# SEDIMENTARY ENVIRONMENTS AND THEIR PRODUCTS: SHELF, SLOPE, AND RISE OF PROTO-ATLANTIC (IAPETUS) OCEAN, CAMBRIAN AND ORDOVICIAN PERIODS, EASTERN NEW YORK STATE

by

Gerald M. Friedman
Department of Geology
Rensselaer Polytechnic Institute
Troy, New York 12181

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## INTRODUCTION

On this field trip, instead of tracing formations, we shall study sedimentary facies. We plan to hop from the products of one environment to those of another. At each exposure we shall study the rocks in terms of lithology, geometry, sedimentary structures, and fossils, and concentrate on the pattern of deposition which created the facies that we shall examine. Remember that the various exposures of Cambrian and Ordovician rocks to be visited are not time correlative. Each field stop will stand on its own; facies analysis will proceed within the boundary conditions of a single exposure. On this field trip the name of the formation becomes secondary; hence this field trip has been designed irreverently; it pays no heed to formation boundaries.

The fascination of the area around R.P.I. is its diversity of sedimentary geology: in one day of field trips we can examine sedimentary facies of Cambrian-Ordovician age which originated in shallow as well as in deep marine waters. Few other areas can match this diversity of sedimentary facies. The geologic coincidence for this diversity of sedimentary environments in the area of the R.P.I. Campus is its unique location: from Early Cambrian through Early Ordovician R.P.I. would have been on a carbonate shelf. Between Early Cambrian and Early Ordovician times the shelf to basin transition was east of Rutland, Vermont. Tectonic movements shoved Cambrian and Ordovician rocks of slope, rise, and basin facies across the shelf facies so that today the exposures on and near the Campus of R.P.I. are basin or basin margin (rise) facies with shelf facies of Cambrian and Ordovician age occurring to the west (Friedman, 1972) (Fig. 1).

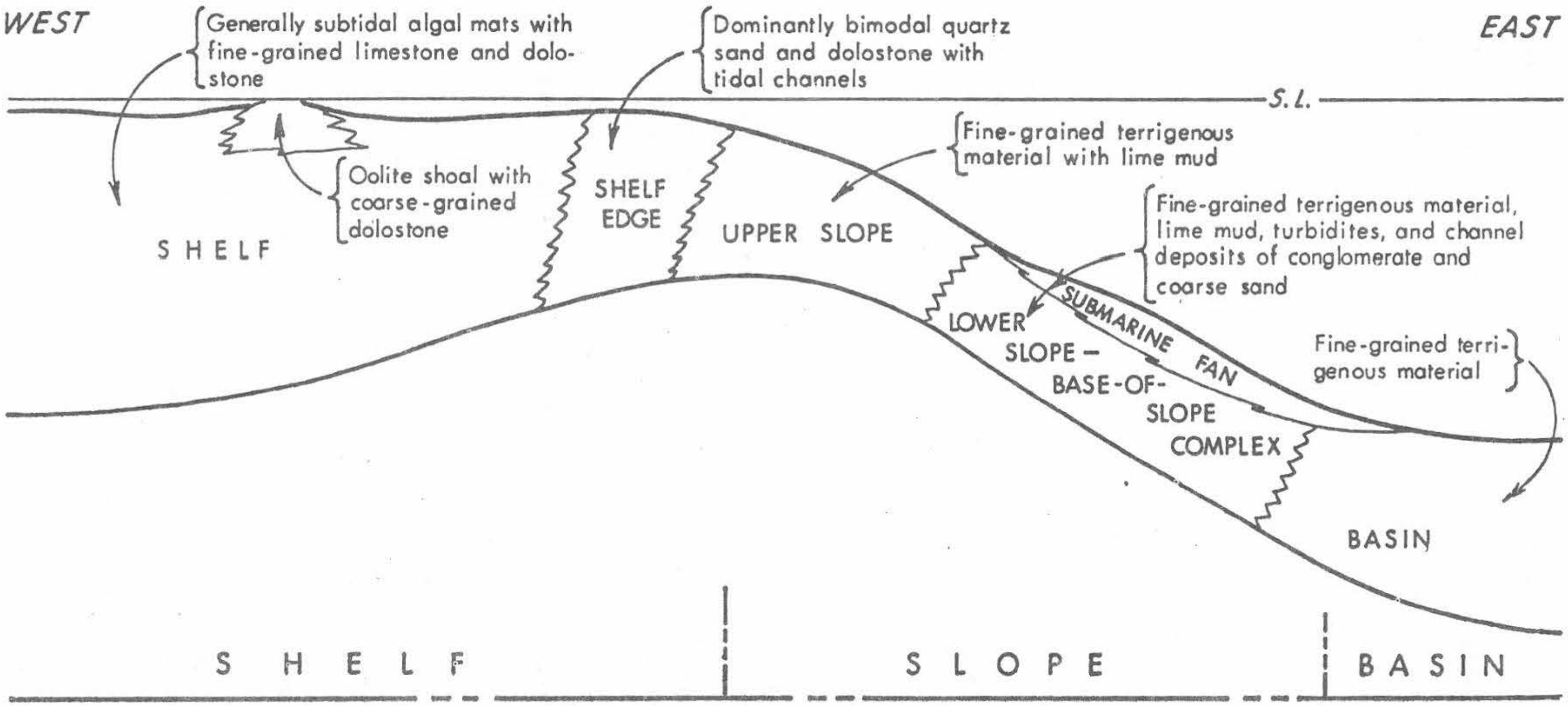


Figure 1. Diagrammatic sketch map showing depositional environments and characteristic sediments of Proto-Atlantic (Iapetus) Ocean for eastern New York and western Vermont during the Early Paleozoic (Keith and Friedman, 1977, Fig. 2, p. 1222).

During Cambrian-Ordovician time, most of the North American continent was a shallow epeiric shelf sea, like the present-day Bahama Bank. At the eastern edge of this shallow sea, i.e. at the eastern edge of this continent, a relatively steep slope existed down which carbonate sediment moved by slides, slumps, turbidity currents, mud flows, and sandfalls to oceanic depths to come to rest at the deep-water basin margin (rise), where a shale facies was deposited (Sanders and Friedman, 1967, p. 240-248; Friedman, 1972, p. 3; Keith and Friedman, 1977, 1978; Friedman and Sanders, 1978, p. 389,392). Shale also formed much of the basinal facies in the deep water beyond. Because allochthonous transport has been inferred for large blocks of rocks presently exposed on and near the R.P.I. Campus, the evidence on the ground shows that the Campus is the site of Cambrian and Early Ordovician rocks of basin margin (rise) and deep basin facies (shales deposited in the Middle Ordovician (Schenectady) west of Campus are autochthonous basin facies). Thus deep-water basin margin (rise) and basinal facies can be visited on and near the R.P.I. Campus, whereas to the west carbonate shelf facies are exposed that are analogous to those of the west shore of Andros Island on the Great Bahama Bank (Fig. 1). The paleoslope was probably an active hinge line between the continent to the west and the deep ocean to the east, similar to the Jurassic hinge line of the eastern Mediterranean between carbonate shelf facies and deep-water shales (Friedman, Barzel, and Derin, 1971). Such hinge lines in the early geosynclinal history of mountain belts are fixed by contemporaneous down-to-basin normal faulting (Rodgers, 1968, quoting Truempy, 1960), as probably occurred with the rocks of the area near R.P.I. Later thrusting to lift the deep-water facies across the shelf facies along hinge-line faults resulted in the contiguity of the two facies. This later displacement was so great that the Cambrian and Early Ordovician deep-water sediments were shifted far west of their basin margin.

This field trip has been divided into two parts, each part corresponding to half a day. In the morning and early afternoon we shall study facies of deep-water origin and in the late afternoon those of shallow epeiric origin. Each of the two depositional settings will now be explained.

## DEEP-WATER SETTING: A SLOPE-FAN-BASIN-PLAIN MODEL

The strata of deep-water setting are part of the Taconic Sequence (Fig. 3). These rocks have received the attention of geologists for more than 150 years, and because of their exceedingly complex structural and stratigraphic relations have been the object of considerable debate. In fact approximately 150 years ago Ebenezer Emmons' advocacy of the Taconic System (1842, 1844, 1848, 1855) and the division of thought on this problem resulted in the famous duel between James Hall and Emmons which ultimately forced Emmons to leave New York State. A court decision involving several of the most well-known geologists of the last century assured Hall's victory by forcing Emmons out of New York; he settled in North Carolina away from his Taconic rocks.

Strata of the Taconic Sequence extend from north to south approximately 150 miles (Fig. 2), and for the most part within New York State,

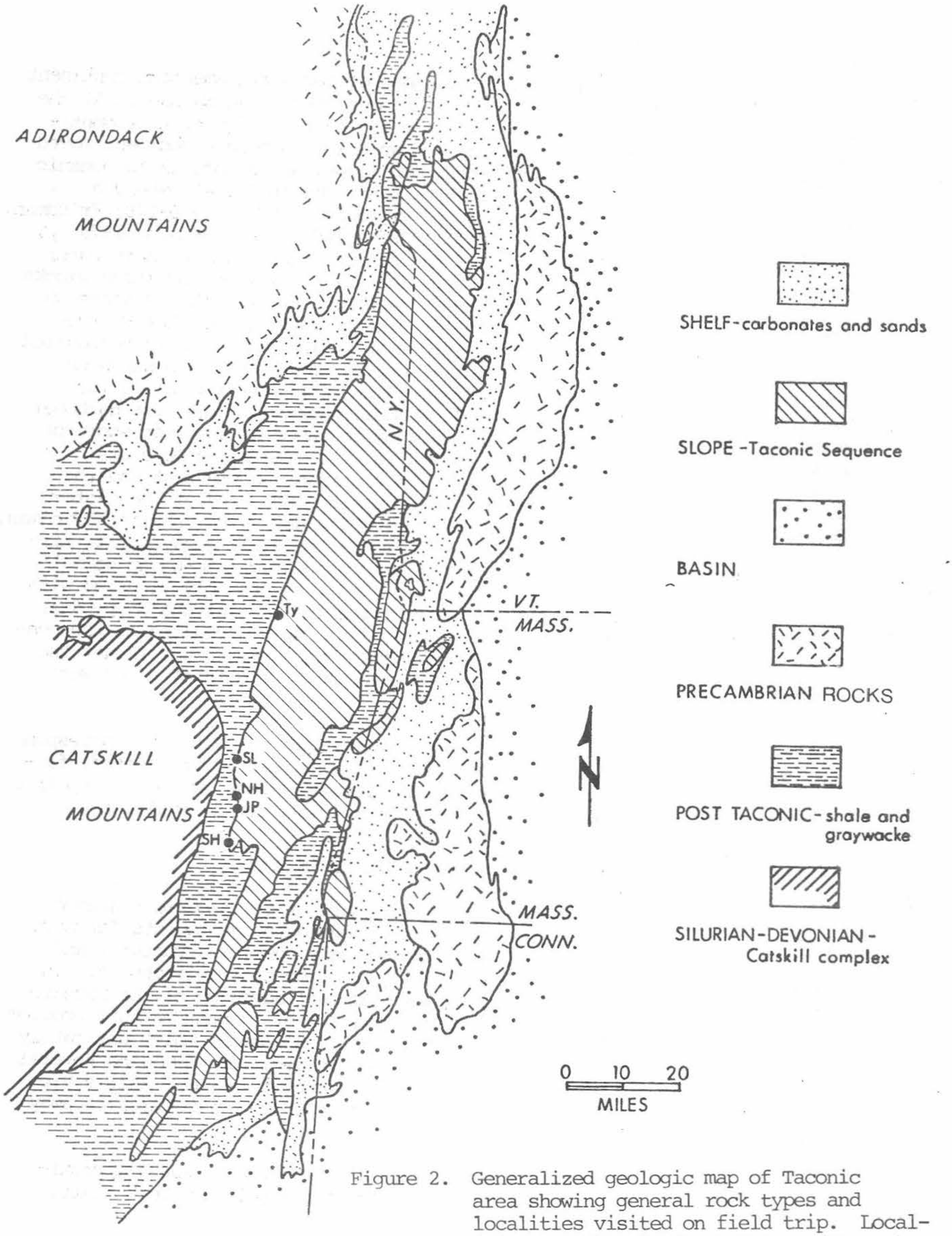


Figure 2. Generalized geologic map of Taconic area showing general rock types and localities visited on field trip. Localities are SH = South of Hudson (Stop 1); JP = Judson Point (Stop 2); NH = Nutten Hook (Stop 3); SL = Schodack Landing (Stop 4); TY = Troy area (R.P.I. Campus) (Stops 5-7) (after Keith and Friedman, 1977, Fig. 1, p. 1221).

