SEDIMENTOLOGY OF THE DENLEY LIMESTONE (MIDDLE ORDOVICIAN, TRENTON GROUP) IN CENTRAL NEW YORK

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Introduction

The Denley Limestone of the Trenton Group (Middle Ordovician) in central New York is characterized by nearly 90 meters of alternating beds of limestone and shale. The origin of limestone and shale couplets in general is problematic, however, in the case of the Denley Limestone, the limestones can be shown to be bioclastic turbidites in origin. These bioclastic turbidites are recognized by Bouma divisions within the limestone beds. Interbedded shale horizons represent the *in situ* sediment. This sedimentologic interpretation has implications for the paleoenvironmental setting of the Denley Limestone.

This field trip will ask you to address the following questions: (1) How can resedimented carbonates be distinguished from *in situ* sediment? (2) How can tempestites be distinguished from turbidites? (3) Why should one bother with the tempestite/turbidite distinction?

Regional Geology

Outcrops of the Middle Ordovician Trenton Group extend through the St. Lawrence Valley of southern Quebec, the Camplain Valley of New York and Vermont, and eastward through the Mohawk and Black River Valleys of central New York before extending once again into Canada above Lake Ontario (Figure 1). In addition to being so widespread, these rocks have long attracted attention for their abundant and diverse marine faunas. Early models by Kay (1953) for the depositional setting of the Middle Ordovician Trenton Group described an eastward (present coordinate) dipping carbonate ramp which passed into an adjacent shale basin. More recent publications by Cisne and Rabe (1978) and Cisne, et al. (1982a) describe a revised interpretation for the depo-tectonic setting of the Middle Ordovician sequence. These authors suggested that these sediments accumulated in a outer shelf to trench slope
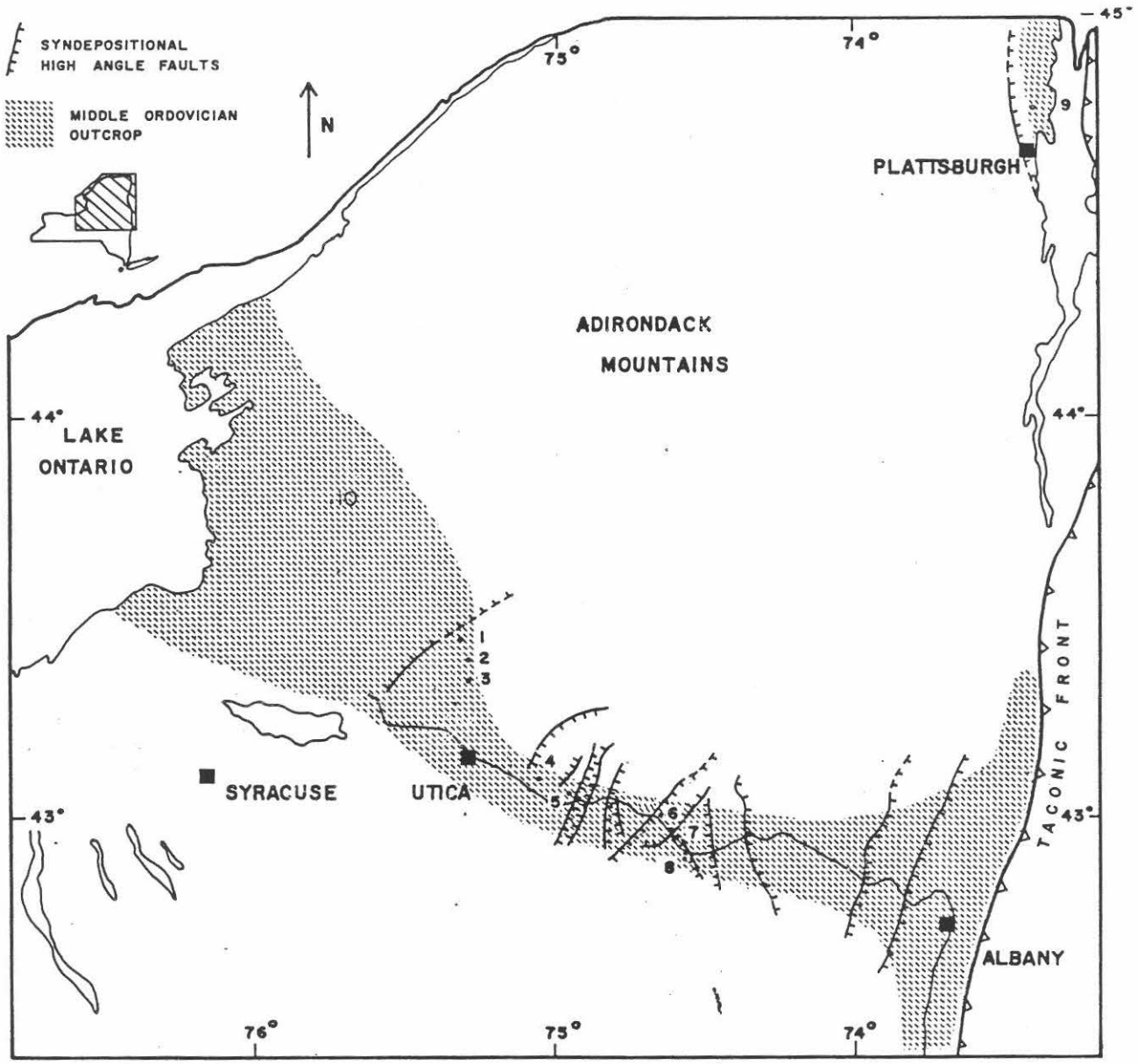
Figure 1. Outcrop map of the Trenton Group in New York State. Key locations include: 1-Trenton Falls Gorge; 2-Buttermilk Creek; 3-City Brook; 4-Herkimer; 5-Little Falls; 6-Caroga Creek; 7-Palatine Bridge; 8-Canajoharie Creek; 9-Beekmantown; 10-Roaring Brook.
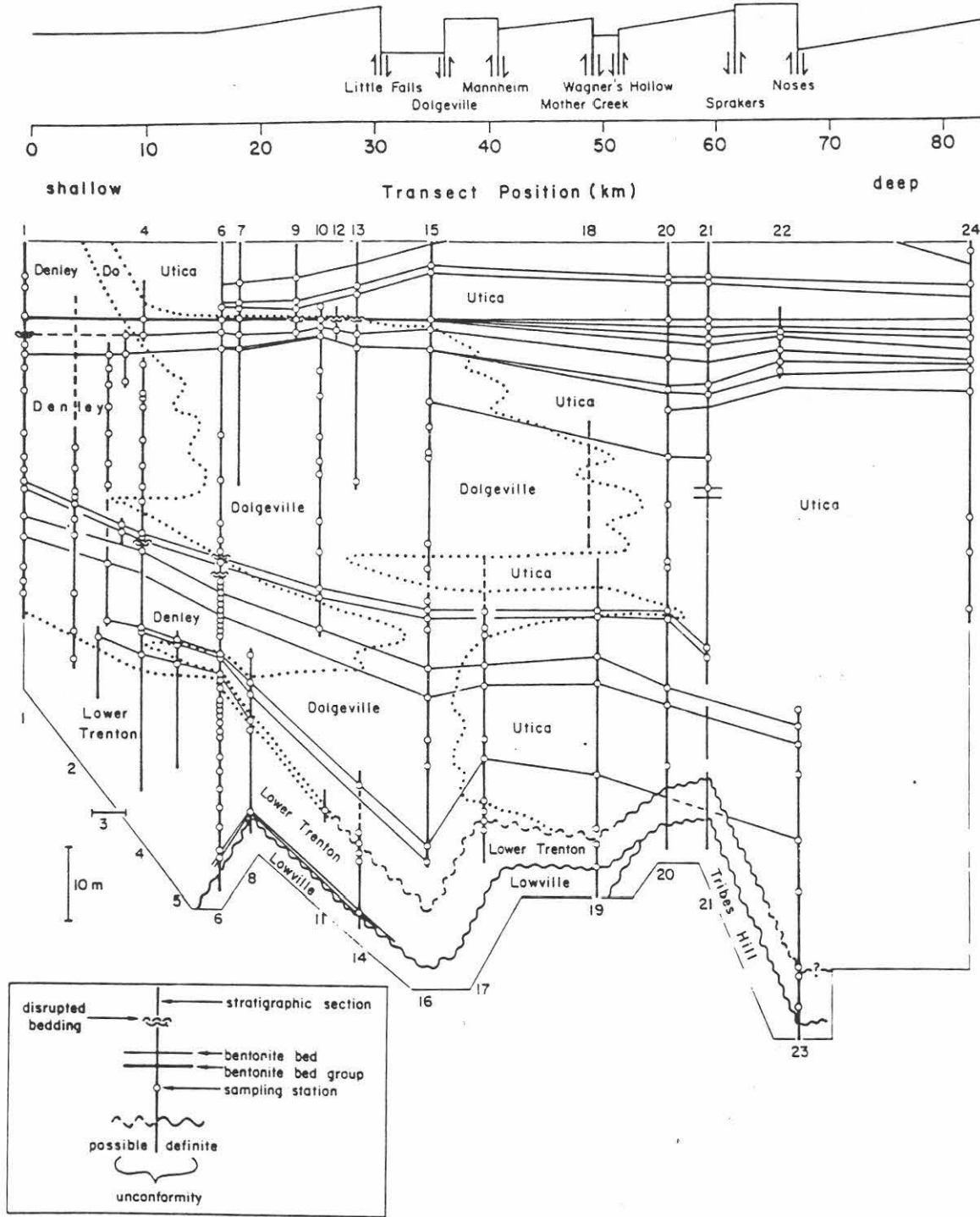
Figure 2. Stratigraphic sections of the Trenton Group and over-and underlying units are represented by vertical lines and have been correlated by bentonites (sub-horizontal lines). Sampling horizons for faunal studies are indicated by circles on vertical lines. The structural cross section at the top of the diagram indicates that the Trenton strata thicken across basins and thin across basement highs, suggesting that faulting was syn-depositional. Sections: 1-Trenton Falls Gorge; 2-Gravesville-Mill Creek; 3-Poland; 4-Rathbun Brook; 5-Shedd Brook; 6-Buttermilk Creek; 7-Farber Lane; 8-Norway; 9-Miller Rd.; 10-North Creek; 11-Gun Club Rd.; 12 & 13-New York State Thruway; 14-Burrell and Bronner Rds.; 15-W. Crum Creek; 16-Dolgeville Dam; 17-E. Canada Creek; 18-Mother Creek; 19-Caroga Creek; 20-Canada Creek; 21-Flat Creek; 22-Currytown Quarry; 23-Van Wie Creek; 24-Chuctanunda Creek. From Cisne and Rabe, 1978.

