of thinly bedded argillaceous limestone (Fig. 11). This point makes careful consideration of the thick- to massively bedded peloidal limestone especially important at this stop.

Figures 13 a-b show the petrology of the granular or intraclastic limestone. These are well-rounded, moderately well-sorted, limestone and dolomite lithoclasts; some of the clasts are clearly second cycle. The lack of clear internal structure in the peloidal limestone is problematic. The basal unit must be either a single 16-m-thick sheet (or pod) of sediment or thinner amalgamated sheets which show no contacts due to material homogeneity.

The tectonic imprint on these rocks, especially on the thinly bedded limestones, is considerable. Some discussion of the "breccia" zone at the top of the section (distorted zone in Fig.12) will introduce criteria for depositional breccias.

Mileage

1.3	Retrace along Shookstown Road to fork.
1.6	Take LEFT fork to Montevue Road.
2.5	Turn RIGHT to junction U.S. 15 North.
2.9	Turn LEFT to entrance ramp and proceed to second exit.
4.2	Motter Avenue exit. Proceed north on Opossumtown Pike to fork in road.
6.8	Take RIGHT fork and park.

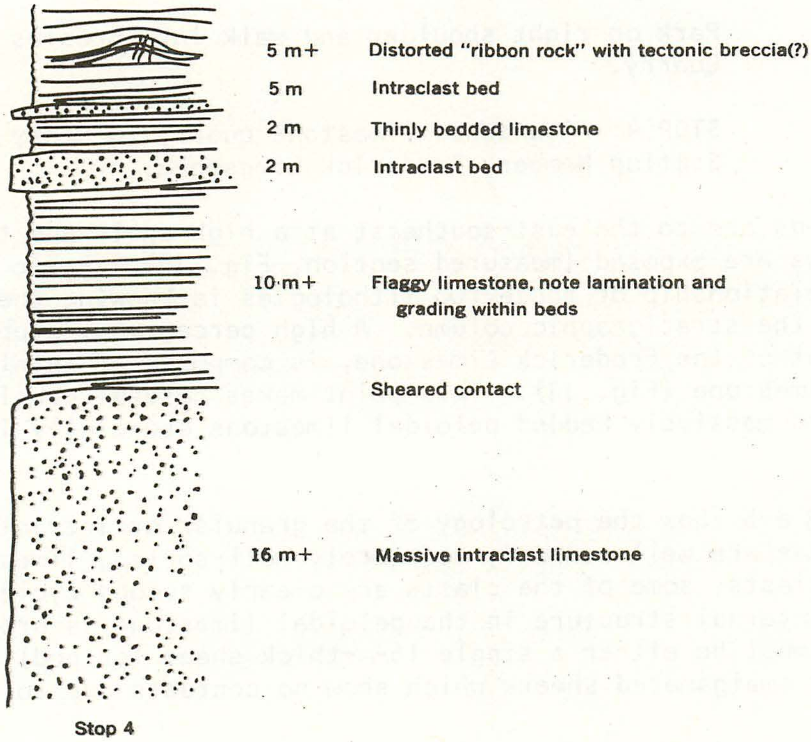


Figure 12. Sketch of stratigraphic section exposed in quarry pit on Brosius property (stop 4), Rocky Springs Station Member of the Frederick Formation.

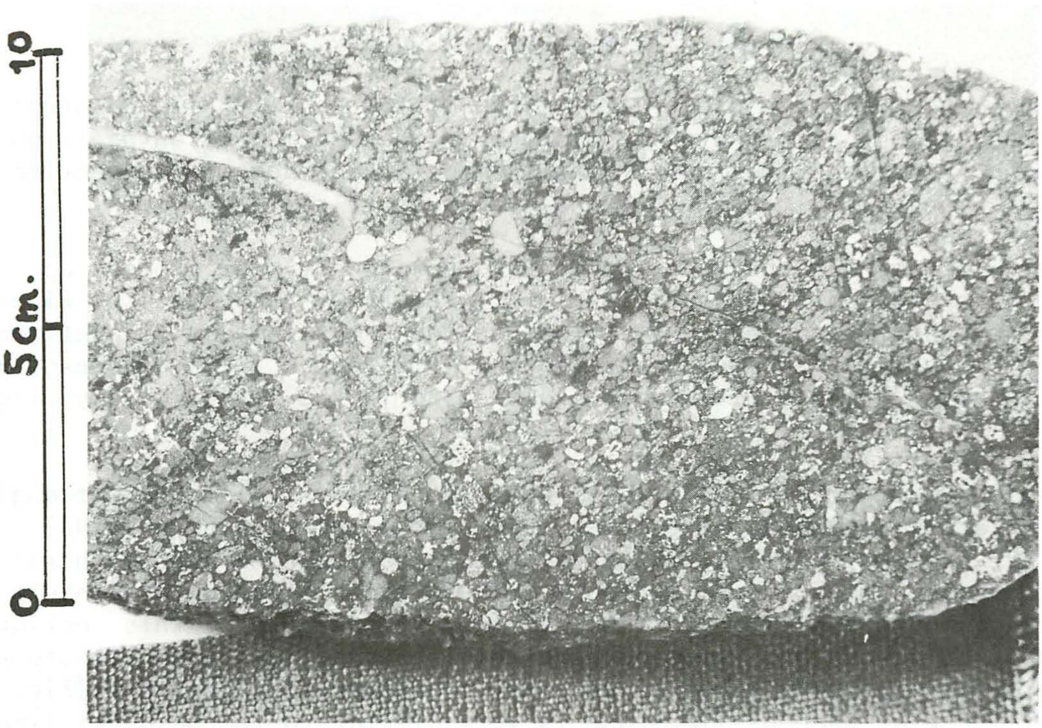


Figure 13a. Polished, etched, and stained slab of granular limestone from Brosius quarry. Lithoclasts are both dolomite and limestone: Note absence of internal structure and the degree of size sorting.

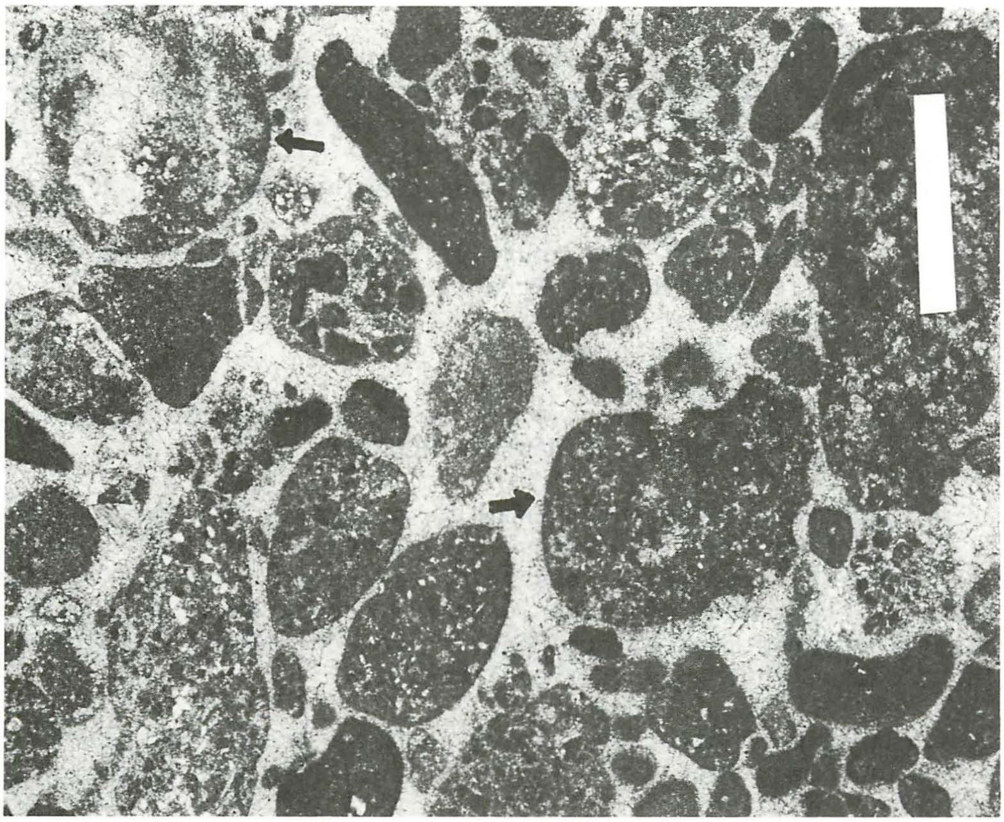


Figure 13b. Photomicrograph of intraclast limestone cemented by calcitic microspar; note rim cement on clasts. Field is about 5 cm across.

STOP 5: Staley Farm and quarry.

These exposures are closer to the top of the Rocky Springs Station Member and present a more dynamic picture of the sedimentation patterns within the Frederick Limestone. Rasetti made a considerable collection of Dresbachian trilobites for his 1961 paper at this locality.

We will begin at the western edge of the property and proceed up section (back toward the bus). The 2.0-m interval at the bottom of Figure 14 contains abundant parallel to very low angle, cross laminations defined by quartz silt in thinly bedded, argillaceous limestone. This low-energy lithology contrasts sharply with the rocks exposed in the Staley quarry (Fig. 14).

The polymict breccia (Fig. 14a) contains primarily intraformational clasts (flaggy, laminated limestone), but sparse oolitic and peloidal clasts are present. The matrix contains both oolites and coarse quartz sand; these are extrabasinal elements. The breccia fines upward into a laminated limestone similar to the lithology at the base of this section. Note the erosive contact between these thinly bedded laminated limestone and the overlying thickly bedded peloidal to arenaceous limestone (Fig. 14b). Texturally the arenaceous limestone is very similar to the peloidal limestone at Stop 4, but tabular beds are well defined here, documenting upper flow regime bed forms (Fig. 14c).

Mileage

6.8	Retrace route along Shookstown Road. Note hummocks in fields on west side of the road; these are semi-continuous pods of polymict breccia.
9.4	Cross U.S. 15 north and continue on Motter Avenue.
9.6	Turn LEFT just south of Frederick High School (14th Street) to East Street.
10.0	Turn RIGHT and park.

STOP 6: Railroad cut in Adamstown Member, Frederick Limestone. NO HAMMERS PLEASE!