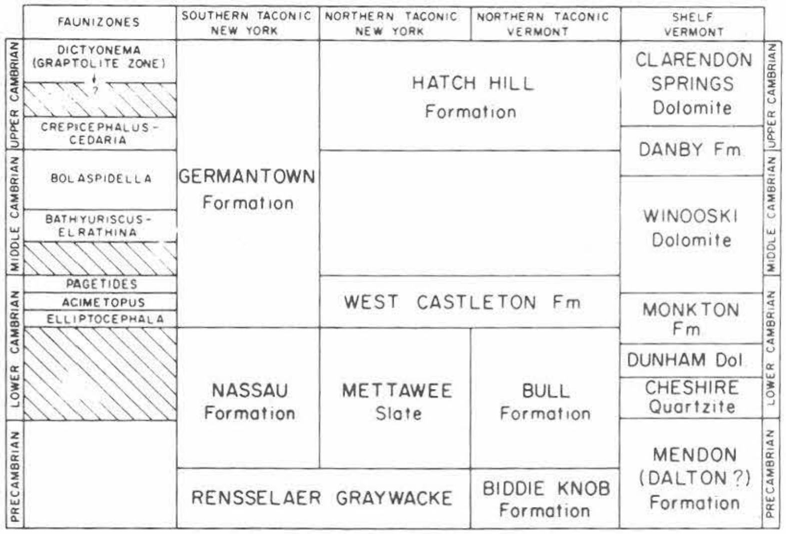


Figure 3. Stratigraphic correlation chart. Deep-water deposits seen on field trip are of West Castleton Formation (Lower Cambrian). Hachured areas represent faunizones not represented in rocks shown on chart (Keith and Friedman, 1977, Fig. 3, p. 1222).

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are composed of shales and sandstones. Carbonate rocks are minor by comparison, but are important as they reflect depositional conditions. Although the stratigraphy and tectonics of the area have been the subject of considerable controversy, a debate that has become known as the "Taconic Problem," stratigraphic succession and structure have more recently been clarified (Bird and Rasetti, 1968; Zen, 1967).

Environmental reconstruction for the Cambrian part of the Taconic Sequence in eastern New York State indicates a depositional environment analogous with a modern continental rise or more specifically with a slope-fan-basin-plain model (Fig. 10) (Keith and Friedman, 1977, 1978). Carbonate sediment and generally coarse quartz sand were removed from the Cambrian shelf and deposited with muds of the slope, now slates and siltstones, by a variety of processes at work on the slope and within submarine canyons. The shelf-derived sediment can be divided into six main lithofacies, each bearing the imprint of the principal process or processes involved in its deposition. These include: (1) carbonate-clast conglomerates (inferred products of debris flow), (2) massive, coarse sandstones (apparent deposits of fluidized sediment flow and grain flow), (3) graded sandstones and limestones (presumed turbidites), (4) parallel-laminated sandstones and limestones (probable turbidites), (5) thin, structureless micrites (inferred deposits of vertical settling-out of suspension), and (6) current-ripple-laminated limestones and sandstones (thought to be the products of reworking by contour-following bottom currents or submarine overbank levee deposits). All of these processes were working together or in opposition. Analysis indicates that only the lower slope and base-of-slope portion of the early Paleozoic continental margin has been preserved in the Taconic Sequence (Keith and Friedman, 1977, 1978).

We shall discuss briefly these lithofacies.

### Carbonate-Clast Conglomerate (Figs. 4 and 5)

Monomictic carbonate to polymictic carbonate conglomerates occur throughout the Taconic Sequence; a significant percentage of sandstone clasts may be present in some beds. The clasts have a general preferred orientation parallel to the bed boundaries, where they are exposed, but some clasts in a bed will be oriented up to 90$^{o}$ to the general trend.

Conglomerates resembling those described here have been mentioned in the literature extensively (Walker, 1970; Mountjoy et al., 1972; Walker and Mutti, 1973; Walker, 1975; Friedman and Sanders, 1978). Walker (1975, 1976) has proposed descriptive models for conglomerates of turbidite association (resedimented conglomerates) based on the presence or absence of grading (inverse or normal), stratification and imbrication. The conglomerates seen on this field trip with their lack of grading and stratification and local imbrication fall closest to Walker's disorganized-bed model. The recognition of a debris-flow model for many of these conglomerates having a lack of organized internal structure has become well established (Dott, 1963; Johnson, 1970; Cook et al., 1972; Hampton, 1972; Middleton and Hampton, 1973; Walker, 1975, 1976; Friedman and Sanders, 1978). A debris flow is defined as a flowing muddy mixture of water and fine particles that supports and transports abundant coarser particles (Friedman and Sanders, 1978, p. 95, 558). The mechanics of motion in any sediment gravity flow are complex, and a simple debris flow model cannot fully explain the features in the conglomerates of the Taconic Sequence (Keith and Friedman, 1977, 1978).

Such a model does fit well with the large clasts in a clay matrix, the lack of size grading, and the poor to nonexistent sorting. The range of composition of the clasts can be easily accounted for, as being derived from the shelf buildup and the basin-margin beds. Some conglomerates appear to be quite local in origin, and interbedded with beds similar to the source beds for the clasts, which also seems compatible with a debris-flow model. The upward decrease in clasts in some beds, with the pervasive preferred orientation and local imbrication all are puzzling as they indicate movement and settling of the individual clasts within the flow. The smaller grain size and presence of some degree of rounding, especially for clasts derived from the shelf, suggest some degree of transport. With increased transport, progressive dilution of the debris flow would take place (as suggested by Hampton, 1972), producing more fluid-like behavior and transition towards turbidity

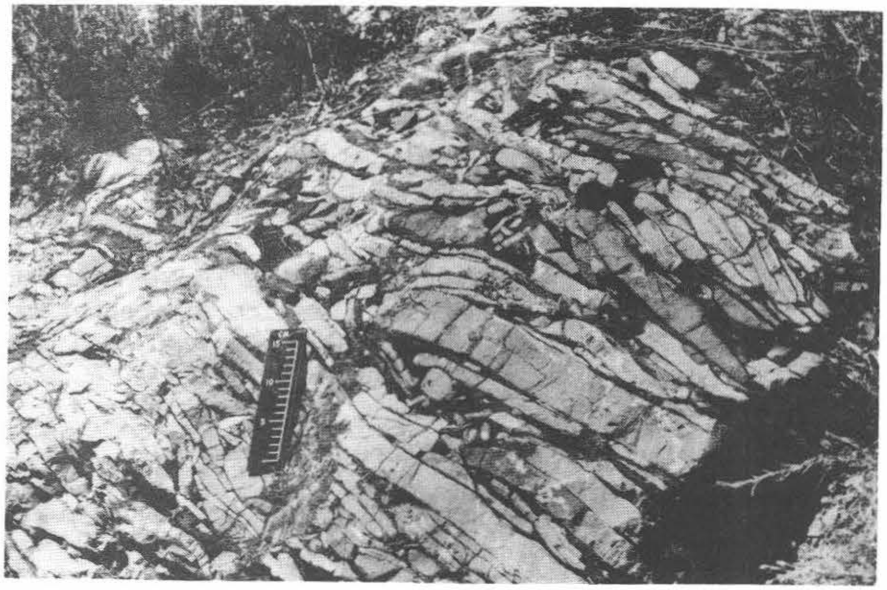

Figure 4. Carbonate-clast conglomerate of shallow-water origin displaced by debris flow from shelf edge into deep water. From exposure south of Hudson (Stop 1; SH on Fig. 2).

Figure 5. Rubble of incoherent slump or debris flow composed of boulders of limestone, sandstone, and chert. This rubble, known as brecciola, originated in shallow water behind shelf edge and was displaced into deep-water, dark-colored shales. Note calcite-healed fractures in view. Boulder in center is approx. 30 cm across. Campus of Rensselaer Polytechnic Institute (Stop 5).

current flow. However, none of the conglomerates discussed here show features indicative of turbidity-current activity such as grading and stratification. At this point all that one can say is that the depositional mechanism appears to be closer to debris flow than to any other (Keith and Friedman, 1977, 1978).

It is not clear whether the conglomerates of the Taconic Sequence were deposited as sheets or were confined to channels. Some of the conglomerates are associated with turbidites, which are generally considered to be confined to submarine canyons or to channels on a submarine fan. Thus, these conglomerates might have been similarly confined.

In summary, the carbonate-clast conglomerates appear to be the products of deposition by debris flow. The question of whether they are channel deposits or sheet flows is not fully resolved, and both types may well be present (Keith and Friedman, 1977, 1978).

## Massive, Coarse Sandstone

These beds of massive sandstone show no bedding, lamination, or grading. The beds seem to fall into two groups, which are: (1) coarse-grained sandstone, and (2) thicker, coarse- to very coarse-grained sandstone. The beds are generally very coarse grained, with no internal features other than a few micrite pebbles. In places the beds contain either micrite pebbles, or wisps that stand out on the weathered surface which appear to be concentrated zones of sand that are more resistant to weathering than the bulk of the bed (Keith and Friedman, 1977, 1978).

The massive beds correspond to beds described extensively from turbidite sequences in the literature (Friedman and Sanders, 1978; Walker, 1967, 1970). Beds generally fitting this description have been called "fluxoturbidites" after the original description by Dzulynski et al. (1959). This term has become of limited usefulness due to the vagueness of the description and resulting misuse. Walker (1970) found, after extensive literature study, that there does exist a facies with certain features including: (1) unusually thick beds; (2) coarse grain size; (3) grading that was repetitive, poor or absent; (4) erosional bases with the finer interbeds being thin, irregular or absent; (5) pebbles commonly present; and (6) tops that may be sharp, rather than gradational. Walker (1970) compared these beds to classical proximal turbidites compiled from the literature and found no significant differences (Keith and Friedman, 1977, 1978).

A depositional mechanism that appears to fit these thick coarse-grained, generally structureless sandstone beds is fluidized sediment flow. This mechanism works when a loosely packed sand is subjected to an initial shock, destroying its fabric, so that water is incorporated and the sand liquifies, i.e., the grains are supported by excess pore pressure. Since the sand is not sealed, pore fluid loss is rapid, and the flow short-lived. As the pore fluid escapes the viscous properties of the mass disappear and the sediment comes to rest. Because the concentration of sediment relative to fluid is high, features associated with traction deposits, such as different types of lamination, cannot form (Keith and Friedman, 1977, 1978).

Generally, the beds of this lithofacies appear to fit a nebulous category of thick, coarse-grained massive sandstones "proximal" in nature (or possibly channel deposits). They were deposited by one or more processes, involving fluidization of the sediment (Keith and Friedman, 1977, 1978).

## Graded Sandstones and Limestones

The graded beds are found associated with beds of other lithofacies. These beds are prominent except south of Hudson, where they are only a minor constituent of the exposed section. Shales are interbedded with this lithofacies at all exposures, except for Judson Point, where sandstone beds are commonly in depositional contact with each other, or with only a very thin shale parting between them (Keith and Friedman, 1977, 1978).

The graded beds range in composition from pure sandstone to limestones, with little or no sand. There are some beds that are half sand and half carbonate. Generally, within one exposure the lithology will be fairly constant. At Judson Point, the beds of this lithofacies are essentially pure sandstone. South of Hudson the beds all contain nearly equal amounts of carbonate and sand. Carbonate is present as rounded intraclasts, individual grains, and as a matrix in the sandy beds. The rounded intraclasts are commonly found near the base of the bed. The intraclasts are composed of pelmicrite, pelsparite or micrite. One intraclast of oomicrite was seen. Sparite and pelmicrite occur as matrix for sandy carbonates (Keith and Friedman, 1977, 1978).