setting, adjacent to the Taconic Arc. An analogy would be the present day Australian flank of the Timor Trough, where the northwestern Australian carbonate shelf is dissected by numeorus high angle block faults which control the thickness and distribution of carbonate lithofacies. Sediments accumulating in these isolated basins are primarily bioclastic turbidites in origin (Veevers, et al., 1978), derived from the adjacent shallow water carbonate shelf. Cisne and Rabe (1978) and Cisne, et al. (1982a) suggested that the Middle and Upper Ordovician strata of central New York were deposited on a fragmented shelf in the foredeep where each fault block accumulated a unique stratigraphy. By using bentonite horizons to correlate fault blocks, Cisne and his coworkers constructed paleotopographic maps which illustrated the existence of local topographic highs and lows superimposed on an overall easterly dipping slope into the trench (Figure 2). A possible mechanism for producing extensional block faults within a compressional tectonic regime was presented by Chapple (1973), who suggested that the formation and passage of a peripheral bulge through the foreland basin would generate extensional faults. Mehrtens (1988) described the existence of syn-depositional block faults in the Taconic foreland basin of southern Quebec and also documented their effect in controlling the stratigraphy and sedimentology of these Middle and Upper Ordovician strata.

Stratigraphy

Kay (1937 and 1953) was the first to present a stratigraphic framework for these units which was later modified by Titus and Cameron (1976) and Titus (1988).

The sedimentology of the basal units of the lower Trenton Group were described in detail by Titus and Cameron (1976) and are interpreted to represent a continuum of progressively deepening environments from lagoonal (Napanee and Selby Formations) to shoal (lower Kings Falls Formation) to shelf facies (middle and upper Kings Falls Formation) and ultimately into deeper water shelf (Sugar River Formation).

The Denley Limestone, the focus of this study, overlies the Sugar River Limestone (Figure 3). At its type locality at Trenton Falls (Figure 1, locality 1) the Denley has been divided into three members, in ascending order the Poland, Russia and Rust Members.
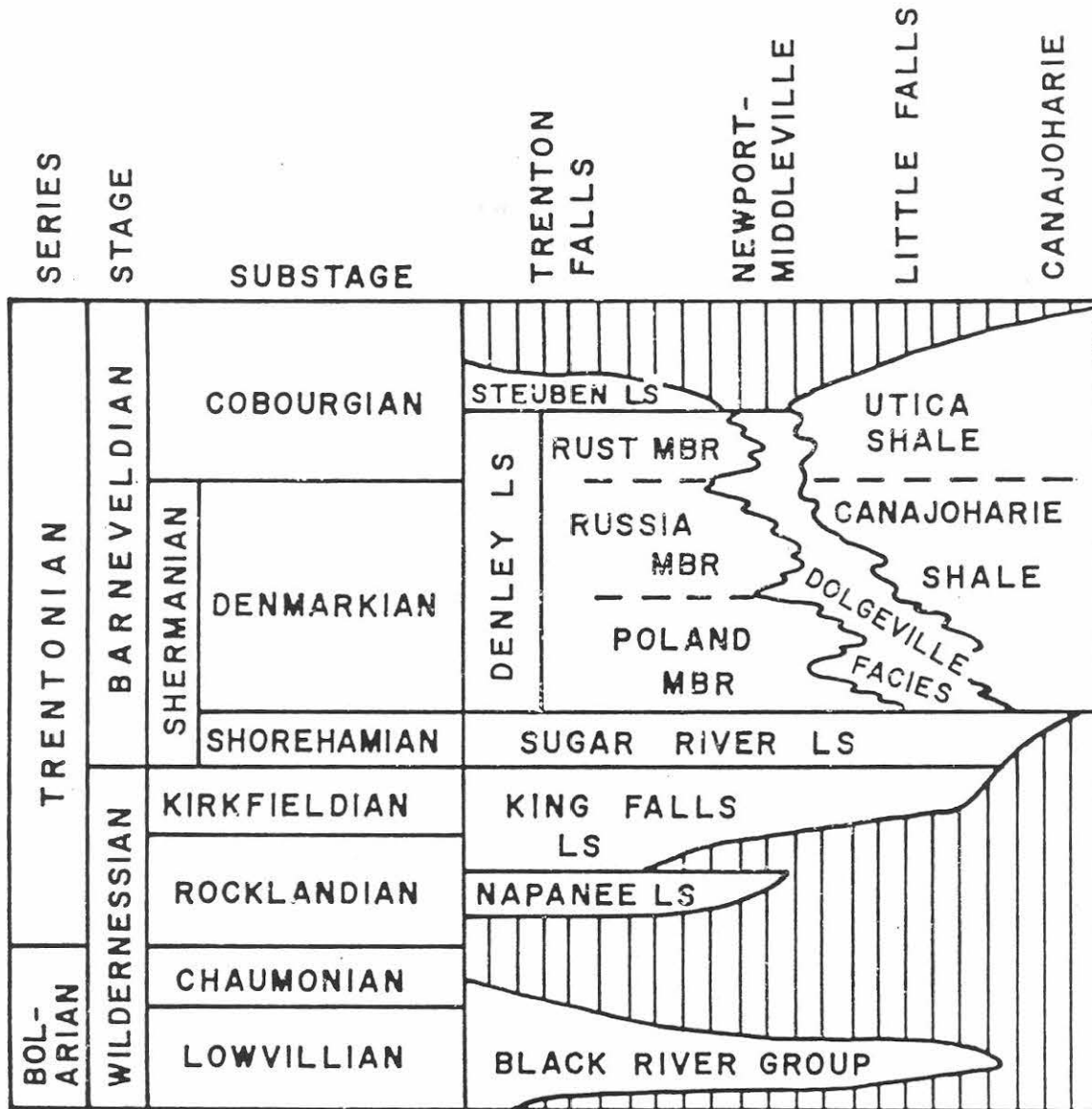
Figure 3. Correlation chart for the Black River and Trenton Groups in central New York, modified from Titus and Cameron (1976).