This 2-m-thick set of exposures exhibits a variety of primary bedding structures in thinly bedded limestone. Structures other than planar laminations are rare in flaggy limestone below this unit. Also, a considerable increase in the amount of biogenic debris occurs above this interval. The increases in current energy and biogenic components are important in documenting a change in the depositional basin.

Some of the primary structures to be seen are scour and fill (Fig. 15 a-b) on several scales, ripple cross lamination, isolated ripple forms (starved ripples), gradded bedding, and more parallel laminations. The beds are defined by dolomitic horizons which are also pressure solution surfaces. Wispy dolomitic laminations similar to those in the Chambersburg (Stop 2) are present here, and are even more prevalent elsewhere in the Adamstown Member.

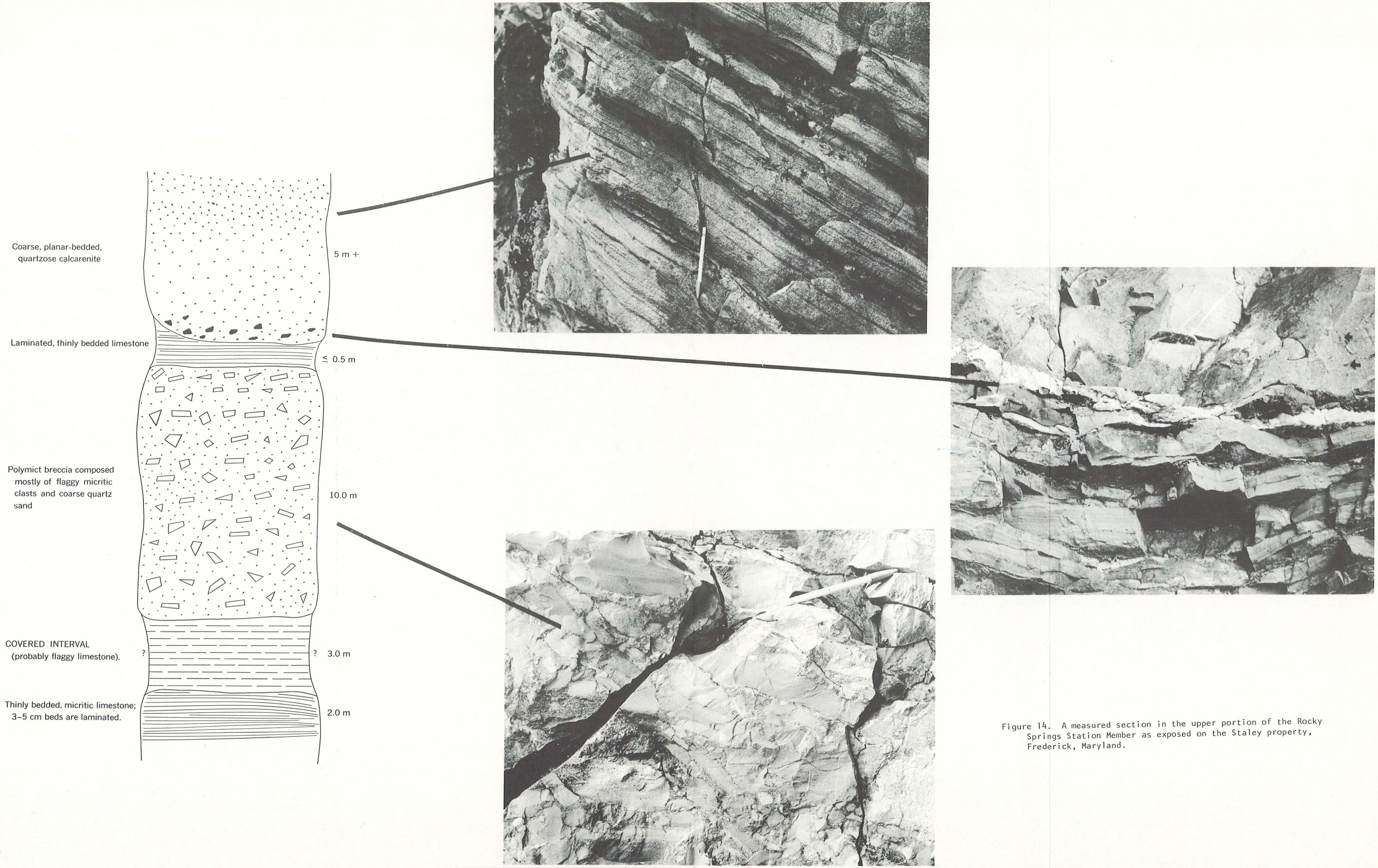


Figure 14. A measured section in the upper portion of the Rocky Springs Station Member as exposed on the Staley property, Frederick, Maryland.

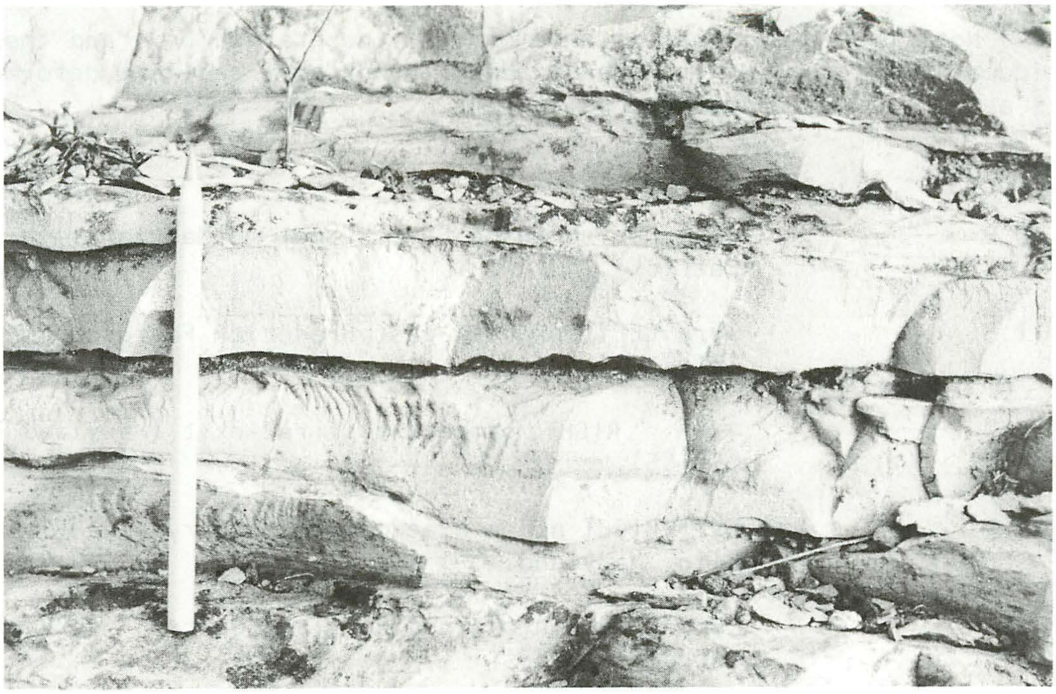


Figure 15a. Coarse granular limestone bed of Adamstown Member, Frederick Limestone, showing scour and fill relationship to underlying parallel-laminated bed.

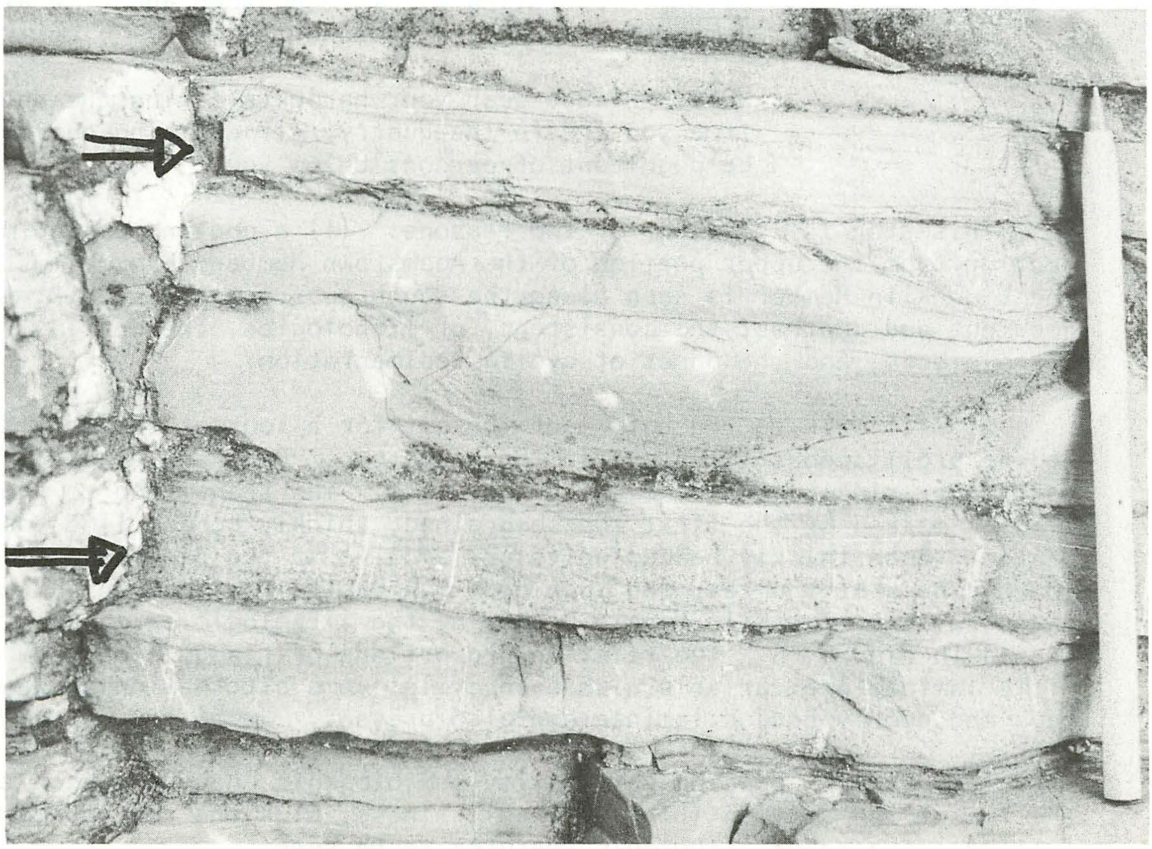


Figure 15b. Typical flaggy limestones near top of the Adamstown Member (Stop 6). Petrologic components and stratification types are variable from bed to bed with Adamstown. Note the transition from low-angle, ripple fore-set lamination (lower arrow) to parallel lamination with a corresponding decrease in grain size.