Beds of this lithofacies display many kinds of sedimentary structures. Graded beds, parallel lamination, and cross-lamination (commonly ripple lamination) are all common. Grading takes on several forms in the beds studied. Many beds at Judson Point show delayed grading (Dzulynski and Walton, 1965), where most of the bed is coarse- or medium-grained sand, uniformly distributed, up to the very top, where the bed quickly becomes argillaceous with essentially no intermediate grain sizes. The grading then takes place in a narrow zone at the top, rather than throughout the bed. Beds at the locality south of Hudson commonly show coarse bimodal sand at the base in a carbonate matrix, with the sand decreasing in amount upward, leaving only the carbonate at the top. This would be a type of discontinuous grading with no medium-grained portion (Keith and Friedman, 1977, 1978).

Parallel lamination is quite common. It appears to be especially well developed in the medium-grained sandstone and the carbonate beds. The laminae are generally less than 1 mm in scale, and in the limestone the lamination is commonly due to fine-grained quartz being concentrated along the laminae. The coarse-grained sandstones, as seen at Judson Point, show only faint lamination, if any at all. Ripple lamination is quite well developed in some beds, but is not common. Not seen elsewhere was larger scale cross-lamination that could be considered cross-bedding in a bed south of Schodack Landing. Many examples of the various internal structures, alone or in combination with others, can be seen (Keith and Friedman, 1977, 1978).

Beds of sand-sized material, displaying grading and lamination in a systematic order (Bouma Sequence) and which are interbedded with basinal shales are turbidites (Fig. 6).

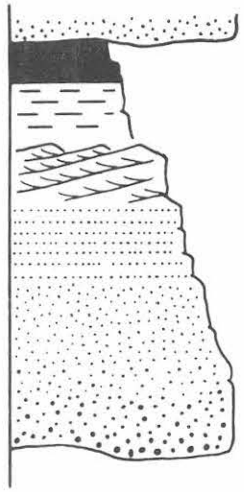


Figure 6. Vertical sequence in sediments deposited by gravity-powered bottom flows. This sequence consists ideally of five divisions, labeled A, B, C, D, E, and named the Bouma sequence after A. H. Bouma (1962):

A. Either a graded sandstone in which the particle size decreases systematically upward or a massive sandstone; the original sand of this "high-speed" depositional layer has a sharp base that divides it from the underlying "low-speed" shaley layer of the preceding sequence. A typically is a product of liquefied cohesionless-particle flow.
B. Parallel-laminated sandstone that represents conditions of upper-flow regime, hence is likewise a "high-speed" structure.
C. Ripple cross-laminated fine or very fine sandstone that represents the lower-flow regime, hence is a "low-speed" structure.
D. Faint parallel laminae of mudstone.
E. Shaley layer at top of sequence. At the contact between E and the overlying sandstone A of the next sequence, abundant sole marks may be present. The fine-grained fallout from the tail of a turbidity current may be difficult or impossible to distinguish from pelagic sediments.

Sequences of turbidites commonly consist of monotonously interbedded alternating and laterally persistent layers of sandstones and shales.

Not all divisions of the Bouma sequence need always be present;

sequences may consist of any combination of the five divisions, such as B-C-E, A-E, A-B-C-D-E, E-C, or others. The characteristics of gravity-powered bottom flows include (1) sharp base with sole marks, (2) divisions of Bouma sequence, (3) graded layer or massive sandstone, and (4) monotonously interbedded alternating and laterally persistent sandstones and shales (After Bouma, 1962; Walker, 1976, Fig. 1, p. 26; Friedman and Sanders, 1978, Fig. 12-52, p. 393).

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There is a considerable body of literature on the problem of proximal versus distal environments in turbidites. A proximal turbidite has : (1) sharp and flat based beds, (2) thicknesses of 10 cm to 1 m, (3) a sand/shale ratio of about 5:1, (4) amalgamation of sandstone beds present, but uncommon, (5) uncommon parallel and cross-lamination, and (6) the typical bed is an AE sequence where the intervening BCD divisions are missing (Walker and Mutti, 1973). The graded beds at Judson Point fit these characteristics fairly well, although the sand/shale ratio is not as high. A distal turbidite has (1) sharp and flat based beds, (2) thicknesses of 1 cm to 10 cm, (3) a sand/shale ratio of 1:1 or less, (4) prominent grading, (5) grain sizes from fine sand to silt, and (6) base-cut-out sequences, usually BCDE, BDE, and CDE (Walker and Mutti, 1973). The graded beds seen at localities other than Judson Point generally fit the first four criteria fairly well, but are coarser grained and generally do not have base-cut-out sequences with the possible exception of certain laminated beds to be discussed in the next section. In general, these graded beds bear more resemblance to distal, rather than proximal, turbidites, but may be transitional (Keith and Friedman, 1977, 1978).

### Parallel-Laminated Sandstones and Limestones

Beds identified as belonging to this lithofacies comprise a significant amount of the lithofacies at all of the major sections to be seen on this field trip and are the major lithofacies at Nutten Hook. They are also the only lithofacies besides the conglomerates found in the city of Troy area, especially on and near the R.P.I. Campus.

The beds of this lithofacies range from medium-grained, parallel laminated sandstones (60%), to medium-grained sandstones with parallel lamination and some cross-lamination (22%), to limestones (9%), and coarse-grained sandstones (9%). Most of the coarse sandstones occur at Judson Point. The limestone beds are pelmicrites with the lamination due to the concentration of fine quartz sand and silt along the laminae. In places a bed will contain fossil fragments. Most of the sandstone beds are composed of medium-grained quartz sand with a variable amount of carbonate matrix forming the laminae. Some of the sandstone beds will contain fossil fragments, and, in fact, nearly all the identifiable trilobite fauna recovered by Bird and Rasetti (1968) from Judson Point, and Nutten Hook, and used by them for dating, came from beds identified in the Keith and Friedman (1977) study as belonging to this lithofacies. All but one of the sandstone beds and all of the limestone beds of this lithofacies show lamination of some sort. Commonly, only parallel lamination is present in the sandstones, but some sandstone beds and most of the limestone beds show some cross-lamination.

The beds here probably represent channel-edge equivalents of the coarser, probable channel deposits represented by the conglomerates, massive sandstones and turbidites. For the most part, the beds of this lithofacies would appear to be single beds of division B of the Bouma Sequence.

In summary, beds of this lithofacies are intimately associated with turbidites and may even be types of turbidites themselves (Keith and Friedman, 1977, 1978).

### Thin Structureless Micrites

This lithofacies is composed of beds of dense, texturally simple micrite that does not show any features in thin section other than neomorphism where the original lime mud has become recrystallized (Fig. 7). Beds of this lithofacies are found at several of the sections seen on this field trip and comprise a significant amount (approximately 20%) of all the lithofacies south of Schodack Landing and Nutten Hook. Single and multiple beds are found interbedded with beds of other lithofacies. At other localities isolated stringers can be found in places. South of Hudson and Nutten Hook even beds of micrite are interbedded with shale (Fig. 8) and beds of cross-laminated and parallel-laminated pelmicrite. These beds show some pull-apart or boudinage structure and, locally, slump folds. South of Schodack Landing the micrite beds are not associated with any coarser beds and make up 70-75% of that part of the section. Pull-apart is common in these beds. The beds south of Schodack Landing change upward to lenses and stringers of micrite in shale gradually becoming thin and discontinuous. A local conglomerate is present in part of the exposure at Schodack Landing (Keith and Friedman, 1977, 1978).

Thin interbeds of fine-grained limestone (usually micrite) intercalated with dark shale, as described for this lithofacies, have been noted from a number of areas (Sanders and Friedman, 1967; Wilson, 1969). These beds are generally referred to as hemipelagic, because they are a combination of terrigenous sediment and pure pelagic sediment.

The beds discussed here do not contain pelagic microfauna, thus, the only source of abundant lime mud is very shallow water (< 30 m) environments. Shallow-water production of lime mud can be quite high, coming from a variety of sources. Once produced, currents can move the lime mud quite easily from the shelf into deeper water. This process would seem to be the only plausible explanation for the micrite beds of this lithofacies. The lime mud was probably carried in dilute suspensions, either by contour currents, nepheloid layers, or dilute turbidity currents (Walker and Mutti, 1973). Isolated beds of micrite could conceivably be attributed to single or an episode of several dilute clouds of lime mud being carried into deeper water. A problem

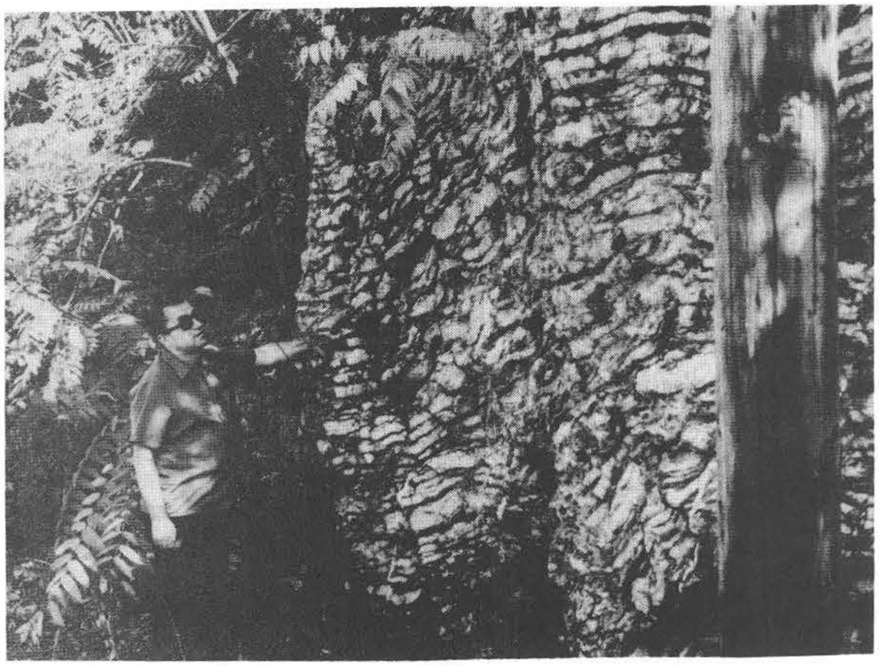


Figure 7. Interbeds of micrite with shale partings. The abundant lime mud was derived from very shallow-water (< 30 m) environments. Currents moved the lime mud into deep water. On left is the well-known Polish geologist S. Dzulynski whose work on deep-water deposits is now classical. Schodack Landing (Stop 4; SL on Fig. 2).

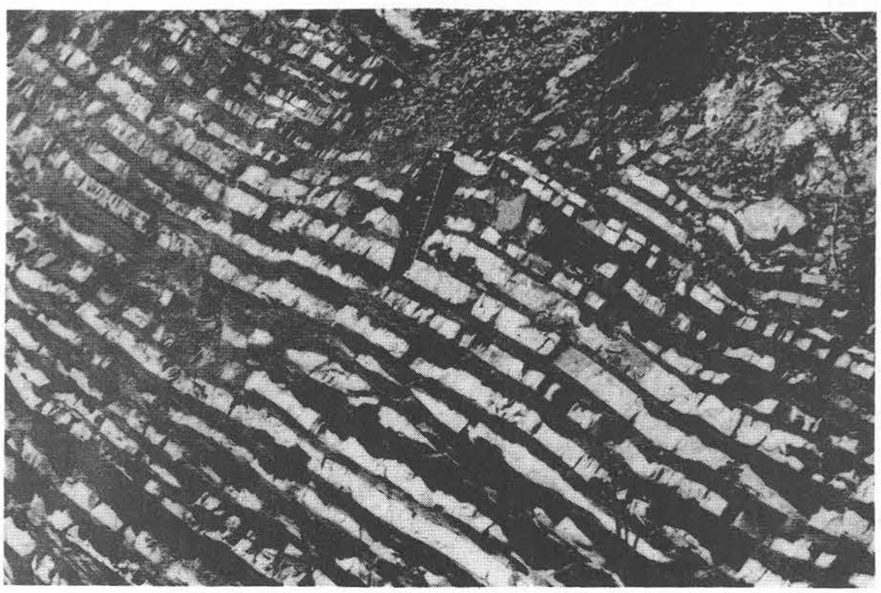


Figure 8. Interbeds of micrite and shale. This micrite is mostly a pel-micrite. The original lime mud was derived from very shallow-water environments. South of Hudson (Stop 1; SH on Fig. 2).

arises, however, with rhythmic succession of micrite and shale beds of very constant and even thickness. Sanders and Friedman (1967) stated that the environmental interpretation of such sequences may be extremely difficult, for similar sequences are seen in near-shore environments.