The contact of the Sugar River and Denley Formations is visible at several localities and appears gradational (Figure 4).

The Denley Limestone is overlain by a variety of units, depending upon position within the basin. At its type section at Trenton Falls the Denley is overlain by the Steuben and Hillier Limestones. Titus (1988) describes the Steuben as a coarse-grained calcarenite bearing wave-generated structures such as cross bedding which he interpretes as a shoal facies. The Hillier Limestone is a finer-grained calcsiltite lacking evidence of wave reworking and is interpreted by Titus as a shelf to outer shelf deposit. These limestones are in turn conformably overlain by the Utica and Canajoharie Shales (Riva, 1972, his figure 16). Eastward of the Trenton Falls type section the Denley is overlain by the Dolgeville Facies, a laminated mudstone with thick shale interbeds, which Kay (1953) described as the transition beds from the Denley to the Canajoharie Shale.

The deepening-shallowing-deepening sequence recorded by the Trenton Group in central New York has been interpreted in various ways. Titus (1988) attributes this oscillation to facies mosaicing accompanying base level changes generated by epeirogeny of the Adirondack Arch. An alternative model proposed by Cisne and Rabe (1978) suggests that bathymetric changes, irregular bottom topography, and condensed stratigraphic sequences result from the activity of syndepositional block faults within the Taconic foreland basin which subsequently exerted control of sedimentation patterns.

Sedimentology of the Denley Limestone

The Denley Limestone occupies a stratigraphic position in the Trenton Group at the culmination of the deepening trend which initiated with the Napaee and Selby Formations. The Denley contact with the underlying Sugar River Limestone is gradational and is defined as the first appearance of an unfossiliferous, "lumpy-bedded" mudstone lithology. This lithology is interbedded with fossiliferous wackestone and packstone limestone beds and shale interbeds bearing diverse and abundant assemblages of benthic marine organisms. Figure 4 illustrates the stratigraphy at two outcrops where the Sugar River/Denley contact is well exposed. Although the contact is gradational, the Denley and Sugar River can

ROARING
BROOK

BUTTERMILK CREEK
CITY BROOK

S 35°E

S 70°E

DENLEY L.S.

DENLEY L.S.

SUGAR RIVER L.S.

SUGAR RIVER L.S.

N 55°W

N 65°E

KINGS FALLS L.S.

KINGS FALLS L.S.

2 m

■ PALEOCURRENT
  MEASUREMENT
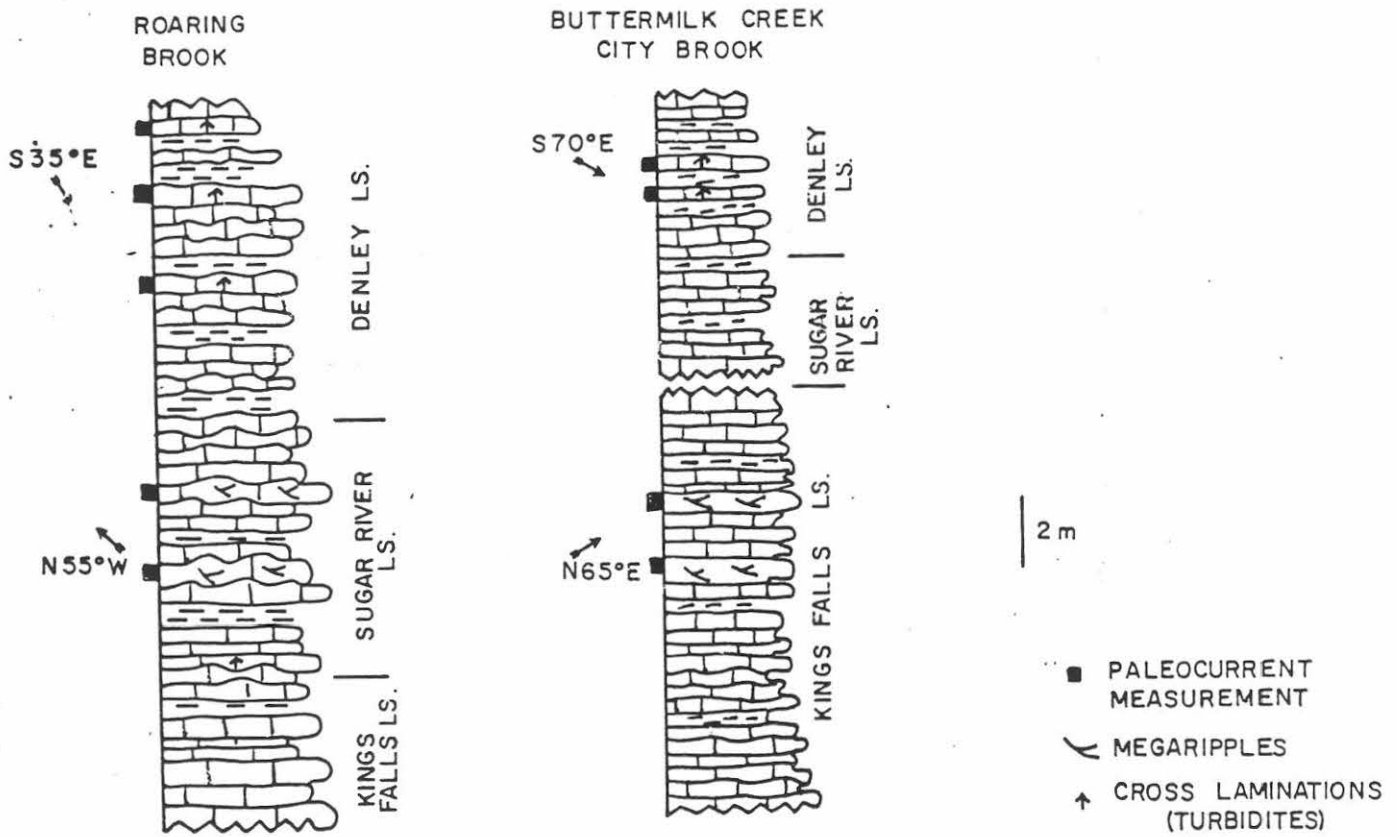
MEGARIPPLES

CROSS LAMINATIONS
(TURBIDITES)

Figure 4. The contact between the Sugar River and Denley Limestones is gradational, for example, as seen at Roaring Brook (Figure 1, locality 10) and Buttermilk Creek/City Brook (Figure 1, locality 3).

be differentiated on the following criteria: (1) the Denley is a wackestone to packstone in composition while the Sugar River is a packstone to grainstone; (2) the Denley has thicker shale interbeds, locally exceeding 1cm in thickness; shale is often absent between limestone beds in the Sugar River; (3) the Denley contains limestone horizons which contain a predictable sequence of sedimentary structures which are interpreted as Bouma divisions; (4) the Denley contains horizons of slump folds and breccias (Figure 5): (5) the Sugar River and underlying Kings Falls Limestones display features which suggest deposition at or near wave base, including beds that pinch and swell, cross bedded grainstones, and tempestite horizons; (6) Paleocurrent measurements from ripple crestline trends are approximately 90 degrees different between the Kings Falls and Sugar River and Denley Limestones, reflecting currents oriented relative to a shoreline or shoal (Kings Falls) versus those oriented downslope (Denley).