Note the lateral persistence of the fine-grained beds and the lenticularity of some of the coarse beds. Minor soft-sediment deformation is associated with coarse pods.

Mileage

10.0	Continue south on East Street to Maryland 144 (East Patrick).
11.5	Turn LEFT, proceed past Frederick Fairgrounds (on left).
12.7	Turn RIGHT, proceed to first exit (Maryland Route 355-85).
14.3	Exit RIGHT and proceed south on Maryland 85 to Lime Kiln, Maryland.
18.4	Turn RIGHT into Alpha Portland Quarry. Park along entrance road.
	LUNCH STOP
	After lunch proceed to "Frederick pit."
19.2	STOP 7: Operating pit in Adamstown and Lime Kiln Members, Frederick Limestone.
	NOTE: Please wear your hardhats during the entire time you are in the quarry. If climbing quarry wall, be cognizant of persons below you.

This stop is included for two reasons: (1) a continuous 200-m section from the upper portion of the Adamstown Member through most of the Lime Kiln Member is seen along the south quarry wall, and (2) to document and contrast the consistency of lithologies, the continuity of certain beds, and the onset of cyclic sedimentation.

We will walk to the bottom of the pit for a look at the very thinly bedded argillaceous limestone in the Adamstown. Beds are generally well defined by riddled and(?) by wispy dolomite. The transition to the Lime Kiln is marked by the first coarse-grained, thickly bedded limestone. Most of these thickly bedded units are erosive at the base and gradational to thin beds at the top; ten such beds punctuated the section in this quarry. A generalized Lime Kiln "cycle," showing the lithologic arrangement, is presented in Figure 16. The relative proportions of flaggy limestone and dolomitic laminae are variable with each cycle; some alternations between thin beds and poorly bedded laminae are also present.

Increases in bedding variability and biogenic input are seen toward the top of the section (Figs. 17a-b). These, plus the pod-shaped channel fills are the major lithologic features to be seen.

GENERALIZED LIME KILN CYCLE (approximately 10 m thick)

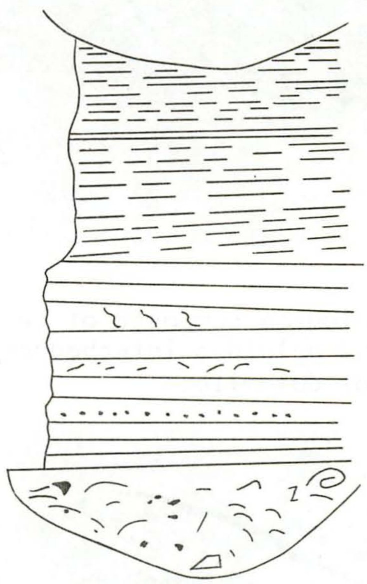


Figure 16. Sketch of packaging of lithologies and sedimentary structures as exposed in the Lime Kiln Member in the "Frederick Pit", Alpha Portland Quarry, Lime Kiln, Maryland (stop 7). The basal unit, probably a channel fill deposit, is more obviously lensoid and erosive near the top of the exposure.

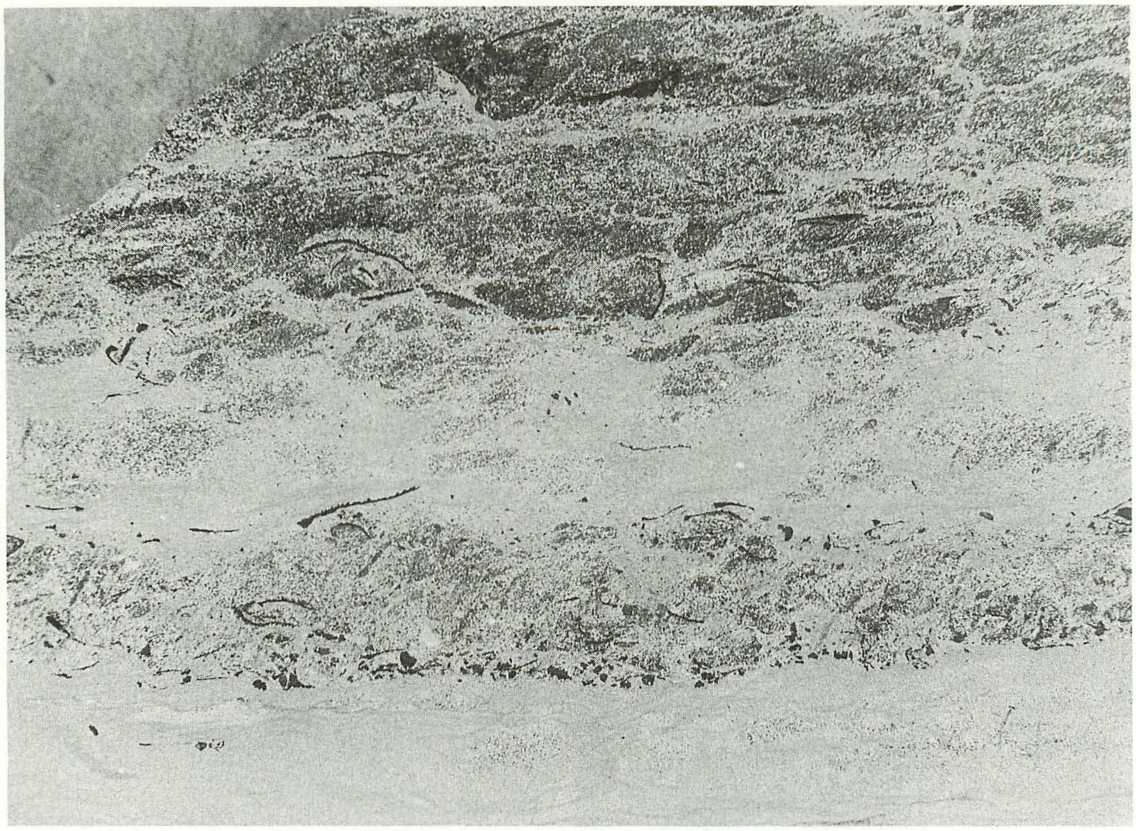


Figure 17a. Thinly bedded limestone-dolomite composed of calcareous, current-oriented, fossil debris and peloids; interbedded with wispy to irregularly bedded, argillaceous dolomite.

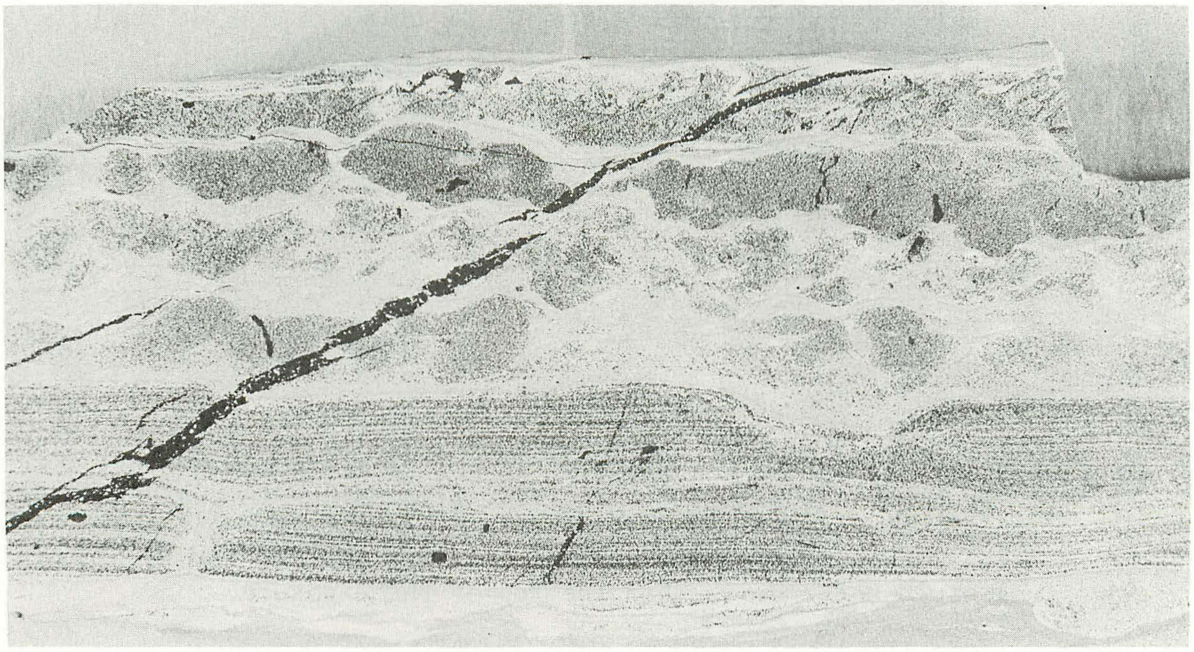


Figure 17b. Planar laminated limestone bed with a scoured top surface and overlain by poorly bedded-mottled limestone. Scour contains an unstratified fill on right side and a thin drape on left side.

Mileage

19.2	Return to Maryland Route 85 along Alpha Portland roadways.
20.0	Turn LEFT toward Frederick.
23.1	Turn RIGHT onto ramp for I-270 north and keep left (follow signs for U.S. 15 north).
24.5	U.S. 15 north continue past U.S. 40, Motter Avenue, to Biggs Ford Road.
33.0	Turn RIGHT on Biggs Ford Road.
33.8	Cross Monocacy River. The river crested at this road level during tropical storm Agnes (1972); locally the flood plain was 1.5 miles wide.
34.6	Turn LEFT on Dublin Road--cross Devilbiss Bridge Road.
37.0	Turn LEFT at Glen Trout Farm.
	STOP 8: Pasture exposures in lower part of Grove Limestone.

The exposures at this stop should be somewhat reminiscent of the rocks seen at Stop 1 in the Conococheague. Except for the absence of "ribbon rock," most other lithologic elements are present. Three major lithologies can be defined (Fig. 10); each characterized by distinct sedimentary structures.