To summarize, these beds are composed of structureless micrite that is commonly associated with beds or laminae of pelmicrite. This fine-grained material was picked up in suspension on the shelf and carried into deeper water, possibly by contour currents, nepheloid layers, or dilute turbidity currents. The resulting deposits are thin beds of carbonate interbedded with fine-grained terrigenous material (Keith and Friedman, 1977, 1978).

## Current-Ripple-Laminated Limestones and Sandstones

This facies consists of thin beds generally ranging from 1.3 cm to 10 cm, with the average thickness of 4.1 cm. This average is considerably less than that for the graded beds (about 19 cm) and less than that for the parallel-laminated beds (about 7 cm), both of which are similar in terms of sedimentary structures. As with the graded sandstones and limestones and thin, structureless micrites, the best exposures of these beds are in the cuts, south of Hudson, Judson Point, and Nutten Hook. No beds of this lithofacies were found south of Schodack Landing. South of Hudson and at Nutten Hook, beds of this lithofacies occur with the thin structureless micrites (Keith and Friedman,'77, '78).

Lithologically, these current-ripple-laminated beds seem to fall into two types -- pelletal limestone with fine-grained quartz sand, or fine-grained quartz sandstones to siltstones. These beds are always laminated with either parallel laminae or striking cross-laminae.

These current-ripple-laminated beds do not show the variety or orderly sequence of features associated with average turbidites. They are also finer grained and thinner bedded than the graded beds described earlier. The laminated beds of this lithofacies probably were deposited by one of three separate processes: submarine overbank levee deposits associated with turbidity currents, distal turbidites, or possibly contour-following bottom currents (Fig. 9). For a more detailed discussion see Keith and Friedman (1977, 1978).

## Environmental Reconstruction for Deep-Water Deposits

The rocks of the Taconic Sequence studied here are clearly the products of deposition in a slope environment (Figs. 1 and 10). The depositional mechanisms that were active (debris flow, sediment flow, turbidity currents, hemipelagic sedimentation, and contour currents) appear to be characteristic of the lower part of the slope and the base of the slope. All of these processes, except the contour currents, form a continuum such that one sediment gravity flow could act as a debris flow, sediment flow, turbidity current, or suspended cloud depending upon its time and spatial position on the slope.

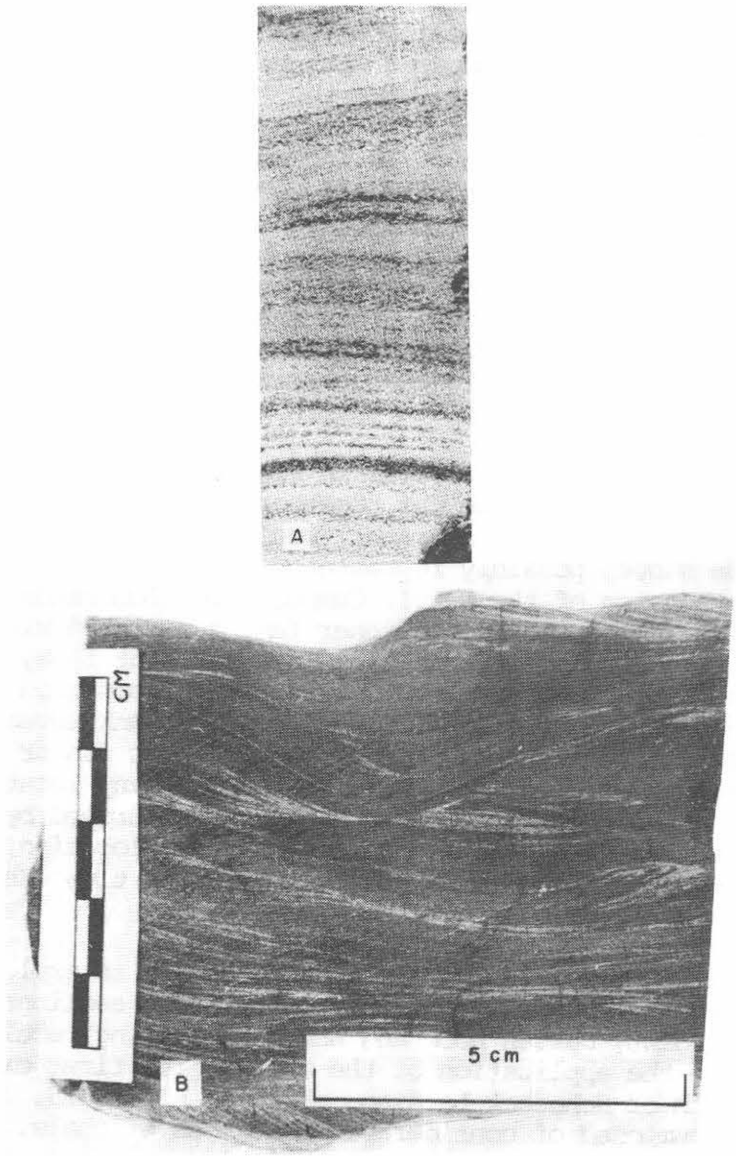



Figure 9. Photographs of modern- and ancient contourites.
A. Core of modern contourite raised from Caicos Outer Ridge, Bahamas, western Atlantic Ocean. This sediment is a well-sorted, medium-grained skeletal sand; note horizontal laminae. (E.D. Schneider.)
B. Polished slab of inferred contourite of Cambrian age (West Castleton Formation) sampled near campus of Rensselaer Polytechnic Institute, Troy, New York. This inferred contourite is a current-ripple cross-laminated pelletal limestone; quartz silt accentuates the laminae. (B.D. Keith.)
(Friedman and Sanders, Fig. 12-51, p. 392).

There are many problems associated with the reconstruction of the slope environment of the Taconic Sequence. Foremost is the tectonic complexity that has been superimposed since deposition of the sediments. Details of physiography cannot be compared with modern slopes, but the general type and rate of sediment input and the transport mechanisms that were active can be compared with modern analogs. The modern example that fits very nearly with the lithofacies described in the Taconic Sequence is the slope-fan-basin-plain system that is fed by submarine canyons. The conyon is incised into the slope and acts as a conduit for the movement of shelf sediments into deep water. The fan built out from the mouth of the canyon is then primarily composed of shelf-derived sediment. The fan can be divided into several morphologic features. The inner (or upper) fan has one major channel with prominent levees to either side. This leads to the mid-fan area (or supra-fan) composed of many distributary channels and interchannel areas. The outer (or lower) fan is characterized by no defined channel system and merges into the basin plain (Keith and Friedman, 1977, 1978).

The relationship between the model in Figure 10 and the lithofacies described in this guidebook can be put together. The coarsest and least structured sediments (conglomerates) would form thick deposits at the base of the slope, possibly represented by some of the thicker conglomerates in the area of the R.P.I. Campus. Conglomerates would also be found in the lower canyon and inner fan, associated with coarse sands, as products of debris flow and fluidized sediment flow, respectively. Farther out into the fan, turbidity-current deposition becomes dominant, as channel and interchannel deposits. Overbank levee deposits could be found associated with any channel in the inner fan or mid-fan area. The hemipelagic micrite beds could be found at any location on the slope and fan where they were not subsequently destroyed by current activity. Contourite beds could also be found at any location, depending upon the position of the current at any particular time (Keith and Friedman, 1977, 1978).

The test of this model is whether it can be used to explain some of the exposures seen on this field trip. The exposed sections (South of Hudson, Judson Point, Nutten Hook and Schodack Landing) would best serve to illustrate the application of the model. The first example is the section south of Schodack Landing, shown in Figure 15. The base of the section is composed of considerable thickness of shale, and at least one conglomerate bed; overlying the shale is a sequence of thin micrite and shale beds, possibly the product of transport from the shelf. The conglomerate overlying these beds is probably the result of local slumping, since the clasts all appear to be derived from the underlying limestone beds. The next higher conglomerate indicates that feeding from the shelf has started, producing coarse sand and biosparite clasts, but only as an isolated event. However, the subsequent presence of channel and interchannel turbidites and a conglomerate, followed by massive sandstones and more turbidites shows active feeding from the shelf and fan development. The beds show definite mid-fan development and possibly an inner fan channel as well. Abruptly, the system appears to have been abandoned, as shown by the resumption of shale deposition, with only a local thin limestone (Keith and Friedman, 1977, 1978).

The section at Judson Point (Fig. 13) is dominated by turbidite beds and several massive coarse sandstone beds. The presence of

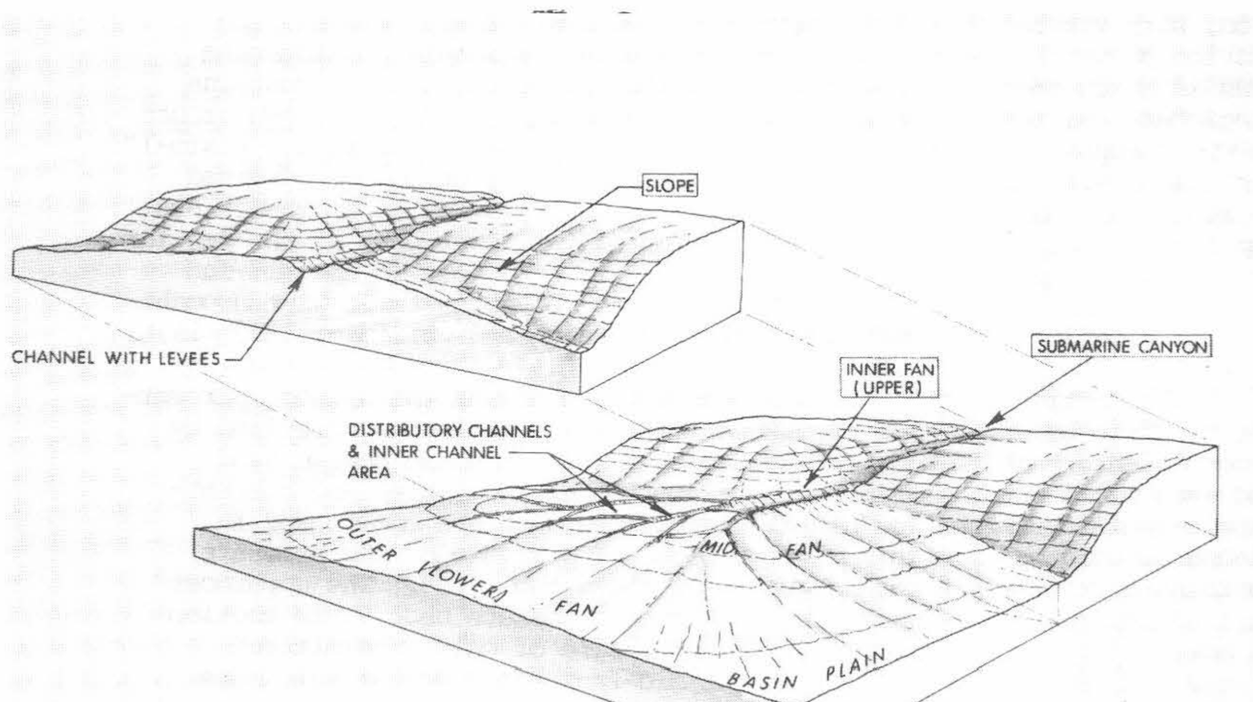



Figure 10. Diagrammatic block diagram of submarine canyon and fan complex, showing major morphologic features. Vertical relief exaggerated (Keith and Friedman, 1977, Fig. 19, p. 233).

several AE beds of the Bouma Sequence is characteristic of "proximal" turbidites. The massive beds are common in the lower part, but uncommon in the upper part of the section. The presence of thick massive sands and local conglomerates and thin-bedded laminated sands suggests channel and levee deposits of the inner fan area with the main channel periodically changing its course. Two of the conglomerates are somewhat lenticular in nature and truncate some underlying bed, suggesting channel deposition. For reasons that are not entirely clear, the only carbonate present is a 2 m-thick section at the top of the lower half of the exposure. The beds appear to be fine- to medium-grained hemipelagic and contourite beds, with a conglomerate near the top that contains clasts of the beds below. Possibly the section at Judson Point was influenced by locally dominant sand source. A more likely possibility is that the inner fan area is generally characterized by sands and that carbonates are generally carried farther out by more mature turbidity currents (Keith and Friedman, 1977, 1978).