The sedimentology of the Denley Limestone was initially undertaken as part of a study on the evolution of the trepestone bryozoan *Prasopora,* whose colonies cover bedding planes throughout the unit (Mehrtens and Barnett, 1979). Initially, the 90-m thick Trenton Group type section at Trenton Falls gorge (Figure 1, locality 1) was sampled and large thin sections were made of entire beds. Petrographic analysis revealed that limestone beds often contained sequences of sedimentary structures, in ascending order: layers of skeletal fragments, mm-scale thickness of planar laminae composed of finely crushed skeletal debris; mm-scale laminae of micrite; bioturbated micrite; and shale (Figure 6). These sequences were identified as Bouma divisions within bioclastic turbidites, suggesting that, at least in part, the Denley Limestone represented turbidite deposition. Following recognition of a bioclastic origin for many of the limestones, sampling to determine the stratigraphic and paleogeographic distribution of the turbidites was undertaken at other Trenton Group exposures. Outcrops sampled included Upper West Canada Creek, Rathbun Brook, Shed Brook, Roaring Brook, City Brook, Caroga Creek, and outcrops around the Champlain Valley of New York and Vermont. In the course of this study it became clear that a comprehensive study of bioclastic turbidites was lacking and that great potential exists for misidentification of bioclastic turbidites with tempestites (see Kreisa, 1981).
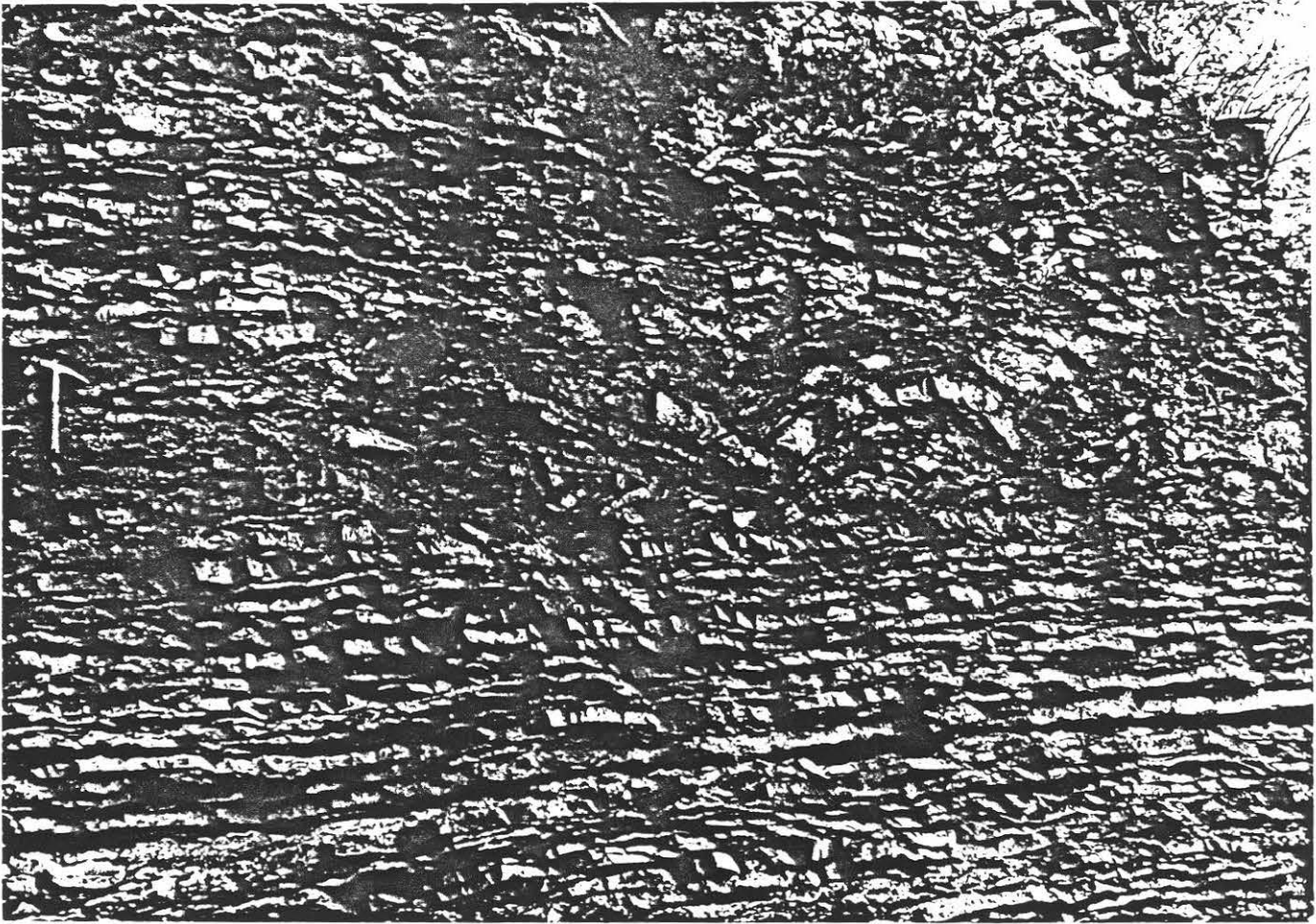
Figure 5. Slump fold and breccia horizon (at hammer level) in the Denley Limestone along West Canada Creek. The presence of brecciated beds indicates that the sediment was at least partially lithified prior to movement, which suggests early, possible submarine, lithification occured.
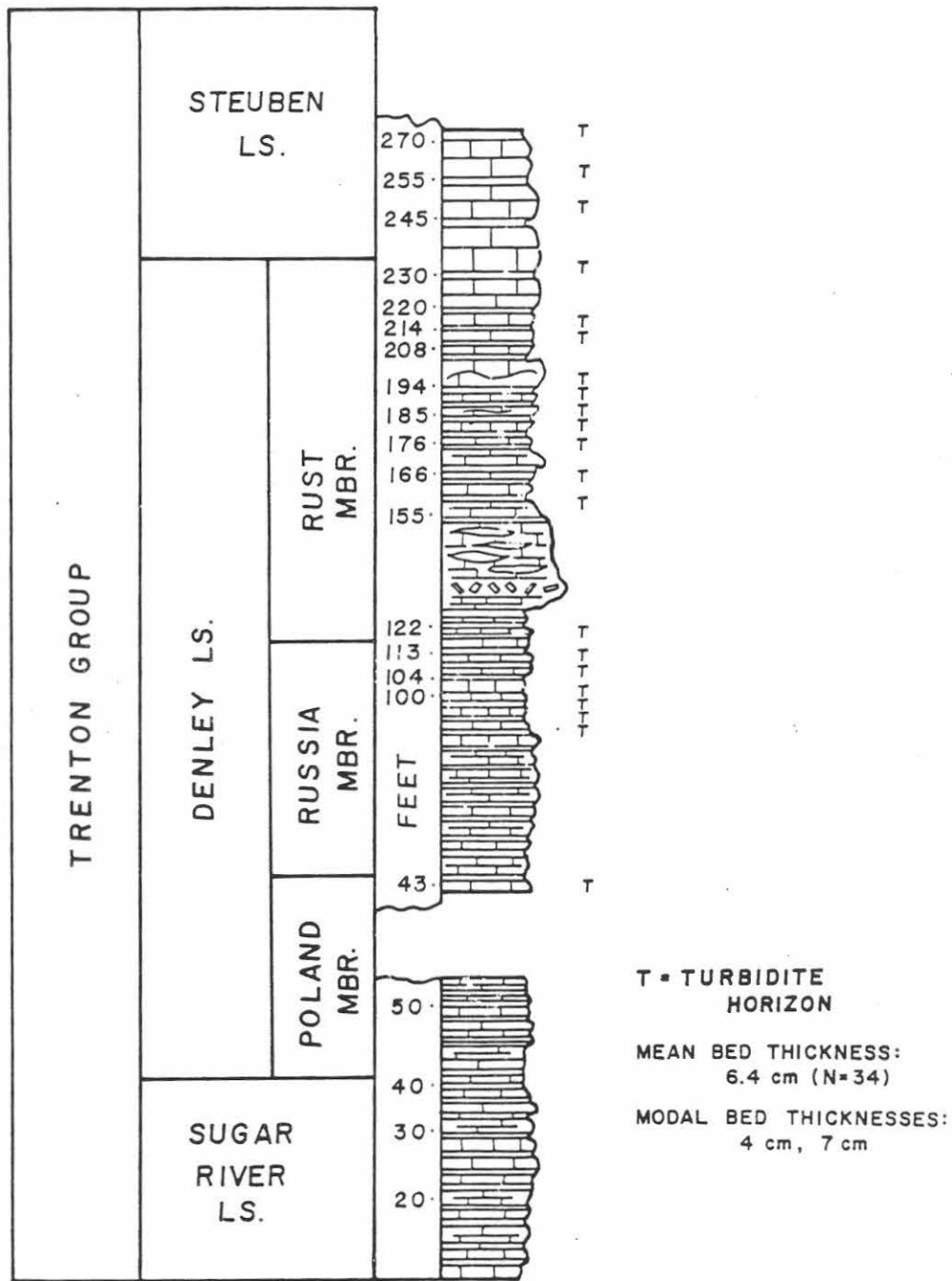
Figure 6. Measured stratigraphic section of the Sugar River-Denley and Steuben Limestones at Shed Brook and West Canada Creek (Trenton Falls Gorge). Horizons which upon thin sectioning were identified as turbidites are indicated by a "T".