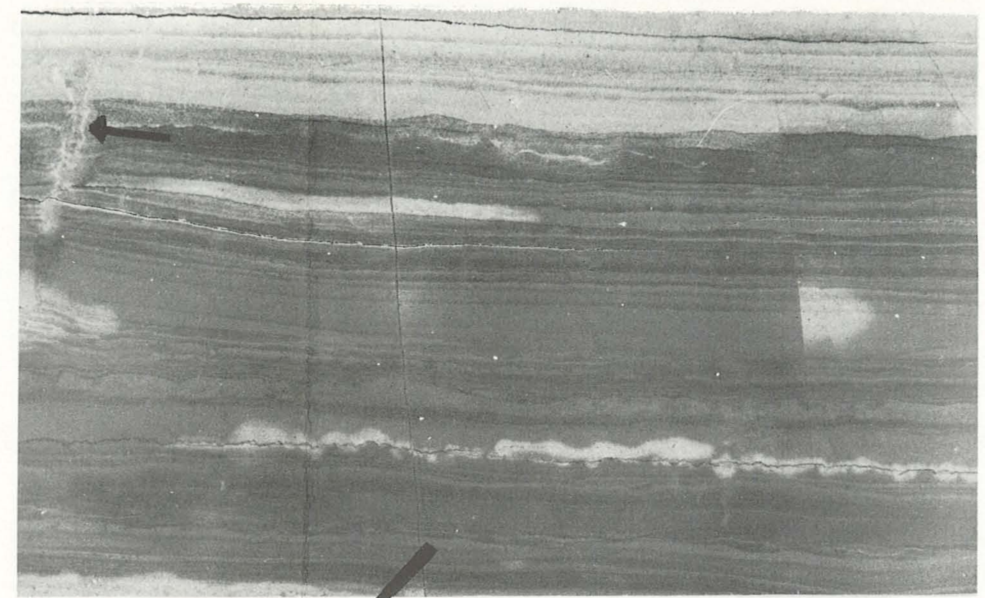
The coarse, cross-stratified sediments and the coarse sediment-infill between large, high-relict stromatolites are documentation for a high-energy platform deposit (Fig. 10 a-b). Crinkled laminations and vertical disruptions, probably representing mudcracks (Fig.10 c), are some of the documentation for tidal-flat sedimentation.

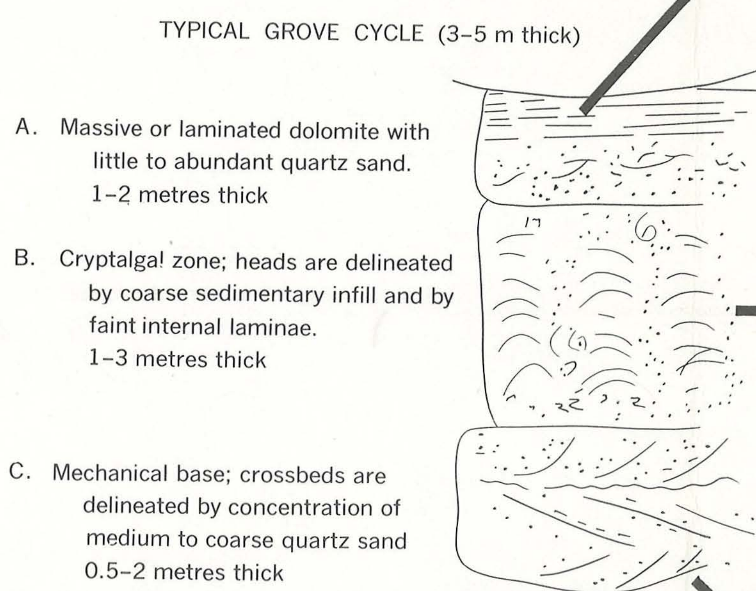
Several cycles can be walked out in this and adjacent pastures. Individual lithologies can be traced for up to 1.6 km through the presence of large-scale pressure solution features, poor exposures, and small-scale faults make such correlations somewhat tenuous.

Documentation of platform carbonate rocks (Grove Limestone) above basin carbonate rocks (Frederick Limestone) within a conformable sequence gives fundamental information on the evolution of a depositional basin and on the margin of the Cambrian-Ordovician shelf margin.

Mileage

37.0	Return to Dublin Road. Turn RIGHT to Devilbiss Bridge Road.





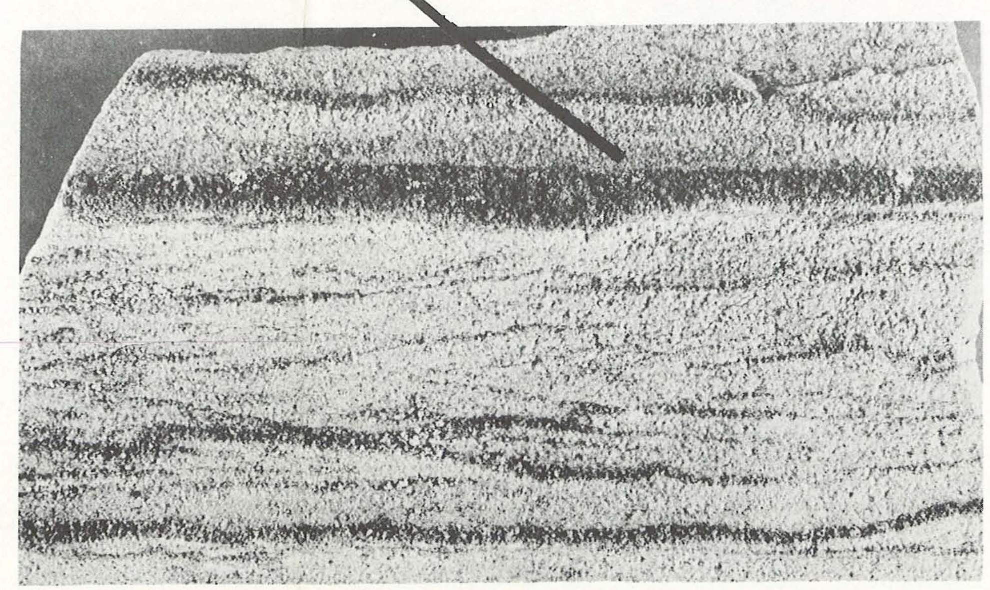


Figure 18. Three major lithologic components characterize most of the Grove Formation. A cyclic arrangement of these components (not to same scale) is displayed in the Trout Farm pasture (Stop 8).

Mileage

37.5	Turn LEFT and proceed across the axis of the syncline to Maryland Route 194.
39.7	Turn RIGHT, proceed through Walkersville to Ceresville at Maryland Route 26.
43.2	Turn LEFT, proceed through Mt. Pleasant to Dance Hall Road.
45.5	Turn RIGHT to Gas House Pike. Exposures of quartzite and Ijamsville Phyllite along both sides of Dance Hall Road are western Piedmont lithologies probably correlative with Chilhowee Group rocks in the Great Valley section.
47.2	Turn RIGHT to west side of roadcut.
48.0	STOP 9: Gas House Pike. Diabase dike (Tr) flanked by by basal carbonate rocks of the Rocky Springs Station Member.
	PLEASE WATCH FOR AUTOMOBILES ALONG THIS ROAD. LOCAL TRAFFIC USES THIS STRETCH AS A DRAG-STRIP RACEWAY.

This exposure contains some lithologies that are quite familiar by now and others that have not yet been seen on this trip. Stratigraphically we are about 25 m above the contact with the Araby Formation. The laminated dolomite at the eastern edge of the exposure would probably have been mapped as Tomstown Dolomite by Jonas and Stose. Some of the laminations in this lithology may be tectonic (note the isoclinal folds); others are probably residues of extreme pressure solution.

West of the 90-m-thick diabase dike are graded, flaggy limestone units that are continuous even around folds. At the extreme west end of the cut a small patch of breccia crops out. Note the absence of oolitic or peloidal clasts, the small size of micritic clasts, and the quartz-sand granular carbonate matrix. This breccia is almost certainly the distal equivalent of a deposit like the one seen at Stop 5 this morning. Proximity to and similarity with western Piedmont carbonate units, especially the Silver Run Limestone, is in part the basis for extending the paleogeographic scheme from the Great Valley section through the Frederick Valley and into the western Piedmont.

Mileage

48.0	Continue west on Gas House Pike toward Frederick.
50.0	Cross Monocacy River at the axis of the syncline. Grove Limestone is nearly flatlying here.
53.8	Turn LEFT at East Street.
54.0	Turn LEFT at Maryland Route 144.

Mileage

55.5 Turn RIGHT to I-70 (U.S. 40 west).

56.8 Exit RIGHT to Maryland 355-85 access to I-270 south, bear RIGHT on Maryland 85.

58.2 Bear RIGHT for I-270 south and retrace to Stouffers Inn, Alexandria, Virginia.

85.4 END OF TRIP.

SEDIMENTOLOGICAL ANALYSIS: FREDERICK VALLEY CARBONATE ROCKS

The sedimentary rocks seen on the second day include a wide variety of lithologies and sedimentary structures that indicate a range of depositional environments. Some of the variables influencing the petrology of these rocks are: current velocity, sediment source, rate of sedimentation, and biogenic activity. The vertical sequence, as well as lateral variation, gives us an understanding of the basin geometry (depth and orientation) and the nature of the shelf-basin transition.

The lower portion of the carbonate sequence (Rocky Springs Station and some of the Adamstown) is composed of lithologies unmodified by biogenic activity (burrowing); the sparse faunas are probably transported. The sediments are typically micritic, recrystallized to microspar, and are packaged as thin beds. These beds contain a paucity of sedimentary structures other than parallel lamination. Grading of these beds is not conspicuous unless some noncarbonate silt or carbonate clasts are present. Complete "Bouma cycles" (Bouma, 1962) are present in thin- to very thinly bedded limestone (Fig. 19) but are rare. Both the graded beds and the erosive bases to fine-grained gradational tops document waning currents. The parallel lamination could be produced either by pelagic fallout or by gentle bottom currents; this is the dominant theme during the initial portion of the basin fill.

The pods and (or) sheets of peloidal limestone and breccia represent episodic, rapid-sedimentation events. These events ranged from submarine slides and debris flows where there was considerable scour and clast interaction, producing polymict breccias, to density flows (grain flows) in which well-sorted, sand-size components were transported with little abrasion of the granules and little scour of the underlying beds (Fig. 20). This continuum (Middleton and Hampton, 1973) is represented at the fine-grain high-water content end by turbidity currents. The mechanism for generating these currents is the initial slump of blocks close to the shelf edge or along the margin of a tidal channel or submarine fan. Blocks, or at least breccia matrix, have moved at least the width of the valley, which, unfolded, is about 16 km, during a single event. The extraordinarily well-sorted sandy peloid or oolite beds are probably the result of strandline deposits carried down submarine canyons as a result of storm swash or simply as the result of circulation patterns close to the platform edge.