The section at Nutten Hook is more difficult to interpret, because it is faulted in several places (Fig. 14). The interval below the covered zone is quite sandy and probably represents an environment similar to that just discussed for Judson Point. The section above this zone is dominated by thin interbeds of limestone of hemipelagic type. The lower fault interrupts the section, but the rocks above and below are quite similar. In places thicker laminated beds are distributed that are probably a "distal" turbidite. This was a local area of quiet sedimentation, with virtually no interruption by sediment gravity flows. The section above the upper fault contains several carbonate conglomerate beds in which the thin limestones, and the top of the section contains conglomerates, thick, coarse, laminated sandstones, and graded sandstones. It would appear that the environment shifted at some point in a "proximal" direction, with the influx of a considerable amount of coarser-grained debris. This shift might be due solely to reactivation of a channel system that was not in use during deposition of the lower part of the section, or due to the buildup of a new channel system, probably in the mid-fan area. The alternative is that the sediments above the fault were brought in tectonically from a more proximal area (Keith and Friedman, 1977, 1978).

The section south of Hudson, New York, contains the highest percentage of shale of any of the exposures (Fig. 12). It is characterized by intermittent, thin turbidite beds, most of which contain coarse sand and even micrite pebbles in the basal portions. Laminated and current-ripple-laminated probable "distal" turbidites also are common and in places associated with thin micrite beds. The middle of the exposure contains a regularly bedded sequence of these two types. The uppermost part of the section is marked by a thin conglomerate bed. This section is more difficult to interpret. It was a site of only intermittent coarse sedimentation, possibly in the mid-fan area. Hemipelagic beds of alternating limestone (micrite) and dark shale are present at the section south of Hudson; currents moved lime mud and terrigenous mud from the shelf into deep water (Keith and Friedman, 1977, 1978).

## SHALLOW-WATER SETTING

Repeating from the Introduction, during the Cambrian and Ordovician periods, a shallow epeiric sea covered most of the North American continent. At the then-eastern edge of this submerged continent, shallow-water limestones and dolostones accumulated. Those which we shall study on this field trip are part of the Tribes Hill Formation of lowermost Ordovician age (Fisher, 1954). The steep paleoslope, which marked the transition from the submerged continent to the deep sea, lay about 35 miles east of the present Tribes-Hill exposures which we shall visit.

The carbonate rocks of the Tribes Hill Formation show many features that suggest that they were subjected to repeated shoaling and intermittently were exposed subaerially. These features include mud cracks, birdseye textures, undulating stromatolitic structures, mottles, lumpy structures, scour-and-fill structures, flat pebbles, cross-beds, and, as a lithology, syngenetic dolostone (Friedman and Sanders, 1967; Friedman and Braun, 1975). Features identical to these are known from most Paleozoic shallow-water carbonates that underlie much of North America. The site of accumulation of the Tribes Hill carbonates, however, differed markedly from that of most other Paleozoic carbonates that stretch across North America. The Tribes Hill carbonates were deposited close to the edge of the continent. Hence diurnal or semi-diurnal fluctuations of the waters of the deep ocean should have left their mark on the Tribes Hill deposits. If so, such deposits can be classed as tidal.

In modern tidal sediments perhaps the most obvious of the morphologic features are tidal channels. In the rocks of the Tribes Hill Formation, what may be ancient tidal channels can be observed. Such channels have not been reported from the Cambro-Ordovician carbonate-rock sequences in other parts of North America.

The sizes of the channels in the Tribes Hill Formation are comparable to the sizes of modern tidal channels. Sharp basal truncations are typical. The material filling the channels consists mostly of carbonate skeletal and intraclastic sand (biosparite and intrasparite) a high energy facies. These channels cut into a mottled dolomitic micrite and biomicrite, a low energy facies. Large blocks of micrite, up to 1 meter in diameter, which are lodged in the fills within the channels, are thought to have been derived by undercutting of the banks (Fig. 19). Hence, to accomplish such undercutting, the currents in these channels must have flowed fast. The contrast between the high-energy facies filling the channels and the low-energy facies in the flats adjacent to the channels likewise suggests that currents in the channels flowed swiftly.

Although in Paleozoic limestones the products of shoal waters are ubiquitous, tidal deposits may have been restricted to the margins of the continents where the epeiric shelf faced the deep ocean. The carbonate rocks of the Tribes Hill Formation may be an example of such a tidal sequence.

Authigenic feldspar is an essential constituent of the carbonate rocks of the Tribes Hill Formation. The high concentration of feldspars caused stromatolitic laminae to weather in positive relief. Such feldspars commonly are the end products of the alteration of zeolites. However, zeolites are unknown from sedimentary rocks as old as Early Ordovician. In rocks older than mid-Paleozoic, any original zeolites probably have changed to feldspars. In volcaniclastic rocks of Cenozoic age, authigenic feldspar is known to be the end product of volcanic glass whose initial alteration product was a zeolite (Sheppard and Gude, 1969; Goodwin, 1973).

The feldspars in the Tribes Hill Formation are interpreted as wind-transported tephra that accumulated at the margin of the Proto-Atlantic (Iapetus) Ocean. The active volcanoes responsible for such tephra may have been parts of ancient island arcs.

## ITINERARY

Figure 11 is the road log and shows the location of all the seven stops.

Depart from parking lot of R.P.I. Houston Field House, take People's Avenue west past Samaritan Hospital (on right) downhill to Eighth Street.

| Miles | Distance between points | |
|---|---|---|
| 0.7 | 0.7 | Proceed for one block to Federal Street, turn right and cross bridge across Hudson River and continue to Interstate 787 south |
| 1.2 | 0.5 | Enter Interstate 787 south |
| 5.8 | 4.6 | Take Interstate 90 east; cross Hudson River |
| 19.0 | 13.2 | Take Exit 12 (sign U.S.9 south) and follow route to Hudson |
| 20.4 | 1.4 | Enter Columbia County |
| 23.7 | 3.3 | Junction with Route 9H; continue on U.S.9 |
| 24.3 | 0.6 | Enter Valatie |
| 25.6 | 1.3 | Enter Kinderhook |
| 27.7 | 2.1 | Town of Stuyvesant |
| 29.3 | 1.6 | Enter Stuyvesant Falls |
| 30.0 | 0.7 | Enter Columbiaville; Junction with Route 9J |
| 34.6 | 4.6 | Enter Stottville |
| 35.4 | 0.8 | Town of Greenport |
| 36.0 | 0.6 | Enter Hudson; continue south on U.S.9 through Hudson |

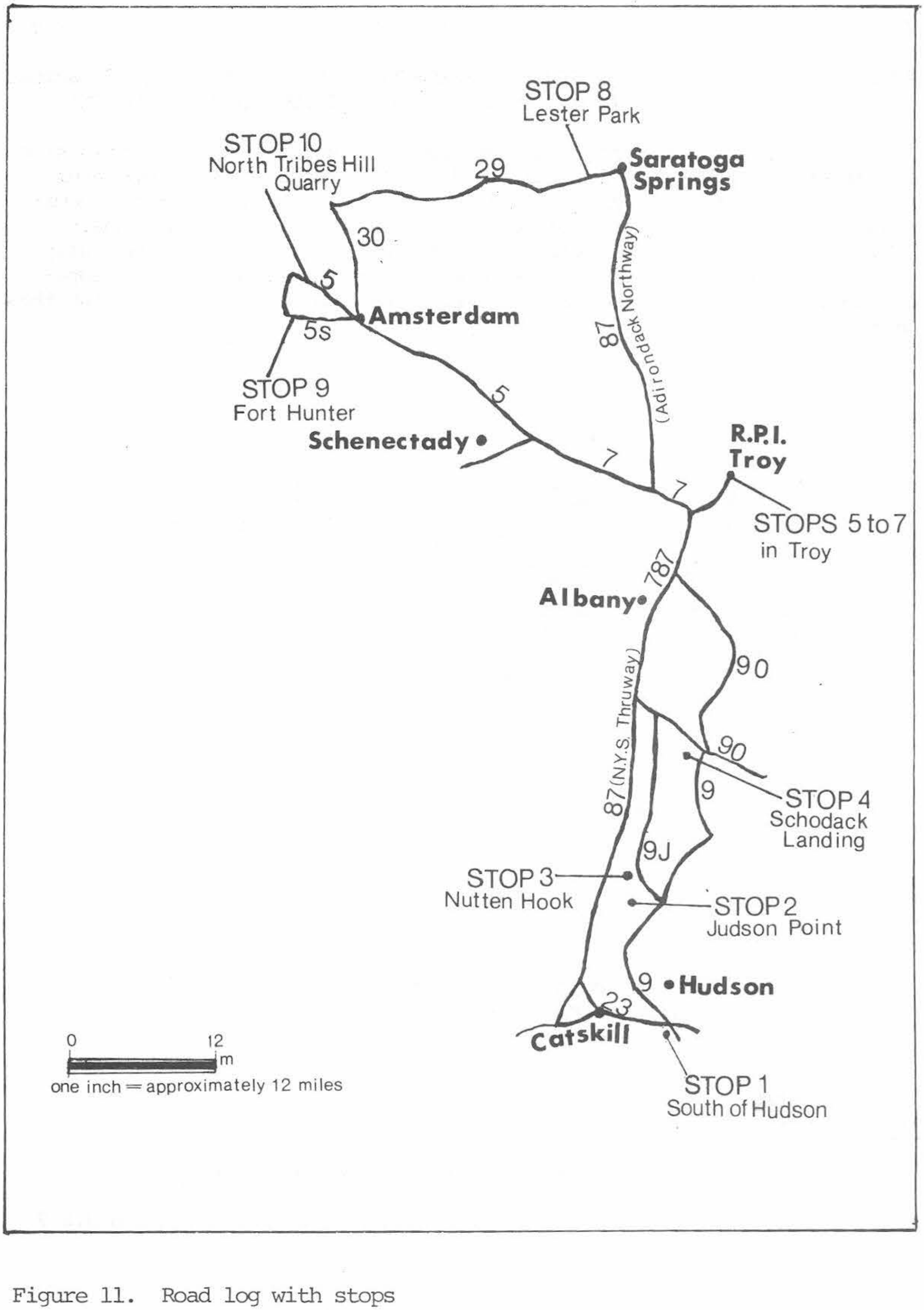



Figure 11. Road log with stops

| Miles | Distance between points | |
|---|---|---|
| 41.4 | 5.4 | Junction with U.S.23; continue south on U.S.9 |
| 42.2 | 0.8 | STOP 1 EXPOSURE ON EAST SIDE OF U.S.9 (across from a white house) (SECTION SOUTH OF HUDSON) |

Figure 12 shows and describes the lithofacies exposed at this stop, and interpretes its depositional setting. The rocks are of deep-water mid-fan origin (Figs. 1 and 10). Note especially the interesting "hemi-pelagic" interbeds of fine-grained limestone (micrite) and dark shale (Fig. 8) and the carbonate-clast conglomerate (Fig. 4). Read carefully the material covered under the heading of "Deep-Water Setting: a Slope-Fan-Basin-Plain Model" so that you understand the objective of making this stop.