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Approximately 70% of the Denley Limestone horizons sampled at Trenton Falls Gorge (n=34) are interpreted as resedimented detritus, most likely turbidites, however there are several other lithologies present within this unit (Figure 7). This variety of lithologies are sufficiently different to suggest multiple origins. Three non-turbiditic lithologies present include: (1) wackestone-packstone beds lacking any sedimentary structures; (2) fossiliferous shale interbeds between the limestone horizons; (3) unfossiliferous mudstone beds. Given the abundance of bioclastic turbidite horizons, these three lithologies can be interpreted in light of the turbidite model.

The wackestone-packstone limestone beds contain disarticulated whole and broken skeletal fragments in a matrix containing variable amounts of micrite. No sedimentary structures, such as grading, laminations, or micrite infiltration are seen. Fossil fragments are unsorted in size. This lithology is interpreted to represent an *in situ* accumulation, and, lacking any evidence of resuspension and settling, is thought to have been deposited below wave base. Care must be taken to not confuse these *in situ* accumulations with top or bottom cut-out turbidites. These are turbidites which, due to an absence of either the necessary grain size or hydraulic conditions, do not exhibit complete Bouma divisions. Thin section examination should reveal any internal structures. Also, if there are long periods of time between bioclastic turbidite emplacement, bioturbation can obliterate Bouma structures. A second *in situ* sediment accumulating within the Denley Limestone is the shale present between limestone beds. These beds can be quite thin, forming a veneer on top of the limestones, however they often support diverse benthic communities (Cisne and Chandlee, 1982; Cisne, et al., 1982b; Hay and Cisne, 1988). The presence of articulated fossils, including trilobites and articulated crinoid stems, attests to the probable quietude of the waters during the deposition of this material.

The final limestone lithology is the unfossiliferous mudstone whose most diagnostic features are the extensive horizontal burrow traces which cover bedding planes and extend several centimeters into beds and the "lumpy bedding" which can produce up to 10cm of relief on a bedding plane surface. The origin of the "lumpy bedding" is attributed to the burrowing activity of the trilobite *Isotelus,* followed by submarine cementation which preserved the high angles of respose of the sediment. The carbonate mud
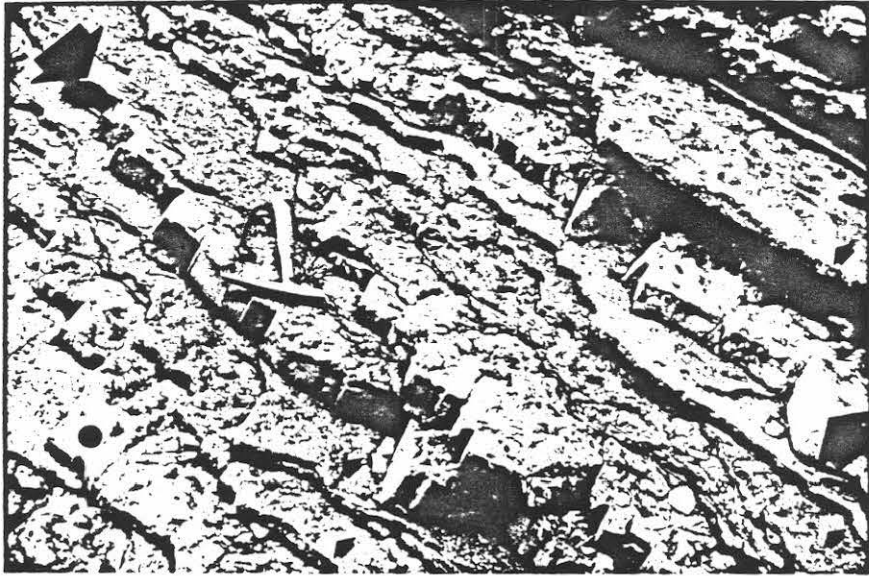
Figure 7. Photograph of the four important lithologies in the Denley Limestone along West Canada Creek. Tubidite beds (largest arrows) are clearly recognizable by their planar bases and bioturbated tops. A bed of the "lumpy mudstone" is labeled with a black dot. Thin beds of packstone-grainstone are indicated with small arrows. The fourth lithology, shale, is present between all limestone beds.

composing this lithology is thought to represent accumulations of peri-platform ooze derived from the adjacent shelf which was resuspended and transported into deeper water in a series of low density tubidity current flows.

The interbedding of these four lithologies suggests that the Denley Limestone was deposited in an outer ramp setting. The bioclastic turbidites and peri-platform ooze were resedimented downslope into an environment where the dominant *in situ* sediments were shale with lesser amounts of in situ fossiliferous limestones. Although turbidites can form in shallow water, an outer ramp, deep water environment for the Denley Limestone is supported by the presence of slump fold and breccia horizons, both of which require a slope on which to form. Orthocone cephalopods oriented parallel to slump fold axes indicate the presence of currents which flowed downslope.