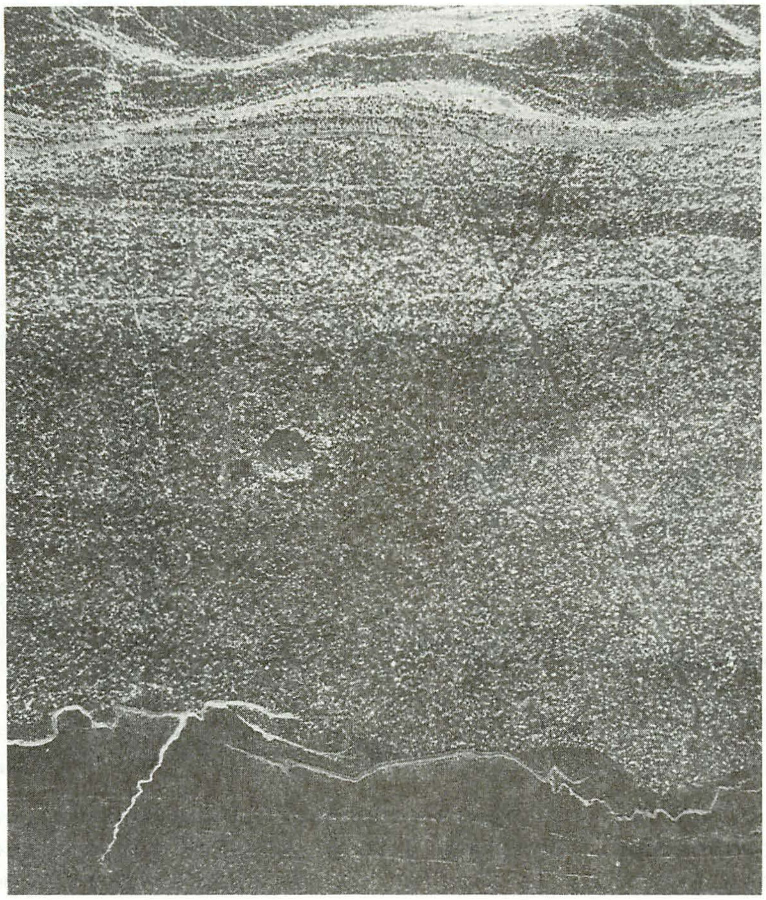


Figure 19. Atypically thick bed from the lower half of the Rocky Springs Station Member (Stop 9) containing all the elements in a Bouma cycle. cycle. An erosive base cuts structureless argillaceous limestone (part E of the Bouma cycle, a ragged stylotie roughly parallels the base of the bed. Elements A through C are gradational from a structureless and graded interval to parallel laminae and ripple cross-laminae. Vertical distance is about 10 cm.

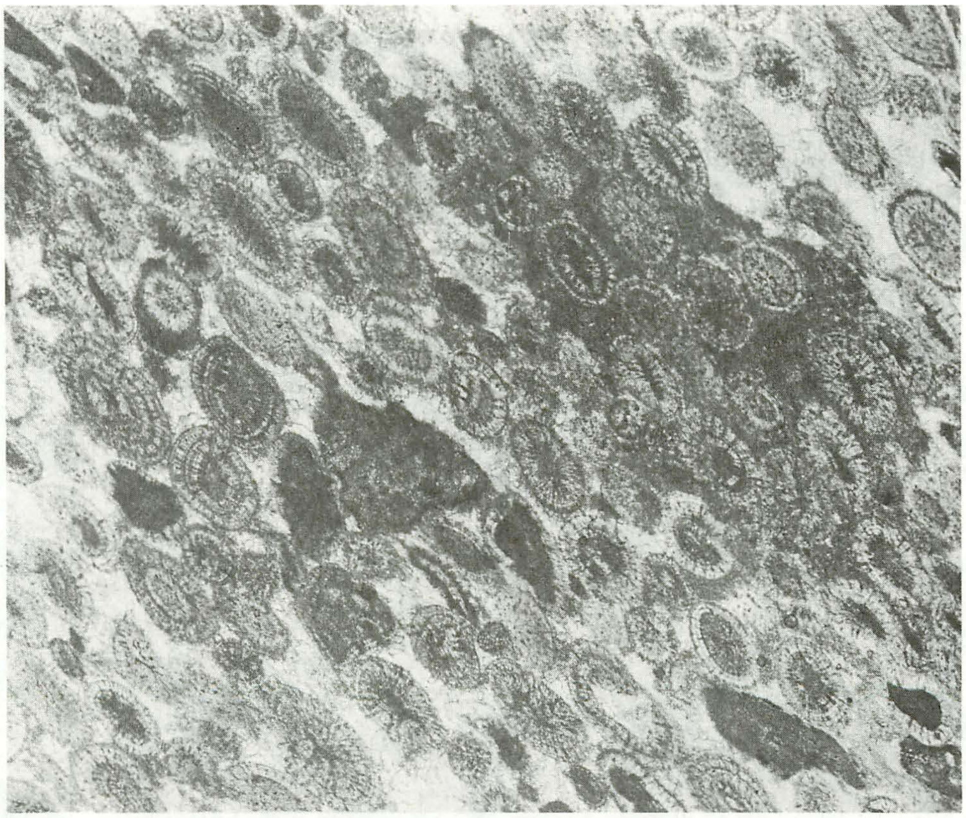


Figure 20. Moderately deformed, massively bedded oolite from the top of the Rocky Springs Station Member. Micritic clot in right center of the photomicrograph suggests relict matrix which has recrystallized to microspar cement elsewhere. Field is about 5 cm across.

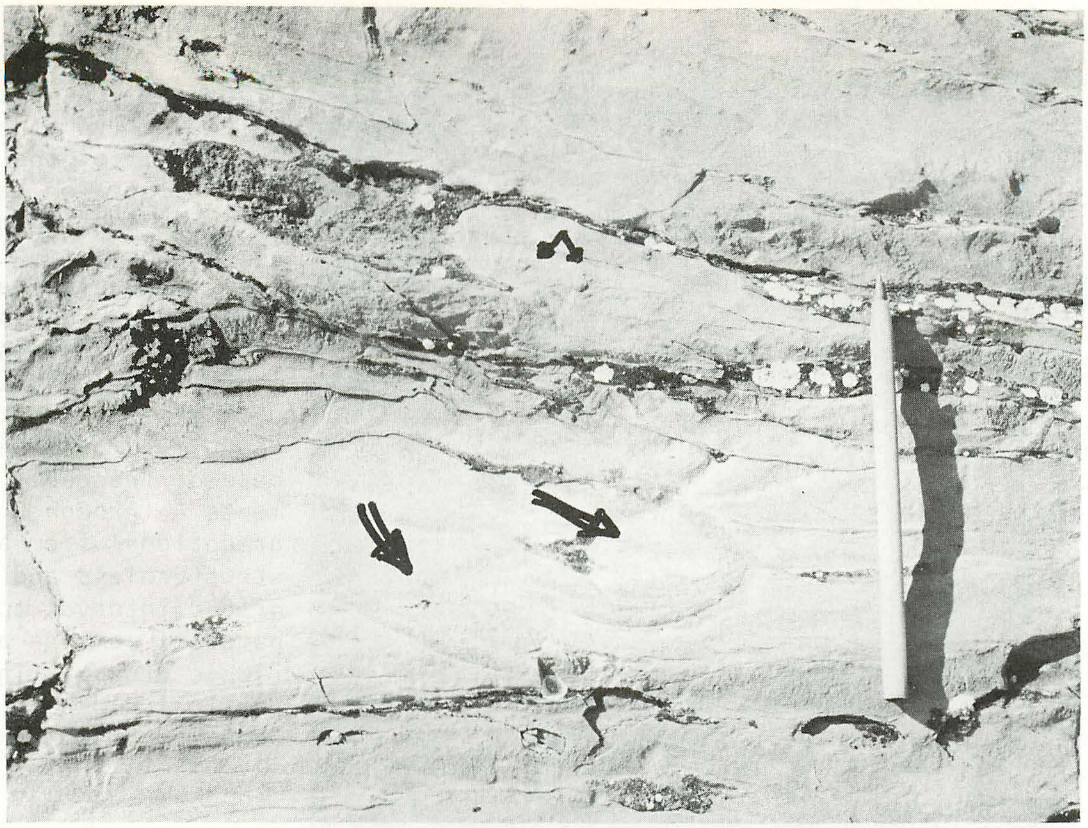


Figure 21a. Photo of an oblique view of open-spiral burrows (arrows) in the Adamstown Member. Beds are 3 to 5 cm thick and defined by dolomitic seams; lithology is similar to the Chambersburg Limestone but contains fewer fossil fragments.