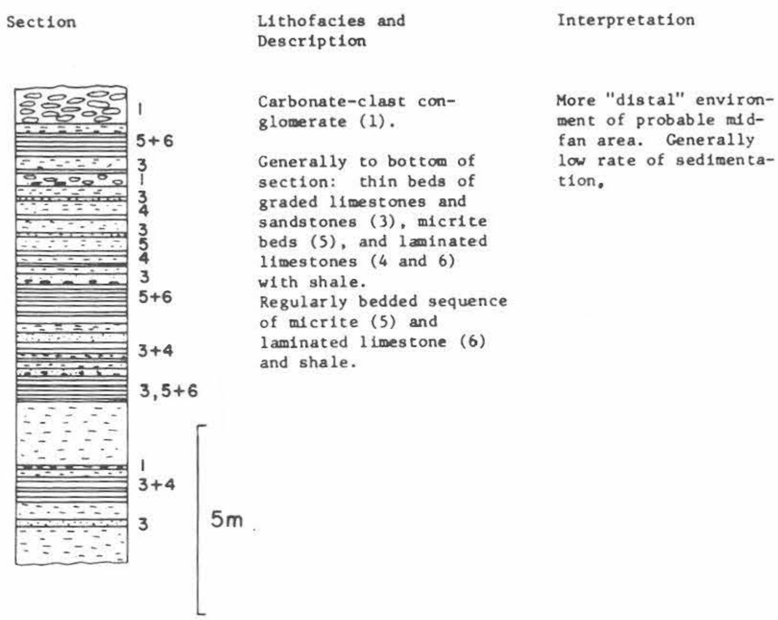



Figure 12. Section south of Hudson Stop 1 (SH on Fig. 2) (Keith and Friedman, 1977, Fig. 23, p. 1237).

| Miles | Distance between points | |
|---|---|---|
| | | Make a U-Turn and head north on U.S.9 |
| 43.0 | 0.8 | Junction with U.S.23; continue north on U.S.9 |

| Miles | Distance between points | |
|---|---|---|
| 46.4 | 3.4 | Enter Hudson; continue through Hudson north on U.S.9 |
| 50.1 | 3.7 | Enter Stottville |
| 52.3 | 2.2 | Enter Columbiaville |
| 53.5 | 1.2 | Junction of U.S.9, Route 9J, and an unmarked asphalt road identified by sign "Dead End." Turn sharp left onto asphalt road and head west towards Hudson River |
| 54.5 | 1.0 | At fork take lower road marked "Dead End" |
| 54.6 | 0.1 | STOP 2. JUDSON POINT |

Figure 13 illustrates the section seen at this stop and describes the lithofacies; it also provides an interpretation of the depositional setting. The rocks are of inner- to mid-fan origin (Figs. 1 and 10). The section is dominated by turbidite beds, and several massive coarse sandstone beds. The presence of several AE beds of the Bouma Sequence is characteristic of proximal turbidites. The occurrence of thick massive sands and local conglomerates and thin-bedded laminated sands suggests channel and levee deposits of the inner fan area. Two of the conglomerates are somewhat lenticular and truncate an underlying bed, suggesting channel deposition. Again review the section entitled "Deep-Water Setting: a Slope-Fan-Basin-Plain Model" for a better understanding of the features observed at this stop.

| Miles | Distance between points | |
|---|---|---|
| | | Return to Rte. 9J |
| 55.8 | 1.2 | Head north on Rte. 9J |
| 57.4 | 1.6 | Town of Stuyvesant |
| 58.2 | 0.8 | Cross railroad tracks at Ferry Road (on left); note historic marker. Head west on Ferry Road. |
| 58.5 | 0.3 | STOP 3. NUTTEN HOOK |

Figure 14 gives details on this section, including an interpretation of depositional environment.

| | | |
|---|---|---|
| | | Return to Rte. 9J |
| 58.9 | 0.3 | Head north on Rte. 9J |
| 60.8 | 1.9 | Enter Stuyvesant |

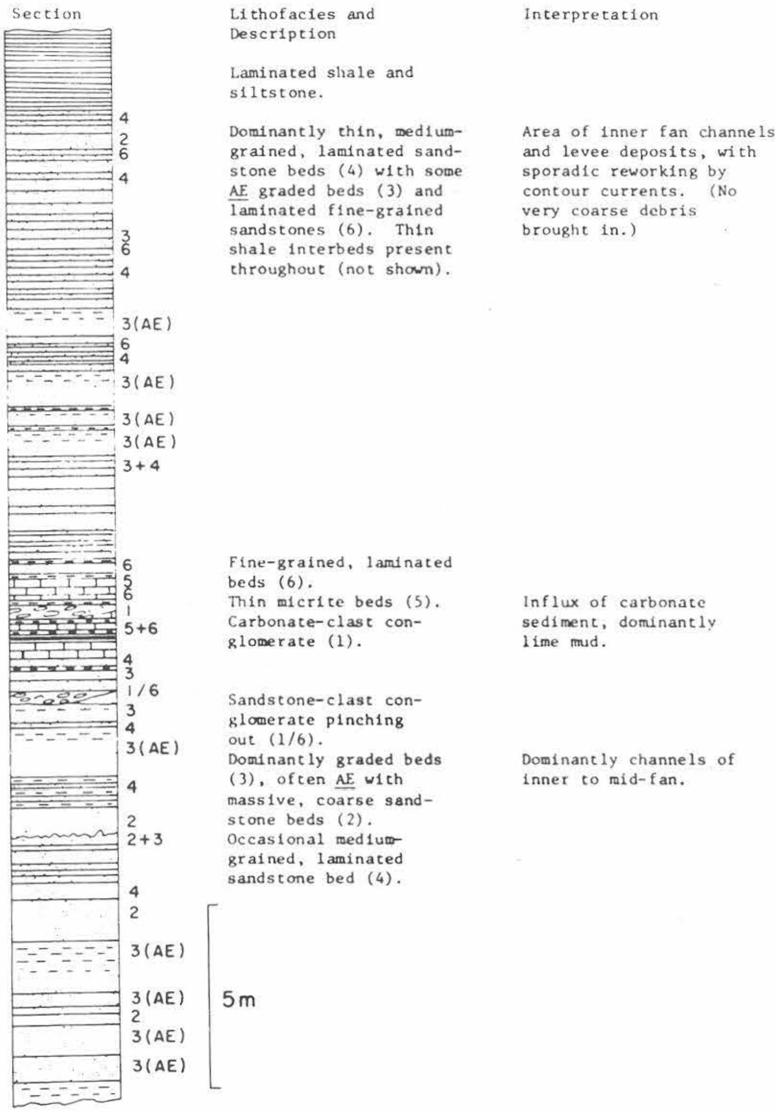
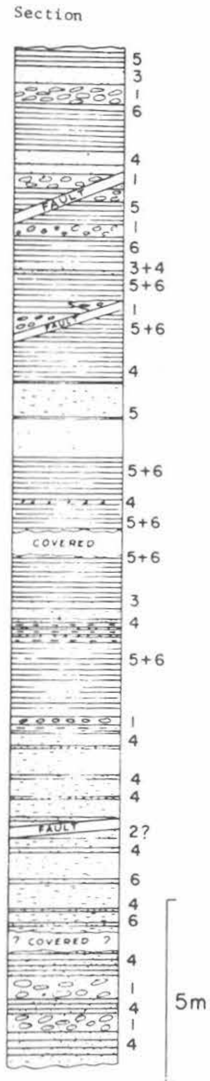



Figure 13. Section at Judson Point (Stop 2; JP on Fig. 2) (Keith and Friedman, 1977, Fig. 21, p. 1235).




| Lithofacies and Description | Interpretation |
|---|---|
| Dominantly thinly interbedded micrite (5) and laminated limestone (6) with occasional beds of carbonate-clast conglomerate (1) and sandstone (4). Section is interrupted by two faults. | Possibly mid-fan channel and interchannel sedimentation with periods of hemipelagic sedimentation and reworking. Relationship between sections above and below second fault uncertain. |
| Dominantly thinly interbedded micrite (5) and laminated limestone (6) with shale. | Dominantly an area of hemipelagic sedimentation. |
| Thin sandstone beds (4), one graded (3). See above, often showing small scale slump folds. | |
| Thin conglomerate (1). Dominantly shale with occasional thin sandstone bed (4), rare laminated sandstone (6), and one massive sandstone truncated by a fault at the top (2?). | Area of only sporadic coarser sedimentation. |
| Thin, medium-grained, laminated sandstone (4) and sandstone-clast conglomerates (1). Occasional shale partings (not shown). | Inner fan (?). |

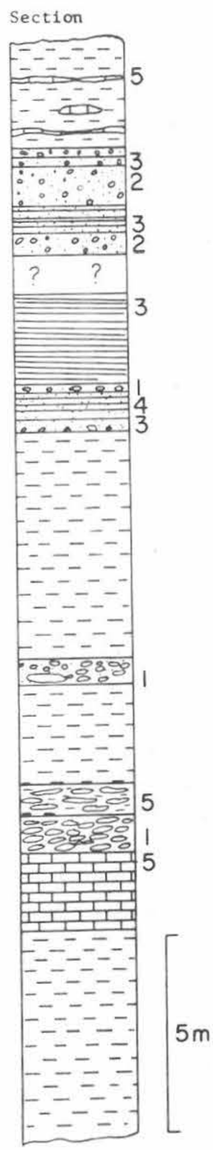
Figure 14. Section at Nutten Hook (Stop 3; NH on Fig. 2) (Keith and Friedman, 1977, Fig. 22, p. 1236).

| Miles | Distance between points | |
|---|---|---|
| 62.5 | 1.7 | Overpass, New York Central Railroad |
| 63.5 | 1.0 | Railroad overpass |
| 65.4 | 1.9 | STOP 4. EXPOSURES SOUTH OF SCHODACK LANDING |

Bus parks on dirt road east of highway. We shall first examine the road cut on the east side of the highway and then walk on dirt road across the railroad tracks to view more fine exposures.

Figure 15 describes and illustrates the section seen and provides interpretation of the depositional setting. Note exposures of bedded micrite with shale partings. This micrite represents lime mud which was derived from the shelf and probably settled from suspension. The conglomerate overlying the bedded micrite is probably the result of slumping, since the clasts appear to be derived from the underlying limestone beds. The strata at this stop show mid-fan development and possibly an inner fan channel as well. Again review the earlier section entitled "Deep-Water Setting: a Slope-Fan-Basin-Plain Model" for additional interpretation of depositional setting.

| | | |
|---|---|---|
| | | Continue north on Rte. 9J |
| 66.3 | 0.9 | Enter Rensselaer County |
| 66.8 | 0.5 | Enter Schodack Landing |
| 69.1 | 2.3 | 2 overpasses; New York Thruway and railroad |
| 70.6 | 1.5 | Enter Village of Castleton on Hudson |
| 77.9 | 7.3 | Overpass of U.S.9; junction with U.S.9; follow U.S.9 west (labelled north) |
| 78.1 | 0.2 | Enter Rensselaer |
| 78.5 | 0.4 | Enter bridge to cross Hudson River |
| 79.2 | 0.7 | From bridge take Interstate 787 north |
| 86.0 | 6.8 | Take Troy-U.S. 7 Exit (23rd Street, Watervliet, Green Island) |
| 86.5 | 0.5 | Cross Hudson River bridge to Federal Street, Troy |
| 87.1 | 0.6 | Proceed east uphill on Federal Street to '87 Gymnasium of R.P.I. Campus |
| | | STOP 5. RENSSELAER POLYTECHNIC INSTITUTE, '87 Gym. Exposure behind fence adjacent to gym. |




| Lithofacies and Description | Interpretation |
| --- | --- |
| Shale with thin beds of micrite (5). | Abandonment of the system. |
| Graded beds (3) and massive, coarse sandstone beds with pebbles (2). | Mid-fan or possibly inner fan channel. |
| Covered.<br>Fine-grained, thin, laminated graded beds (3). | Mid-fan interchannel deposition. |
| Thin conglomerate (1).<br>Laminated, medium-grained sandstone (4).<br>Graded bed (3). | Mid-fan channel. |
| Carbonate-clast conglomerate (1). | Possible start of channel development as an isolated event. |
| Shale with lenses and nodules of micrite (5). | |
| Micrite-clast conglomerate (1). | Local slumping. |
| Micrite (5) with shale partings. | Influx of lime mud in suspension from shelf. |

Figure 15. Section at Schodack Landing (Stop 4; SL on Fig. 2) (Keith and Friedman, 1977, Fig. 20, p. 1234).

Ruedemann (1930, p. 114; also fig. 64) described and photographed this exposure as a good example of a "cliff of mylonite," one of the "excellent exposures of a fault breccia" on the campus of Rensselaer Polytechnic Institute. According to Ruedemann and reconfirmed by Elam (1960) a thrust fault follows part of this street (Sage Avenue) and Ruedemann mistook this conglomerate for a fault breccia. Perhaps the presence of criss-crossing veins in this exposure led to his interpretation of a "cliff of mylonite." Jack G. Elam (1960; unpublished Ph.D. thesis at Rensselaer Polytechnic Institute) assigned the rocks at this exposure to the Schodack lithofacies of Early Cambrian age. Cushing and Ruedemann (1914, p. 69) had introduced the "Schodack Formation" which according to Fisher (1961, p. D8) has now fallen victim to a nomenclatorial "snafu." Zen (1964) has renamed this formation the West Castleton Formation.