Description of Bioclastic Turbidites

Although bioclastic turbidites have been described by many authors (see Mehrtens, 1988 for references). In all of these numerous examples there was ample supporting information for placing the limestones in a slope or basin environments. Until the recent work of Cisne and his coworkers there was no such model for the Denley Limestone. Furthermore, the Denley Limestone is in gradational contact with a unit (Sugar River Limestone) which has attributes of shallow water deposition. Finally, a great deal of attention has been given to the recognition of limestone tempestites which outwardly appear similar in structure to bioclastic turbidites.

The general characteristics of bioclastic turbidites include: (1) division of beds into a lower graded and upper mudstone portion (Figure 8); (2) mudstone which contains pelagic faunal elements versus shallow water faunas in the lower, graded horizons; (3) graded carbonate skeletal sand units capped by laminated or cross laminated units (Figure 9); (4) planar bases and bioturbated tops; (5) partial to complete Bouma divisions. Table 1 provides a more complete list of the characteristics of bioclastic turbidites compared to those of limestone tempestites. Bioclastic turbidites are structurally similar to siliciclastic turbidites described by Bouma (1962) and hydraulically interpreted by Walker (1965), however there are several noteworthy differences, described below. The coarsest-grained sediment deposited from the initial stages of
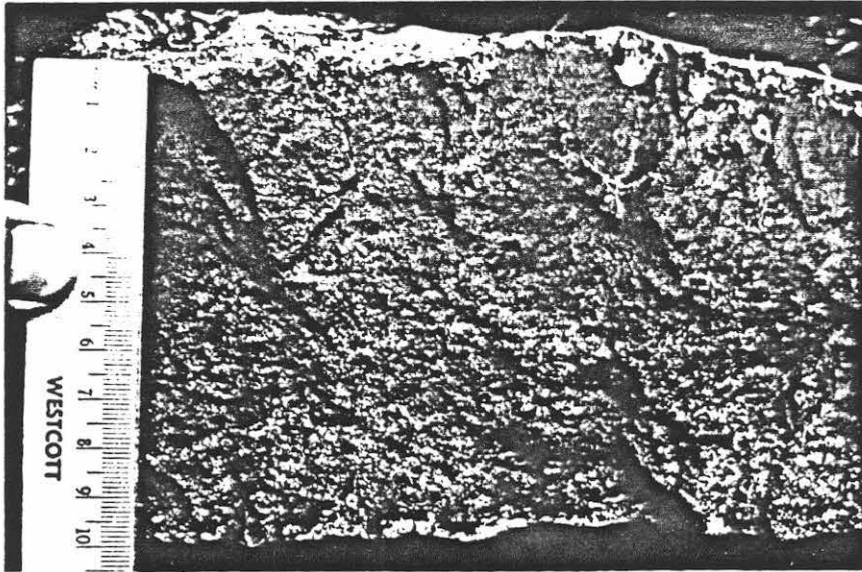
Figure 8. Outcrop photograph of a graded limestone bed. Note the sharp base to the limestone bed, with a concentration of the coarsest skeletal grains, and fining-upwards in skeletal size.
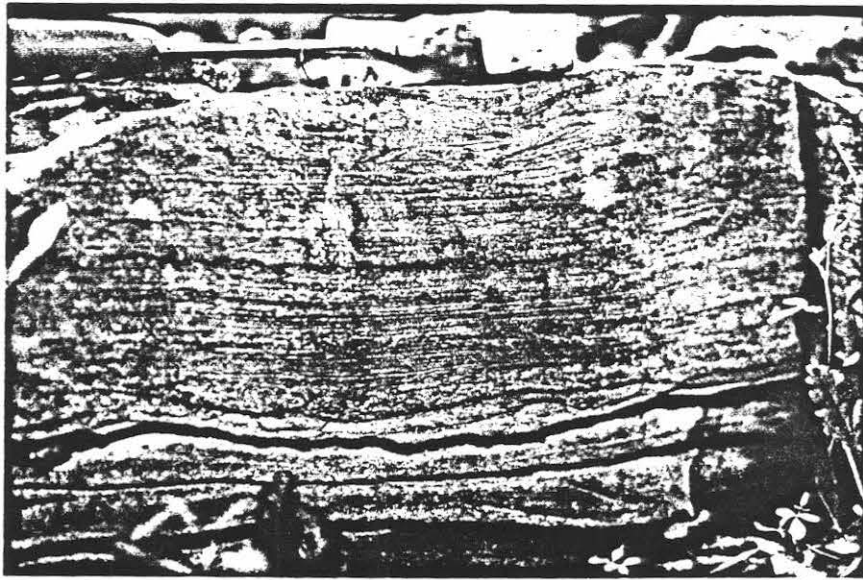

Figure 9. The hammer head rests on a limestone bed which exhibits well defined planar (large arrow) and cross (small arrow) laminations.

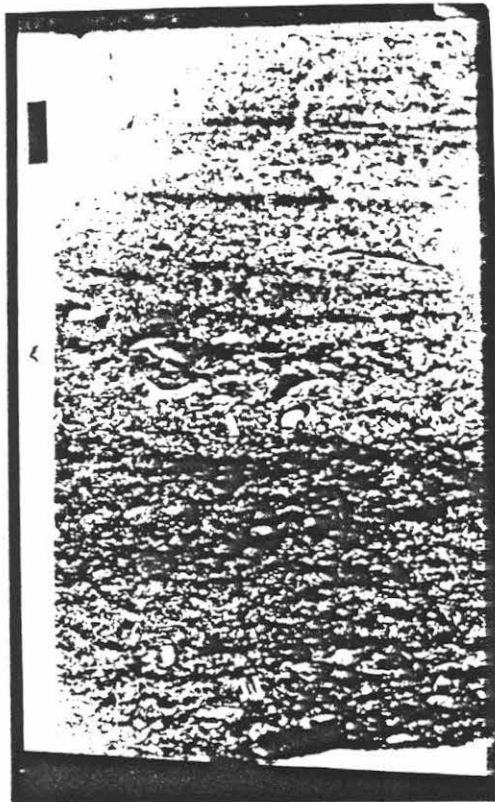Figure 10. Thin section photomicrograph of a turbidite which exhibits grading in skeletal fragments (Ta). Sample is from the uppermost Rust Member of the Denley Limestone. Bar equals 1 cm.
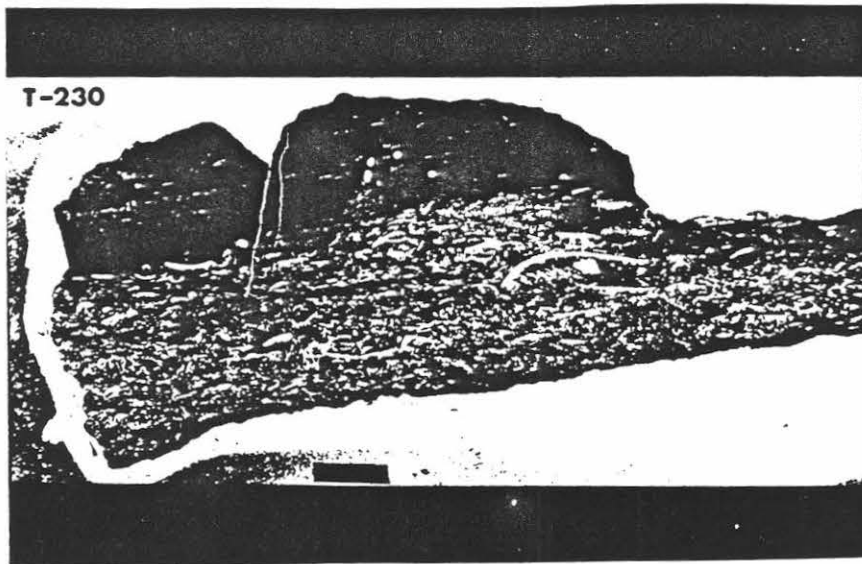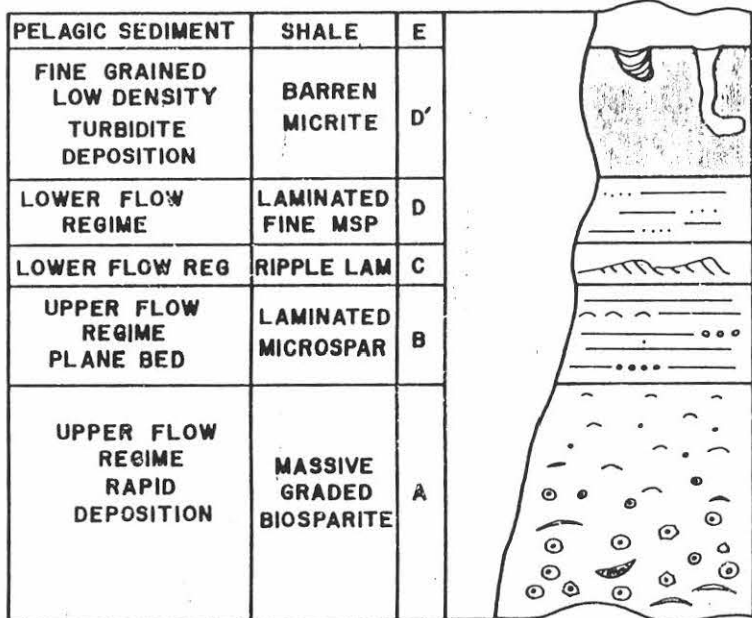