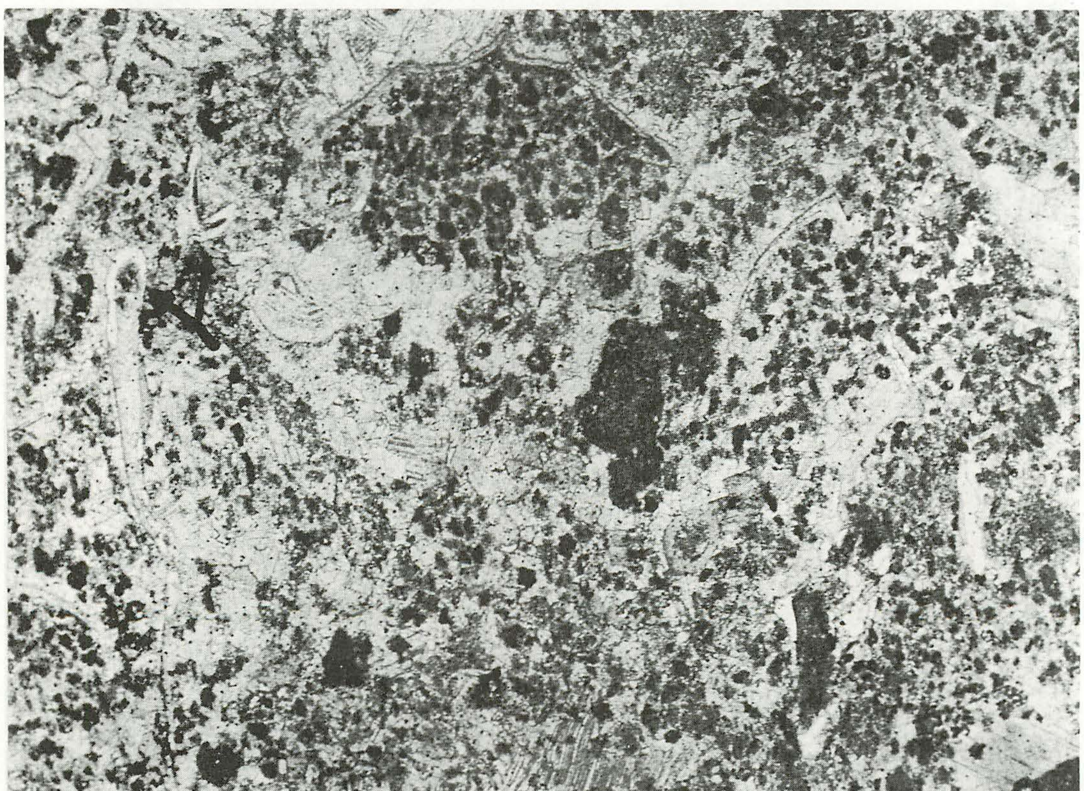


Figure 21b. Photomicrograph of mottled thin beds similar to beds figured in 21a. Fossil debris includes partially silicified trilobites (arrows) and pelmatozoan columnals.

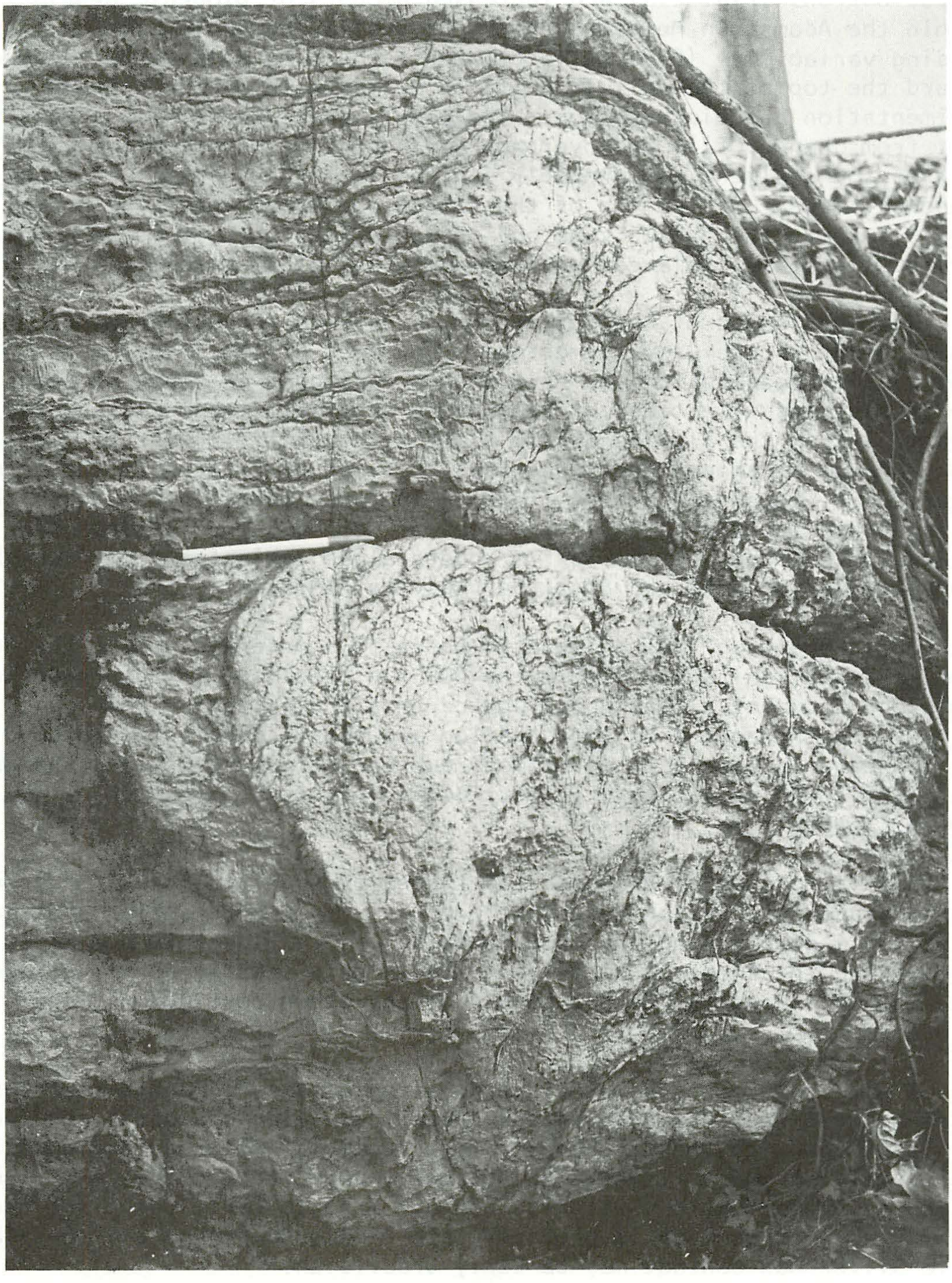


Figure 22. Stromatolite head delineated by poorly developed convex laminae and encased in thinly bedded, wavy limestones. This structure and other isolated heads are at the top of the Lime Kiln Member (less than 3 metres below the Frederick-Grove contact).

Shallowing of the basin is argued on the basic changes in the thinly bedded limestone. Relatively abundant ripple cross lamination and sand-size scour fills indicate increased bottom current. The appearance of sparse burrows (Fig. 21a) and increased amounts of biogenic debris (Fig.21b) within the Adamstown Member support the shallowing basin model. Increased bedding variability (Figs. 17 a-b) within the Lime Kiln Member, especially toward the top of the unit indicates a delicate interplay between rates of sedimentation and bioturbation. The poorly developed cycles probably result from channel fill and overbank sedimentation on a subtidal shelf. Much of the sediment was probably derived from the adjacent platform as winnowed fines. At the top of the Lime Kiln, water depth, at least locally, is above the photic zone and probably less than 10 m deep, because wavy beds contain isolated, poorly laminated, algal stromatolites (Fig.22.)

The shallowing of the basin terminates with the shoal water carbonate sequence in the Grove Limestone. For each of the lithologies which show cyclic organization, we have modern analogues at least in gross terms. The crossbedded limestone corresponds to subtidal, marginal sand bodies described from the Florida-Bahama platform by Ball (1967). Stromatolites show a range of shapes and structures that can be related to the forms described by Logan and others (1964). The structures in the dolomite include wavy to crenulated laminations as well as structureless beds. The laminated beds are similar to modern algae laminates from Florida (compare Fig. 23 a-b) and Shark Bay (Davies, 1970).

The transition from an abiotic basin to a moderately bioturbated slope and subtidal shelf within the 800 m of section in the Frederick Limestone document a continuous upward-shoaling pattern. The gradual increase in the amount of bioturbation and fossil debris in tandem with the increase in intensity of primary current structures suggest progressively shallower conditions; geometrically this is a migration up the slope toward the shelf.

Utilizing a model proposed and tested by Asquith (1970) for progradational sequences, we conclude that the basin in the Frederick area was at least 400 m deep during the Late Cambrian. This figure is a minimum estimate of the thickness of slope deposits in this stratigraphic package. This estimate does not take tectonic or any other post-depositional thinning into account.

A paleogeographic scheme incorporating biostratigraphic relationships between the Great Valley and Frederick Valley and gross structural relationships with the western Piedmont rocks is included in Figure 24. The clastic-carbonate transition becomes younger toward the east; the Chilhowee Group-Tomstown Dolomite contact is late Early Cambrian; the Araby-Frederick contact is probably late Middle Cambrian; and the Ijamsville-Silver Run contact may be Early Ordovician.

In summary, we have during the past two days attempted to show both small- and large-scale sedimentation patterns in ancient carbonate rocks. Both subtle variations between lithologies representing similar subenvironments of a tidal-flat complex and gross lithologic transitions from "deep and dirty" to "shallow and clean" limestone.

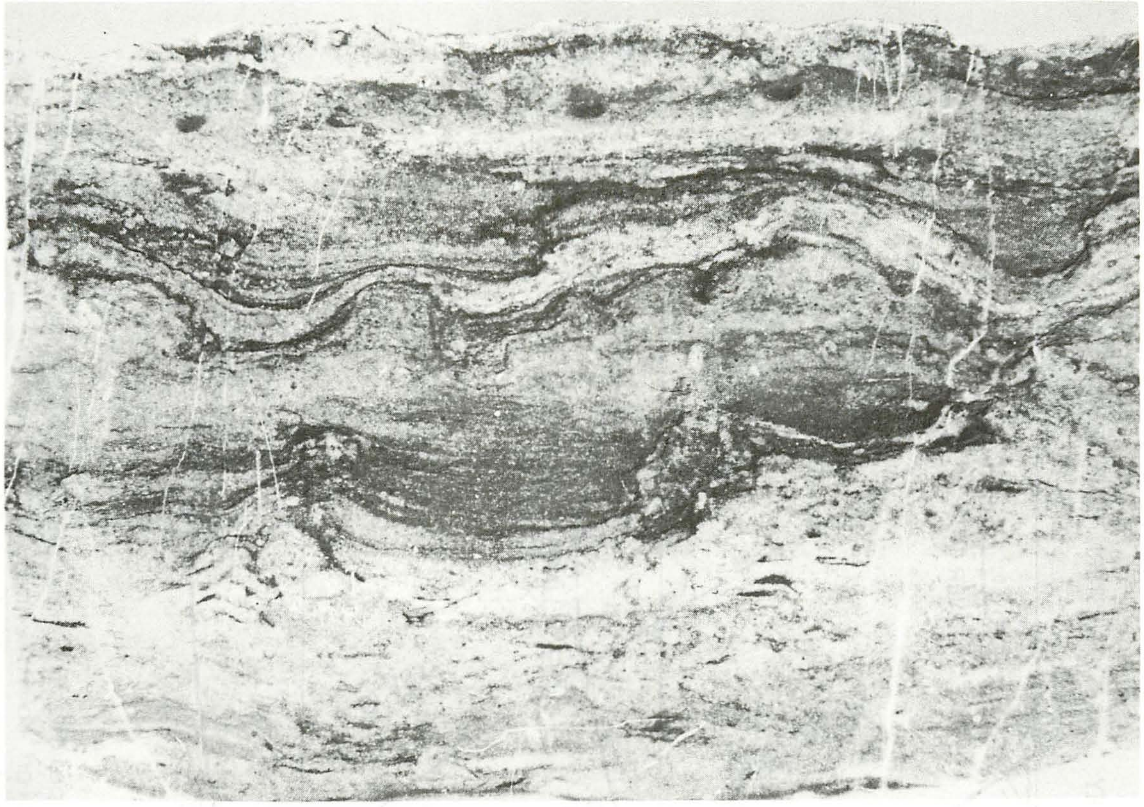


Figure 23a. Laminated, arenaceous dolomite in Grove Limestone (part III of a Grove cycle) composed of continuous, argillaceous laminae and pods of sand-sized material. The slab is 6 cm thick.