Lowman (1961) recognized that the boulders are a conglomerate and not a breccia, and following Kuenen and Migliorini (1950), he introduced the term brecciolas. The term brecciolas refers to graded limestone breccia beds that alternate with dark-colored shales (Lowman, 1961, p. B6; Sanders and Friedman, 1967, p. 242; Friedman, 1972, p. 25; Friedman and Sanders, 1978, p. 390, 395).

The limestone- sandstone- and chert boulders which are embedded in shales at this exposure range from angular to rounded and show considerable variation in size (Fig. 5). Some boulders are coarse-grained fossiliferous limestone fragments with a micritic dolomite matrix. The rocks above the brecciolas are greenish-gray shales.

The boulders are those of rocks that formed under shallow shelf conditions. Their emplacement as boulders into shales, which are considered to be offshore deep-water sediment, indicates that the boulders moved downslope. The environment of deposition inferred for the brecciolas at this stop is that of the lower slope or base of slope (Fig. 1). Although the boulders came from the west down the slope, shelf carbonates (their source) extend many miles east of Troy (and presumably underlie Troy at depth).

Brecciolas which formed along the original east edge of the carbonate shelf parallel to the depositional strike for hundreds of miles define the site of the basin margin (rise) in Cambrian-Ordovician time. This Cambrian-Ordovician basin margin was located east of Troy near the present site of the Green Mountain axis. A relatively steep slope must have existed between the shelf edge and the basin margin with resultant instability that helped initiate slides, slumps, turbidity currents, mud flows, and sand falls.

| Miles | Distance between points | |
|---|---|---|
| | | Continue uphill (east) on Sage Avenue, pass Student Union (on right) to Burdett Avenue, cross Burdett Avenue, and drive on to Parking Lot of Troy High School. Keep to extreme left (north end) of Parking Lot. Walk north to wall of old quarry. |

| Miles | Distance between points | |
|---|---|---|
| 87.5 | 0.4 | STOP 6. TROY HIGH SCHOOL QUARRY |

The spectacular brecciolas at this exposure consist of three members with eleven sub-members (Lowman, 1961). For details of the rocks, refer to Lowman's descriptions (1961, p. B11-B12). The brecciolas are Schodack lithofacies of the West Castleton Formation of Early Cambrian age, as at Stop 5.*

A thin-section study shows the limestones to consist of biomicrites, biointramicrites, and micrites with varying terrigenous quartz and clay minerals. The intraclasts are of pelmicrite. Shell fragments have been selectively dolomitized.

The observation that the limestone boulders are mostly micrites indicates that before removal downslope from their site of deposition the limestones were deposited under low-energy conditions on the shallow shelf to their original west, but at a place now still far to the east of Troy. The abundant fauna shows that the shallow waters were well aerated. The carbonate sediments must have lithified before their displacement downslope.

| | | |
|---|---|---|
| | | Return to Burdett Avenue, turn right (north) on Burdett Avenue to Hoosick Street (NY 7) |
| 88.1 | 0.6 | Turn right on Hoosick Street for one block and turn left on 21st Street to Troy Jewish Community Center. |
| 88.4 | 0.3 | STOP 7. TROY JEWISH COMMUNITY CENTER |

One large block of orthoquartzite, approximately 30 feet by 15 feet, probably settled in deep-water shale. Although limonitic, this orthoquartzite is devoid of rock fragments, hence is a second-cycle or multicycle rock. Note that the exposed shales surrounding this erratic block show that this block occurs singly. This exposure occurs along strike of the brecciolas and many more exposures of the brecciolas occur north of here in Frear Park. In a pit about 100 feet or so north of this block we exhumed from the shale a block of dark gray, fractured and veined micritic dolomitic limestone.

The size and shape of the block of orthoquartzite suggests more than a steep slope. To detach a block of this dimension required considerable instability near the shelf edge, such as severe shakes as occur during earthquakes. This block of rock differs in lithology from the brecciolas which we have seen at the previous two stops. In contrast to the flat limestone boulders of the previous stop this huge

*Note that the carbonate shelf west of Troy contains no rocks older than Late Cambrian; somewhere between west of Troy and the present Green Mountains the Middle Cambrian (?) and Lower Cambrian strata wedge in.

block with its irregular outline suggests that solid bedrock of sandstone was forcibly detached from the shelf edge or basin slope. By analogy with modern events, turbidity currents, slumps, mud flows, and slides are usually funneled through submarine canyons. Could it be that this block was part of the wall of a submarine canyon which became detached during one of the slides and was moved by gravity into the basin or basin margin?

The alternative interpretation would be to consider this block to have been caught up in fault movement. Indeed slicken-sides are present on this block. However, the lower exposed contact with the shale is depositional and not faulted. Because the orthoquartzite block occurs along strike with the other brecciolas, and a limestone block has been found about 100 feet away, the evidence suggests that emplacement was by gravity rather than by faulting.

Convince yourself that this block is not a glacial erratic.

The shales at this stop have been assigned to the Schodack lithofacies of the West Castleton Formation of Early Cambrian age; the displaced orthoquartzite block may be as old as Precambrian.

| Miles | Distance between points | |
|---|---|---|
| | | Return to 21st Street and Hoosick Street (NY7) |
| 88.3 | 1.2 | Turn right on Hoosick Street (NY7) and proceed west following NY7; cross Hudson River; continue on NY7 |
| 91.6 | 3.3 | Latham Circle (continue on NY7) |
| 96.0 | 0.5 | Turn right (north); enter north entrance of Northway, Interstate 87. |
| 97.9 to 98.0 | 1.9-2.0 | Note two exposures of westernmost deep-water sedimentary facies, consisting of Middle Ordovician Normanskill graywacke and shale, in roadcut on right (northbound lane). West of here and underneath the Normanskill at a depth of several thousand feet are Cambrian-Ordovician rocks of shelf facies. |
| 98.4 | 0.4 to 0.5 | Cross Mohawk River on Northway. This beautifully designed bridge won an award in 1958. |
| 110.9 | 12.5 | Note exposure of Middle Ordovician Canajoharie Shale, a dark gray silty shale of outer shelf to slope facies. |
| 113.1 | 2.2 | Take Exit 13 N from Northway (sign: U.S.9 North Saratoga) and follow Route 9 north. |

| Miles | Distance between points | |
|---|---|---|
| 114.9 | 1.8 | Note on left traffic light to Performing Arts Center (Main Gate to Saratoga Spa State Park), but continue straight for another 1.0 mile to traffic light for Performing Arts Center (sign: Saratoga Spa State Park, Summer Theater, Roosevelt Bath, Golf Course). |
| 115.9 | 1.0 | Turn left at traffic light and drive along pine- and spruce-lined lane through Saratoga Spa Golf. Course |
| 116.5 | 0.6 | Turn north (right) on NY50. Bear left following sign to NY29. |
| 117.7 | 1.2 | Drive to traffic light and turn left (west) on NY29. |
| 119.8 | 2.1 | Turn right (north) on Petrified Garden Street where sign on tree says "Petrified Gardens." Drive past "Petrified Gardens" to Lester Park. |
| 121.0 | 1.2 | Alight at Lester Park |

STOP 8. LESTER PARK

This locality is the site of one of the finest domed algal mats to be seen anywhere preserved in ancient rocks. On the east side of the road in Lester Park a glaciated surface exposes horizontal sections of the cabbage-shaped heads composed of vertically stacked, hemispherical stromatolites. These structures, known as Cryptozoons, have been classically described by James Hall (1847, 1883), Cushing and Ruedemann (1914), and Goldring (1938); an even earlier study drew attention to the presence of ooids as the first reported ooid occurrence in North America (Steele, 1825). Interest in these rocks has been revived as they are useful environmental indicators (Logan, 1961; Fisher, 1965; Halley, 1971). The algal heads are composed of discrete club-shaped or columnar structures built of hemispheroidal stromatolites expanding upward from a base, although continued expansion may result in the fusion of neighboring colonies into a Collendia-type structure (Logan, Rezak and Ginsburg, 1964). The stromatolites are part of the Hoyt Limestone of Late Cambrian (Trempealeauan) age. An intertidal origin has been inferred for these stromatolites.

The evidence for deposition under tidal conditions for the Hoyt Limestone at Lester Park includes: (1) mud cracks, (2) flat-pebble conglomerate, (3) small channels, (4) cross-beds, (5) birdseye structures, (6) syngenetic dolomite, and (7) stromatolites (for characteristics on recognition of tidal limestones, see Friedman, 1969).

At Lester Park the heads which are circular in horizontal section range in diameter from one inch to three feet; many are compound heads. The size of the larger heads suggests that they formed in highly turbulent waters.

The line of depositional strike along which the domed stromatolites occur was probably where the waves were breaking as they came across the deeper ocean from the east and impinged on the shallow shelf.

Several petrographic observations in these rocks permit an analogy with modern algal mats in hypersaline pools of the Red Sea Coast (Friedman and others, 1973). Mat-forming algae precipitate radial ooids, oncolites, and grapestones which occur in these rocks; interlaminated calcite and dolomite which in part compose the stromatolites of the Hoyt Limestone correspond to alternating aragonite and high-magnesian calcite laminites which modern blue-green algae precipitate. In modern algal mats the high-magnesian calcite laminites contain abundant organic matter in which magnesium has been concentrated to form a magnesium-organic complex. Between the magnesium concentration of the high-magnesian calcite and that of the organic matter sufficient magnesium exists in modern algal laminites to form dolomite. Hence the observation in ancient algal mats, such as observed in the Hoyt Limestone, that calcite and dolomite are interlaminated, with calcite probably forming at the expense of aragonite and dolomite forming from high-magnesian calcite.

| Miles | Distance between points | |
|---|---|---|
| | | Turn around and drive back (south) to NY29. |
| 122.2 | 1.2 | Turn right (west) on NY29. |
| | | Pass basal Paleozoic quartz-cobble conglomerate (a possible talus deposit) on weathered Precambrian gneiss 1/2 mi. east of Kimball's Corners (NY147). |
| 141.3 | 19.1 | Turn left (south) on NY30. |
| 147.6 | 6.3 | City limits of Amsterdam |
| 149.0 | 1.4 | Cross bridge over Mohawk River. |
| 149.3 | 0.1 | Take Exit for Amsterdam Armory; Turn right on Florida Avenue and go west. |
| 149.8 | 0.5 | Turn right on Broadway. |
| 150.6 | 0.8 | Turn right (west) on NY5S. |
| 153.0 | 2.4 | Fort Hunter, turn right (north) on Main Street. |
| 153.2 | 0.2 | Turn right (east) to Queen Ann Street. |
| 154.1 | 0.9 | STOP 9. FORT HUNTER QUARRY. Alight at slight bend in road and walk to Fort Hunter Quarry which is across railroad track close to Mohawk River. (Fort Hunter Quarry cannot be seen from road; another small quarry visible from road is approximately 0.1 mile farther east, but will not be visited on this trip). |

Stromatolites in the Fort Hunter quarry consist almost entirely of dolomite in the form of irregularly bedded, finely-laminated, undulating structures. The rocks in this quarry are part of the Tribes Hill Formation of earliest Ordovician age (Fisher, 1954). The lithofacies of the Tribes Hill Formation have been studied in detail by Braun and Friedman (1969) within the stratigraphic framework established by Fisher (1954). Figure 16 is a columnar section showing the relationship of ten lithofacies to four members of the Tribes Hill formation. At Fort Hunter we will study the lowermost two lithofacies of the Fort Johnson Member (see column at right (east) end of section, in Fig. 16).

Two lithofacies are observed; (1) lithofacies 1, mottled feldspathic dolomite, and (2) lithofacies 2, laminated feldspathic dolomite. Lithofacies 1 is at the bottom of the quarry, and lithofacies 2 is approximately half way up.

Lithofacies 1. This facies occurs as thin dolostone beds, 2 cm to 25 cm but locally more than 50 cm thick, with a few thin interbeds of black argillaceous dolostone which are up to 5 cm thick. In the field, the dolomite shows gray-black mottling and in places birdseye structures. In one sample, the infilling of the birdseyes shows a black bituminous rim which may be anthraxolite. In the field, trace fossils are abundant, but fossils were not noted. Authigenic alkali feldspar (microcline) is ubiquitous throughout this lithofacies; its identity as alkali feldspar was determined by x-ray analysis and staining of thin sections with sodium cobaltinitrite. The insoluble residue makes up 22 to 54% by weight of the sediment in samples studied with most of the residue composed of authigenic feldspar.