Figure 11. Thin section photomicrograph of a turbidite from the Rust Member of the Denley Limestone which exhibits a coarse-grained skeletal lag (Ta) overlain by structureless micrite (Td'). Bar equals 1 cm.

deceleration of the current form a graded unit (Ta) composed of skeletal material (Figure 10). The high velocity planar laminated unit (Tb) is composed of mm-thin laminae of diminuted skeletal material. The third Bouma division, ripple cross laminae (Tc) is present, but uncommon in bioclastic turbidites. These structures are thought to form from either unidirectional waves behind the nose of the turbidity current of by reworking of planar laminations (Tb) into ripples (Walker, 1965), however the formation of ripple laminations requries cohesionless sand and silt-sized material. It is possible that bioclastic material is too cohesive, and the absence of a silt-size equivalent in carbonate sediment is well known. The origin of the fine-grained laminae (Td) in terrigenous mud turbidites is still enigmatic. (Piper, 1972 a & b; Piper, 1978; Rupke, 1975) but in bioclastic turbidites the laminations can be seen to consist of alternations of very finely crushed skeletal grains and their interparticle cement alternating with micrite. Overlying the finely-laminated Td unit should be Te, a structureless pelagic mud. Piper (1978) has summarized the controversy surrounding the origin of this mud which led him to subdivide the mud fraction into E1 (laminated mud), E2 (graded mud), E3, (ungraded mud), and F (hemipleagic mud= shale cap). The barren and frequently bioturbated carbonate mud present at the top of bioclastic turbidites (Figure 11) is designated Td' (Td prime), a name chosen to most accurately reflect the genetic association with the finely-laminated turbidite material below than with the inter-turbidite material above. Overlying the micrite of Td' is the terrigenous shale (Te) which is often colonized by benthic organisms. Burrowing activity of these organisms often extends well into the turbidite beneath, destroying primary sedimentary structures. Several authors (Piper, 1978; Hesse, 1975; Scholle, 1971) have described this type of bioturbation as diagnostic of post-turbidite recolonization of substrates.

Terminology for describing the internal structures of bioclastic turbidites follows that proposed by Einsele (1982) where "T" designates a turbidite origin (as opposed to "S" for storm, or tempestites), and lower case letters a through e designate the specific bedform. Therefore, Ta = turbidite layer of coarse-grained graded material; Tc = cross laminated turbidite layer, and Tac = vertical sequence of graded to cross laminated layers (Figure 12).

Although the internal structures present within bioclastic turbidites are clearly identical to Bouma divisions there still exists

CARBONATE TURBIDITE

PELAGIC SEDIMENT	SHALE	E
FINE GRAINED LOW DENSITY TURBIDITE DEPOSITION	BARREN MICRITE	D′
LOWER FLOW REGIME	LAMINATED FINE MSP	D
LOWER FLOW REG	RIPPLE LAM	C
UPPER FLOW REGIME PLANE BED	LAMINATED MICROSPAR	B
UPPER FLOW REGIME RAPID DEPOSITION	MASSIVE GRADED BIOSPARITE	A

CLASTIC TURBIDITE

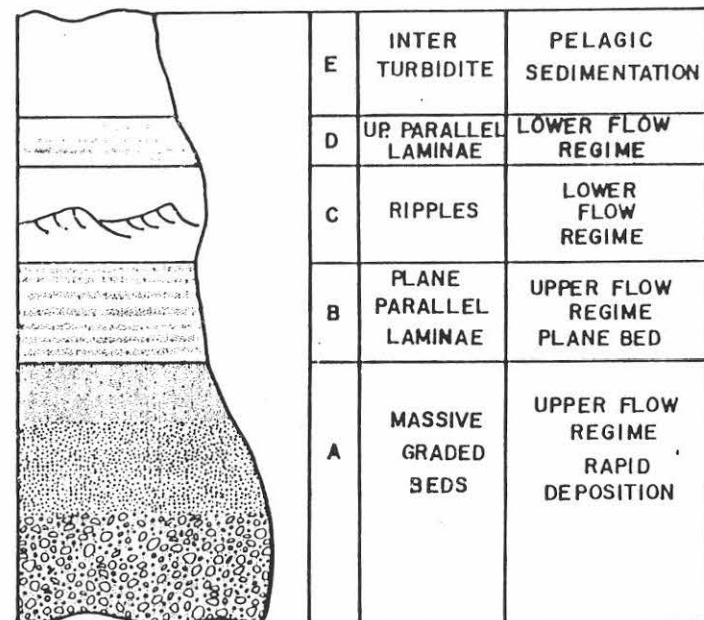| E | INTER TURBIDITE | PELAGIC SEDIMENTATION |
D	UP. PARALLEL LAMINAE	LOWER FLOW REGIME
C	RIPPLES	LOWER FLOW REGIME
B	PLANE PARALLEL LAMINAE	UPPER FLOW REGIME PLANE BED
A	MASSIVE GRADED BEDS	UPPER FLOW REGIME RAPID DEPOSITION

Figure 12. Comparison of the terminology and hydraulic interpretation of bioclastic (left) and clastic (right) turbidies. The primary difference lies in the addition of a structureless micrite (Td′) in the limestone.

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the possibility of mis-identification of turbidites with tempestites. Table 1 shows how subtle some of these differences can be. One analytical technique which has proven to be extremely useful in identifying turbidites has been employment of a simple statistical analysis of the relationship between grain size and bed thickness. Crevello and Schlager (1980) and Kelling and Mullin (1975) employed similar strategies, which are based on the hypothesis that a relationship should exist between the grain size of the sand (in this case skeletal sand) material comprising the turbidite and the size of the turbidity current. Since the storm resuspension of sediment and subsequent settling is the process identified for producing graded tempestites, there is no reason why these types of deposits would exhibit this relationship. A linear regression analysis of skeletal grain size versus the thickness of the Ta layer shows a high degree of correlation (Figure 13).