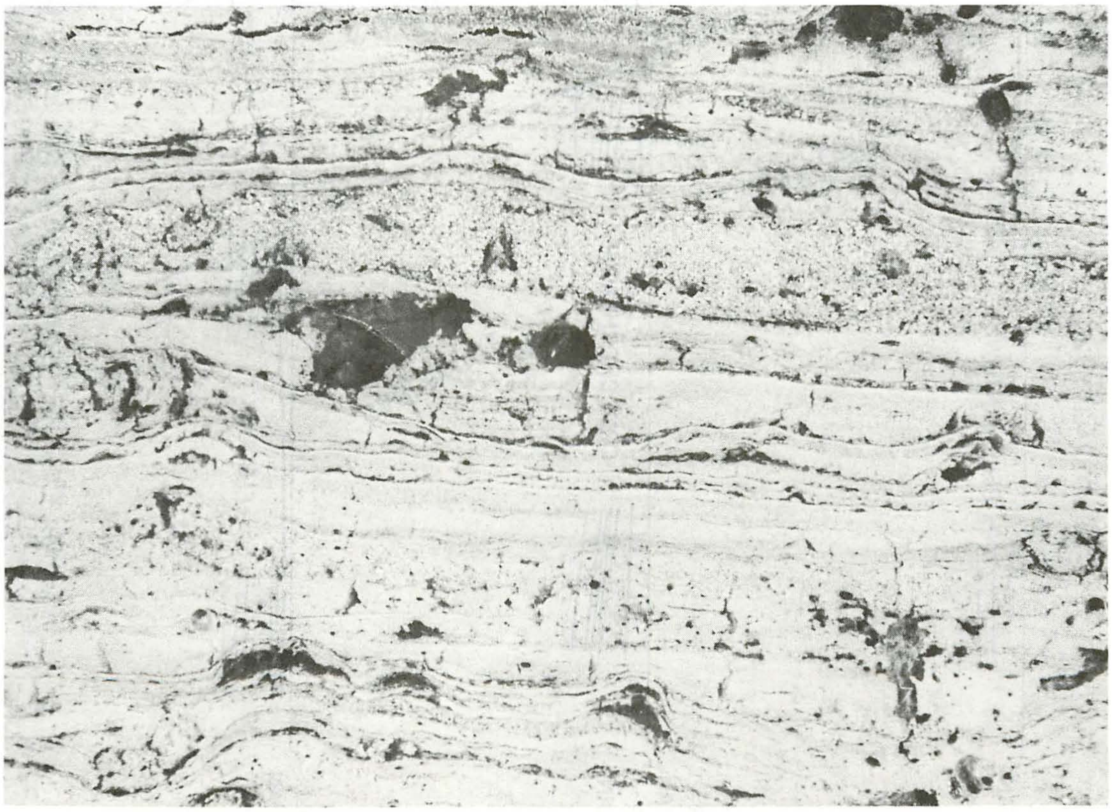


Figure 23b. Modern algal laminate from levee backslope zone, Sugarloaf Key, Florida. Discontinuous lenses of sandy carbonate and continuous micritic laminae are the key elements. This mat type may correspond to the laminate in Figure 23a.

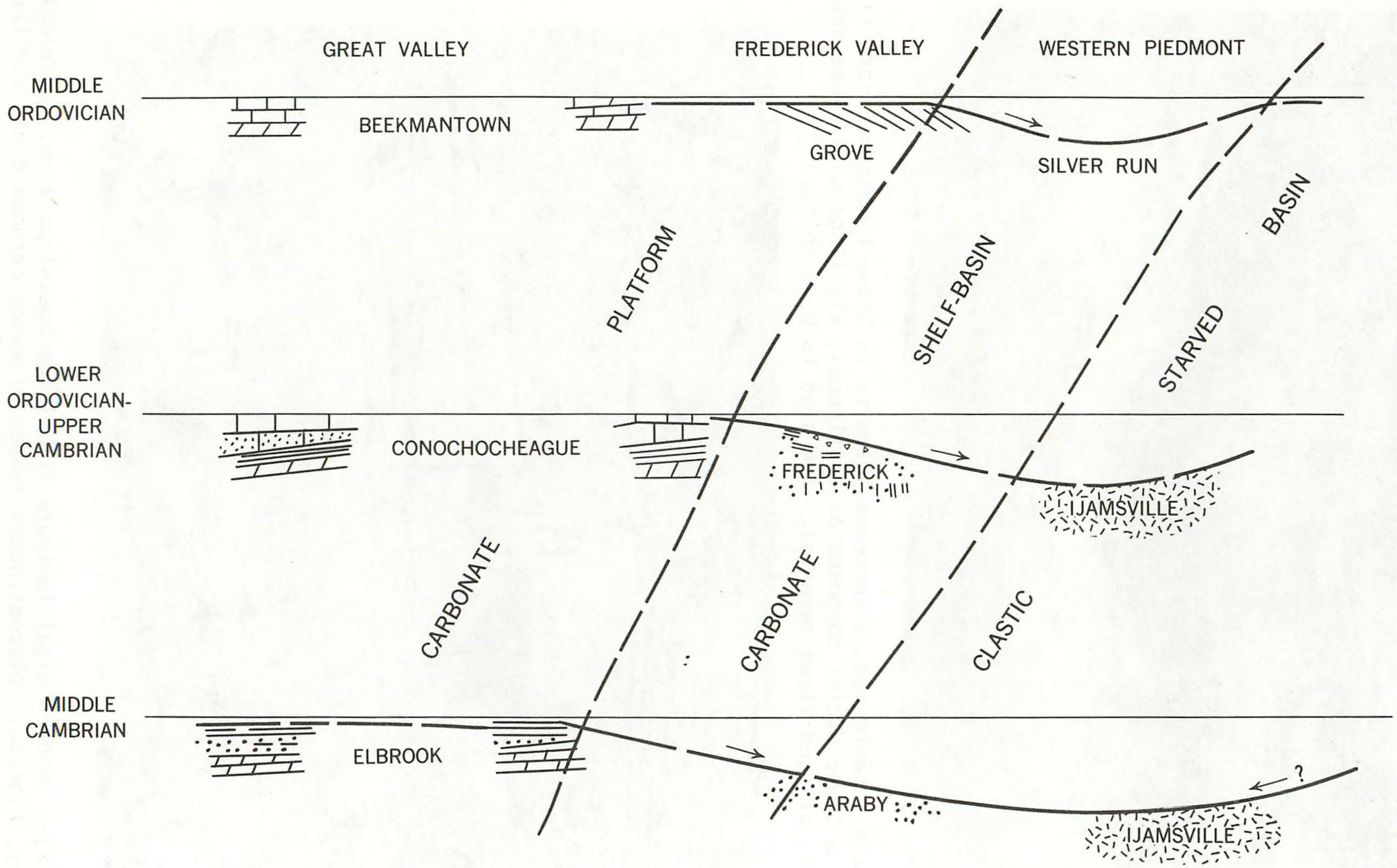


Figure 24. Paleogeographic sketches for three points in time showing the basin evolution from the Great Valley section to inferred relationships in the western Piedmont. The eastward progradation of the platform with continuous sedimentation everywhere necessitates a very gentle and gradual slope to basin transition. Arrows indicate direction of sediment movement.

The lack of good modern analogues for the study of basinal carbonate rocks is beginning to disappear and the critical use of a variety of modern analogues for tidal-flat carbonate rocks promises a new era of comparative sedimentology in the study of carbonate rocks.

REFERENCES

Alling, H. L., and Briggs, L. I., 1961, Stratigraphy of the Upper Silurian evaporites: Am. Assoc. Petroleum Geologists Bull., v. 45, p. 515-547.

Asquith, D. O., 1970, Depositional topography and major marine environments, Late Cretaceous, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 1184-1224.

Ball, M. M., 1967, Carbonate sand bodies of Florida and the Bahamas: Jour. Sed. Petrology, v. 37, p. 576-591.

Bassler, R. S., 1919, Cambrian and Ordovician: Maryland Geol. Survey, Baltimore, Johns Hopkins Univ. Press, 408 p.

Bosellini, A., 1967, La tematica depositionale della Dolomia Principale (Dolomitic Prealpi Venete): Boll. Soc. Geol. Ital., v. 86, p. 133-169.

Bossellini, A., and Hardie, L. A., 1973, Depositional theme of a marginal marine evaporite: Sedimentology, v. 20, p. 5-27.

Bouma, A. H., 1962, Sedimentology of some flysch deposits: Amsterdam, Elsevier, 168 p.

Cloos, Ernst, 1958, Guidebooks 4 and 5, Structural geology of South Mountain and Appalachians in Maryland, *in* Pettijohn, F. J., ed., Johns Hopkins University Studies in Geology No. 17: Baltimore, The Johns Hopkins Univ. Press, 85 p.

Davies, G. R., 1970, Algal-laminated sediments, Gladstone embayment, Shark Bay, Western Australia, *in* Carbonate sedimentation and environments, Shark Bay, Western Australia: Am. Assoc. Petroleum Geologists Mem. 13, p. 69-205.