Lithofacies 2. This lithofacies is mineralogically identical to the previous facies but differs from it texturally and structurally in being irregularly bedded and in containing abundant undulating stromatolitic structures ("pseudo-ripples") (Fig. 17), as well as disturbed and discontinuous laminae. In places there are a few thin interbeds of black argillaceous dolostone. The thickness of the laminites of this facies ranges from 1/2 mm to 2 or 3 mm; on freshly broken surfaces the color of the thinner laminae is black and that of the thicker ones is gray. The insoluble residue, for the most part composed of authigenic feldspar, constitutes between 35% and 67% by weight in samples studied.

These two lithofacies which form the basal unit of the Ordovician, were formed on a broad shallow shelf. Stromatolites, birdseye structures, scarcity of fossils, bituminous material, syngenetic dolomite, authigenic feldspar, and mottling suggest that these rocks were deposited in a tidal environment (Friedman, 1969). Based on analogy with the carbonate sediments in the modern Bahamas, Braun and Friedman (1969) concluded that these two lithofacies formed under supratidal conditions. However in the Persian Gulf flat algal mats prefer the uppermost intertidal environment, and along the Red Sea coast they flourish where entirely immersed in seawater, provided hypersaline conditions keep away burrowers and grazers (Friedman and others, 1973). Hence on this field trip we may conclude that the stromatolites indicate tidal conditions without distinguishing between intertidal and supratidal. For more details on these lithofacies refer to Braun and Friedman (1969).

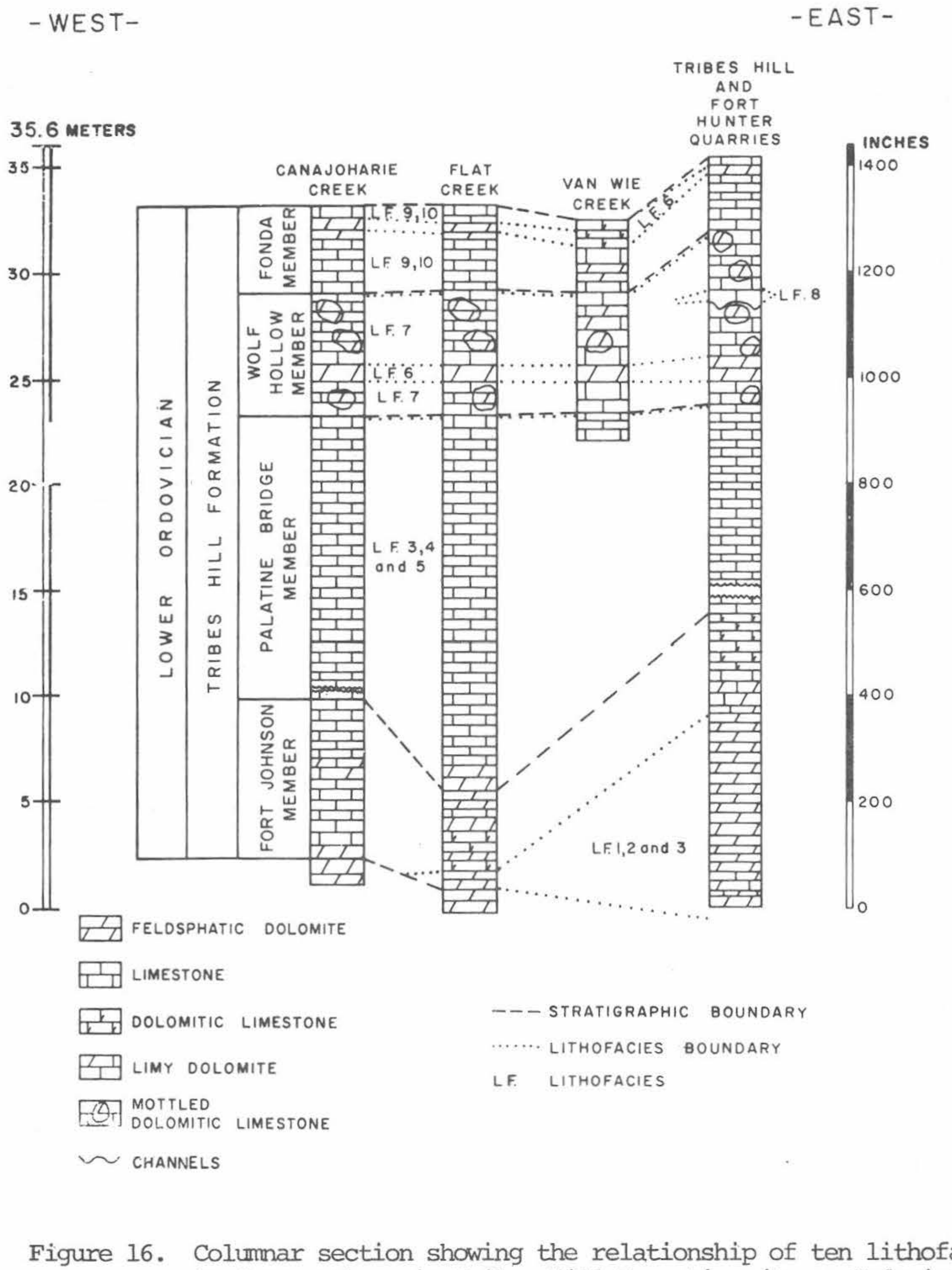



Figure 16. Columnar section showing the relationship of ten lithofacies to four members in Tribes Hill Formation (Lower Ordovician) (after Braun and Friedman, 1969).

| Miles | Distance between points | |
|---|---|---|
| | | Turn around and drive back to Main Street, Fort Hunter. |
| 155.0 | 0.9 | Turn right (north) into Main Street, Fort Hunter. |
| 155.1 | 0.1 | Cross original Erie Canal, built in 1822. Amos Eaton surveyed this route at the request of Stephen Van Rensselaer; after this survey Amos Eaton and Van Rensselaer decided to found a school for surveying, geological and agricultural training which became Rensselaer Polytechnic Institute. |
| | | Follow Main Street through Fort Hunter. |
| 155.7 | 0.6 | Cross Mohawk River |
| 156.2 | 0.5 | Turn right (east) on Mohawk Drive (town of Tribes Hill). |
| 156.6 | 0.4 | Turn left (north) on Stoner Trail. |
| 156.8 | 0.2 | Cross Route 5 and continue on Stoner Trail. |
| 159.5 | 2.7 | Turn right on NY67 (east). |
| 161.0 | 1.5 | Fulton-Montgomery Community College; continue on NY67. |
| 162.6 | 1.6 | STOP 10. NORTH TRIBES HILL QUARRY (on left) |

Route of Walk. Take the trail towards old abandoned crusher, but instead of heading towards the quarry move uphill to the first rock exposures. The rocks to be examined are near the edge of steep cliff.

Description and discussion. In the rocks at this exposure the field relationships show typical channels truncated at their bases (Fig. 18). Lodged within the channels are limestone blocks of variable shape ranging in diameter from about one to three feet (Fig. 19). These blocks resemble similar blocks in tidal channels of the Bahamas which are derived by undercutting of the banks of the tidal channels. The blocks at this exposure are rounded, suggesting that they have undergone some transport.

The rocks composing the channel (i.e. the channel fill) and the blocks of rock within the channels have been described as lithofacies 8 (channel fill) and lithofacies 7 (blocks) of the Wolf Hollow Member of the Tribes Hill Formation (lowermost Ordovician) (see columnar section of Fig. 16); column at the right end of the section) (Braun and Friedman, 1969). The channel fill (lithofacies 8) consists of intrasparite and biointrasparite with sporadic ooids, a high-energy facies, whereas the blocks (lithofacies 7) consist of mottled dolomitic micrite and biomicrite, a low-energy facies of the undercut bank. The micrite blocks which foundered

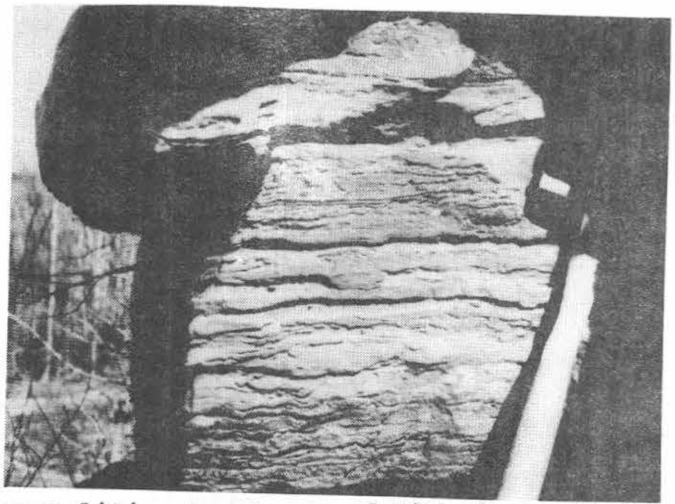


Figure 17. Stromatolitic structures of lithofacies 2 (laminated feldspathic dolomite), Tribes Hill Formation (Lower Ordovician). Fort Hunter quarry.

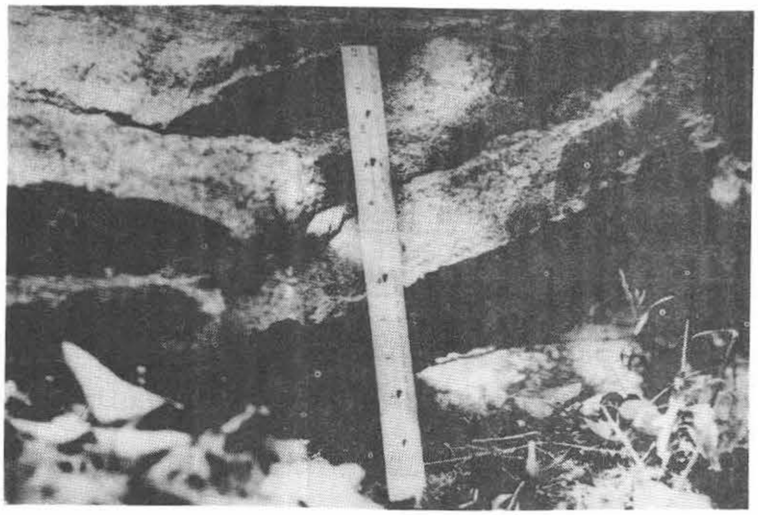


Figure 18. Truncation at base of tidal channel. Rocks in channel consist of lithofacies 8 (intrasparite and biointrasparite), Tribes Hill Formation (Lower Ordovician). North Tribes Hill quarry.

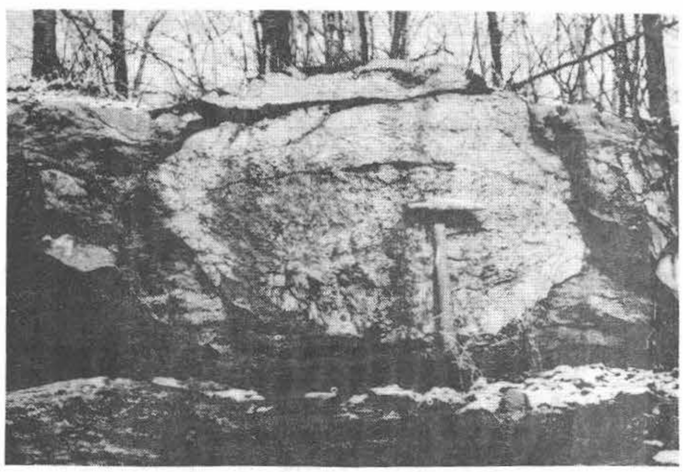


Figure 19. Block of lithofacies 7 (mottled dolomitic micrite and biomicrite), foundered in tidal channel (lithofacies 8), Tribes Hill Formation (Lower Ordovician). North Tribes Hill quarry.

in the channels must have been indurated penecontemporaneously.

Hence during earliest Ordovician time high-energy tidal channels crisscrossed tidal flats at this site. In them water coming from the deep ocean to the east rose and fell with the changing tides.

Return to R.P.I. Campus via New York Throughway and Interstate 787.

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