A second valuable indicator of turbidite origin of a graded or cross laminated limestone bed is the absence of infiltration structures in the uppermost micrite layer (Td'). Kreisa (1981) describes the internal structures produced by storm resuspension and settling, including the late stages of fallout of the finest-grained carbonate mud fraction. The mud settles out and infiltrates around the underlying skeletal grains, which, in addition to producing many shelter fabrics, produces micrite drapes around grains. This type of fabric is not present within turbidites as the sedimentation of micrite is part of the continuum of deposition of coarser through finer grain sizes.

Finally, the presence of escape burrows are highly diagnostic of tempestites. Organisms picked up and deposited during resuspension and settling quickly burrow to the surface, producing traces which rise from the base to top of the bed. Turbidites, on the other hand, scour across the surface as they travel downslope, incorporating skeletal material into the traction carpet. Upon coming to rest the newly-formed bedding plane surfaces are recolonized and burrows descend from this upper surface into the layers below . No escape burrows have been described from modern bioclastic turbidites, so apparently organisms which become incorporated into turbidite flows do not survive transport.

Is the distinction between bioclastic turbidites and tempestites worth making? Certainly there are bathymetric associations for the two types of resedimented limestones. Although bioclastic

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r = .92   m = 3.88
           y = -1.22

GRADED BED THICKNESS (cm)

AVERAGE CRINOID SIZE (mm)

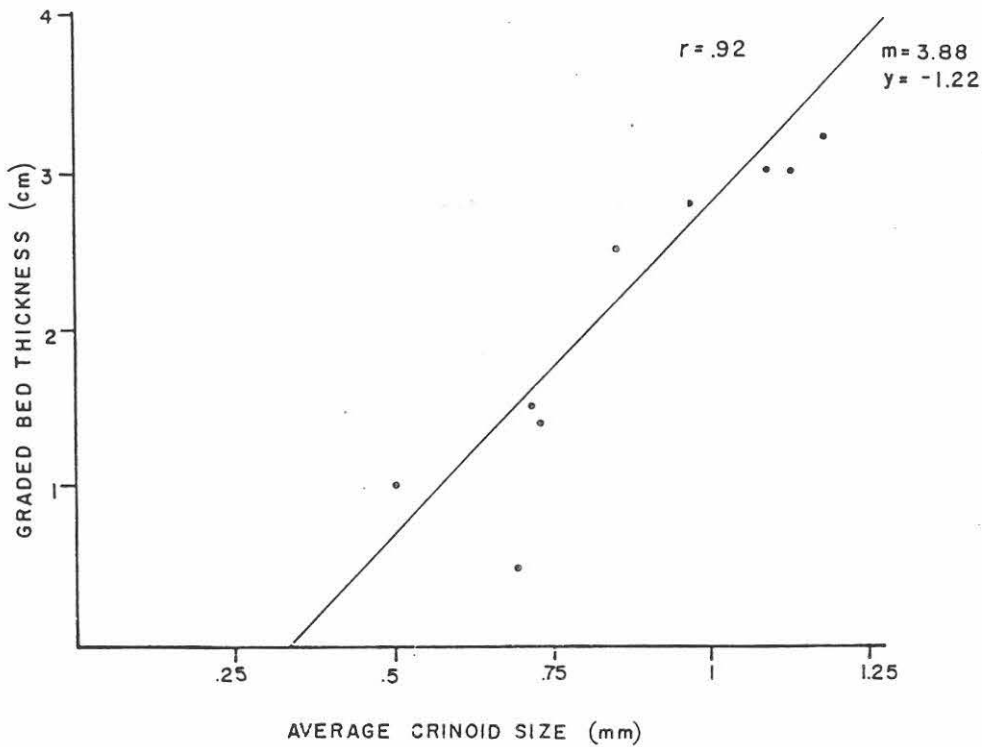Figure 13.   In order to demonstrate the turbidite origin of the graded limestones the diameter of crinoid ossicles were measured and plotted versus the thickness of the graded beds in which they are found.   The best fit line and correlation coefficient (=0.92) produced by a linear regression analysis indicates that their is a relationship between these two variables, a documented property of turbidites.

turbidites need not form in deep water, their preservation is greatly enhanced at depths below wave base and in the absence of concentrated numbers of burrowing organisms. Tempestites, on the other hand, are often associated with depths near wave base (Kriesa, 1981) and therefore record a specific range of bathymetries between fairweather and storm conditions. Thus, paleoenvironmental reconstructions would depend on the accurate identification of turbidites versus tempestites. As Hamblin and Walker (1979) demonstrated so successfully in a siliciclastic sequence, it is possible to identify the transition from the storm-dominated to turbidite-dominated portions of a shelf. If the turbidites accumulated in a slope apron setting, the "traditional" facies associations of deep sea submarine fan turbidites would be lacking, thus making the distinction between turbidites and tempestites even more difficult.

Depositional Model for the Denley Limestone

Any model for the depositional setting of the Denley Limestone must take into account several different lines of evidence: (1) The stratigraphic position of the unit between the underlying shallow water Kings Falls and Sugar River Limestones and overlying black shales of the Utica and Canajoharie Shales. This evidence suggests that the unit is transitional in its bathymetry from shallow ramp to deep water basin. (2) The depo-tectonic setting of the Denley Limestone proposed by Cisne and his coworkers places the unit in a fragmenting foreland basin flanked to the east by a foredeep and to the west by a shallow water ramp. (3) The Denley Limestone consists of four lithologies of which bioclastic turbidites and interbedded shale are the most abundant.

Turbidites can accumulate in two very different settings, one associated with submarine fans and the other with slope aprons. Submarine fan deposits would contain evidence of channelized and interchannel flow, lobate distribution patterns from point sources, and coarsening-upward sequences, none of which are found in the Denley Limestone. Slope aprons, on the other hand, can form on slopes of low angle along a line source, exhibit great lateral continuity of beds, contain few breccia or slump horizons, and lack evidence of channelization. For these reasons, the sediment of the Denley Limestone is interpreted as having formed in a slope apron setting on the distal portion of a fault-dissected, eastward dipping ramp.

Characteristics of Tempestites and Turbidites

Tempestites

1. internal structures, although similar to Bouma divisions lack the repetitive consistency[1,2]
2. association with Skolithos burrows[2]
3. lateral continuity of beds on the order of 10's meters[2]
4. strongly lenticular bedding[1]
5. multiple paleocurrents: fairweather and storm[1,3,4]
6. association with wave-generated bedforms[5,4]
7. association with hummock cross stratification[6,3,4]
8. lateral facies grading into normal marine lithoa and biofacies[2]
9. escape burrows[7]
10. amalgamated beds[4]

Turbidites

1. planar bases, often with scours[8,9]
2. ubiquitous grading and horizontal laminations[8,10,11,12,13,14]
3. multiple internal Bouma divisions[8]
4. burrowing restricted to the upper few cm[11,12,13,14]
5. load casts and convolute laminations[11]
6. association with slump fold horizons and allochthonous blocks[9]
7. resedimented shallow water allochems[9]
8. oriented fossils[14]
9. lateral continuity of beds over 100's meters[11]
10. interbedding with pelagig sediments and faunas[12,13]

Distinguishing Features of Turbidites

1. absence of escape burrows
2. consistency of internal structures
3. association of couplets with deep water facies
4. extreme lateral continuity of beds
5. multiple internal Bouma divisions
6. unidirectional paleocurrents
7. association with slump folds

Sources: 1-Kelling and Mullin, 1975   7-Reineck and Singh, 1972   13-Hesse, 1975
          2-Benchley, Newell and Stanistreet, 1979   8-Tucker, 1969   14-Piper, 1978
          3-Seilacher, 1982   9-Piper, 1972b
          4-Aigner, 1982   10-Piper, 1972a 1972
          5-Nelson, 1982   11-Scholle, 1971
          6-Hamblin and Walker, 1979   12-Rupke, 1975

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