Donaldson, A. C., 1959, Stratigraphy of the Lower Ordovician Stonehenge and Larke Formations in central Pennsylvania: University Park, Pennsylvania, unpub. Ph.D. dissert., Pennsylvania State Univ.

_____ 1969, Stratigraphic framework of stromatolites in Lower Ordovician of the Central Appalachians, *in* Some Appalachian coals and carbonates: models of ancient shallow-water deposition: Geol. Soc. America Field Trip Guidebook, p. 357-384.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture, *in* Classification of carbonate rocks, Ham, W. E., ed.: Am. Assoc. Petroleum Geologists Mem. 1, p. 108-121.

Fischer, A. G., 1964, The Lofer cyclotherm of the Alpine Triassic, *in* Symposium on cyclic sedimentation, Merriam, D. F., ed., Kansas Geol. Survey Bull. 169, v. 1, p. 107-149.

Folk, R. L., 1952, Petrography and petrology of the Lower Ordovician Beekmantown carbonate rocks in the vicinity of State College, Pennsylvania: University Park, Pa., Pennsylvania State Univ., unpub. Ph.D. dissert.

_____ 1959, Practical classification of limestones: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 1-38.

_____ 1960, Petrography and origin of the Tuscarora, Rose Hill, and Keefer Formations, Lower and Middle Silurian of eastern West Virginia: Jour. Sed. Petrology, v. 30, p. 1-58.

_____ 1962, Petrography and origin of the Silurian Rochester and McKenzie Shales, Morgan County, West Virginia: Jour. Sed. Petrology, v. 32, p. 539-578.

Geyer, A. R., Buckwalter, T. V., McLaughlin, D. B., and Gray, C., 1963, Geology and mineral resources of the Womelsdorf quadrangle: Pennsylvania Geol. Survey, 4th ser. Prog. Rept. 169.

Ginsburg, R. N., 1974, Introduction to comparative sedimentology of carbonates: Am. Assoc. Petroleum Geologists Bull., v. 58, p. 781-786.

_____ ed., 1975, Tidal deposits: New York, Springer-Verlag, 428p.

Ginsburg, R. N., and Hardie, L. A., 1975, Tidal and storm deposits, Northwestern Audros Island, Bahamas, *in* Tidal deposits, Ginsburg, R. N., ed.: New York, Springer-Verlag, p. 201-208.

Hardie, L. A. (in press), Sedimentation on the modern carbonate tidal flats of northwest Andros Island, Bahamas: Baltimore, Johns Hopkins Press.

Hunter, R. E., 1970, Facies of iron sedimentation in the Clinton Group, *in* Studies of Appalachian geology: central and southern, Fisher, G. W., and others, eds.: New York, Wiley Interscience, p. 101-121.

Jonas, A. J., and Stose, G. W., 1936, The reclassification of the Frederick Valley (Maryland) limestones: Geol. Soc. America Bull., v. 47, p. 1657-1674.

_____ 1938, Geologic map of Frederick County: Maryland Geological Survey, 1:62,500.

Kendall, C. A., and Skipwith, P. A., 1969, Geomorphology of a recent shallow water carbonate province: Khor al Bazam, Trucial Coast, Southwestern Persian Gulf: Geol. Soc. America Bull., v. 80, p. 865-892.

Keyes, C. R., 1890, Discovery of fossils in the limestones of Frederick County, Maryland: Johns Hopkins Univ. Circ., v. 84, p. 32.

Laporte, L. F., 1967, Carbonate deposition near mean sea level and resultant facies mosaic, Manlius formation (Lower Devonian) of New York State: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 73-101.

Logan, B. W., 1961, Cryptozooan and associated stromatolites from the Recent, Shark Bay, Western Australia: Jour. Geology, v. 69, p. 517-533.

Logan, B. W., Cebulski, D. E., Davies, G. R., Read, J. F., 1970, Carbonate sedimentation and environments, Shark Bay, Western Australia: Am. Assoc. Petroleum Geologists Mem. 13, 205 p.

Logan, B. W., Hoffman, P., and Gebelein, C. D., 1974a, Algal mats, cryptalgal fabrics, and structures, Hamelin Pool, Western Australia, *in* Evolution and diagenesis of Quaternary carbonate sequences, Shark Bay, Western Australia: Am. Assoc. Petroleum Geologists Mem. 22, p. 140-194.

Logan, B. W., Read, J. F., Hagan, G. M., Hoffman, P., Brown, R. G., Wood, P. I., and Gebelein, C. D., 1974b, Evolution and diagenesis of Quaternary carbonate sequences, Shark Bay, Western Australia: Am. Assoc. Petroleum Geologists Mem. 22, 358 p.

Logan, B. W., Rezak, R., and Ginsburg, R. N., 1964, Classification and environmental significance of algal stromatolites: Jour. Geology, v. 72, p. 68-83.

Long, M. B., 1953, Origin of the Conococheague limestone: Baltimore, Johns Hopkins Univ., unpub. Ph.D. dissert., 213 p.

Matter, A., 1967, Tidal flat deposits in the Ordovician of western Maryland: Jour Sed. Petrology, v. 37, p. 601-609.

Middleton, G. V., 1973, Johannes Walther's law of the correlation of facies: Geol. Soc. America Bull., v. 84, p. 979-988.

Middleton, G. V., and Hampton, M. A., 1973, Sediment gravity flows: mechanics of flow and deposition, *in* Turbidites and deep water sedimentation, SEPM Pacific section short course, p. 1-38.

Neuman, R. B., 1951, St. Paul group: A revision of the "Stones River" group of Maryland and adjacent states: Geol. Soc. America Bull. v. 62, p. 267-324.

Palmer, A. R., 1971, The Cambrian of the Appalachian and eastern New England regions, Eastern United States, *in* Cambrian of the New World, Holland, C. H., ed.: London, Wiley-Interscience, p. 169-217.

Pelto, C. R., 1942, Petrology of the Gatesburg Formation of central Pennsylvania: University Park, Pennsylvania State Univ., unpub. M.S. thesis, 60 p.

Purser, B. H., ed., 1973, The Persian Gulf: Holocene carbonate sedimentation and diagenesis in a shallow epicontinental sea: New York, Springer-Verlag, 471 p.

Purser, B. H., and Loreau, J. P., 1973, Aragonitic, supratidal encrustations on the Trucial Coast of the Persian Gulf, *in* The Persian Gulf, Purser, B. H., ed.: New York, Springer-Verlag, p. 343-376.

Rassetti, F., 1959, Trempealeauian trilobites from the Conococheague, Frederick and Grove limestones of the central Appalachians: Jour. Paleontology, v. 33, p. 375-398.

_____ 1961, Dresbachian and Franconian trilobites of the Conococheague and Frederick limestones of the central Appalachians: Jour. Paleontology, v. 35, p. 104-124.

Reineck, H. E., and Singh, I. B., 1973, Depositional sedimentary environments: New York, Springer-Verlag, 439 p.

Reinhardt, Juergen, 1974, Stratigraphy, sedimentology and Cambro-Ordovician paleogeography of the Frederick Valley, Maryland: Maryland Geol. Survey, Rept. Inv. no. 23, 74 p.

Roehl, P. O., 1967, Stony Mountain (Ordovician) and Interlake (Silurian) facies analogs of Recent low energy marine and subaerial carbonates, Bahamas: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 1979-2032.

Rones, M., 1955, Lithostratigraphic, chemical and petrographic investigation of the Lower Middle Ordovician carbonate rocks of central Pennsylvania: University Park, Pennsylvania State Univ., unpub. Ph.D. dissert.

Root, S. I., 1964, Cyclicity of the Conococheague Formation: Pennsylvania Acad. Sci. Proc., v. 38, p. 157-160.

_____ 1968, Geology and mineral resources of southeastern Franklin County, Pennsylvania: Pennsylvania Geol. Survey Atlas 119cd, 118 p.

Sando, W. J., 1957, Beekmantown Group (Lower Ordovician) Maryland: Geol. Soc. America Mem. 68, 161 p.

Schwab, F. L., 1970, Origin of the Antietam Formation (Late P€ - Lower Cambrian) central Virginia: Jour. Sed. Petrology, v. 40, p. 354-366.

_____ 1971, Harpers Formation, central Virginia: a sedimentary model: Jour. Sed. Petrology, v. 41, p. 139-149.

Schenk, P. E., 1967, The Macumber Formation of the Maritime provinces, Canada - a Mississippian analogue to Recent stand-line carbonates of the Persian Gulf. Jour. Sed. Petrology, v. 37, p. 365-376.

Shinn, E. A., Lloyd, R. M., Ginsburg, R. N., 1969, Anatomy of a modern tidal flat, Andros Island, Bahamas: Jour. Sed. Petrology, v. 39, p. 1202-1228.

Stose, A. J., and Stose, G. W., 1946, Geology of Carroll and Frederick Counties, *in* The physical features of Carroll County and Frederick County: Dept. Geology, Mines and Water Resources, State of Maryland, p. 11-131.

Stose, G. W., 1908, The Cambro-Ordovician limestones of the Appalachian Valley in southern Pennsylvania: Jour. Geology, v. 16, p. 698-714.

Swartz, C. K., 1923, Stratigraphic and paleontologic relations of the Silurian strata of Maryland, *in* Silurian, Maryland Geological Survey: Baltimore, Johns Hopkins Press, p. 25-50, p. 105-125.

Tasch, P., 1951, Fauna and paleoecology of the Upper Cambrian Warrior Formation of central Pennsylvania: Jour. Paleontology, v. 25, p. 275-289.

Tourek, T. J., 1970, The depositional environments and sediment accumulation models for the Upper Silurian Wills Creek Shale and Tonoloway limestone, central Appalachians: Baltimore, Johns Hopkins Univ., unpub. Ph.D. dissert., 281 p.

Whitaker, J. C., 1955, Geology of Catoctin Mountain, Maryland and Virginia: Geol. Soc. America Bull., v. 66, p. 435-462.

Walther, J., (1893-94), Einleitung in die Geologie als historische Wissenschaft: Jena, Verlag von Gustav Fischer, 3 vols., 1055 p.

Wilson, J. L., 1952, Upper Cambrian stratigraphy in the central Appalachians: Geol. Soc. America Bull., v. 63, p. 275-322.

Yeakel, L. S., 1962, Tuscarora, Juniata and Bald Eagle paleocurrents and paleogeography in the central Appalachians: Geol. Soc. America Bull., v. 73, p. 1515-1540.

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