Trip BC-3

FORELAND BASIN SEDIMENTATION IN THE TRENTON GROUP OF CENTRAL NEW YORK

C. J. Mehrtens

Department of Geology, University of Vermont
Burlington, Vt. 05405

Purpose

The purpose of this field trip is to re-examine several of the well-known exposures of the Trenton Group in the Mohawk Valley. This re-examination is necessary due to the recent reinterpretations of the depo-tectonic setting and sedimentology of these units. Specifically, the Trenton Group in central New York has been redefined as a foreland basin and a tectonically active shelf edge/trench slope environment (Cisne, et al., 1982). The sedimentology of the Trenton Group has been shown (Mehrtens, in review) to evolve from in situ carbonates to dominantly turbiditic in nature. This field trip will visit several localities where participants will be able to view: (1) variations in the thickness of units over short lateral distances; (2) rapid facies changes within individiual stratigraphic sequences; (3) syn-depositional slump fold horizons; (4) internal structures within limestone beds, identifiable as Bouma sequences. These features are all characteristic of sedimentation in the tectonically active foreland basin. The text for this field trip will review the stratigraphic model presented by Cisne and Rabe (1978) and Cisne, et al (1982). Evidence for the interpretation of the limestone and shale couplets of the Denley Limestone and Dolgeville Facies as bioclastic turbidites will also be reviewed. Previous interpretations of the Trenton Group depo-tectonic setting will be presented and compared to the foreland basin model. It is hoped that this field trip will demonstrate, if nothing else, the strong role that a model or paradigm can play in the interpertation of stratigraphic sequences.

Introduction

Recent publications by Rowley and Kidd (1981) and Cisne and Rabe (1978) and Cisne, et al., (1982) have revised our understanding of the tectonic setting in which Cambro-Ordovician sediments of the Taconic System have accumulated. These workers have reviewed past interpretations that include considering the sedimentary facies associated with the Taconic Orogen to have accumulated in mio- to eugeosynclinal settings (Kay, 1937) and those which recognize convergent margin features associated with continent-arc collision (Zen, 1961, 1967). The original continent-arc model

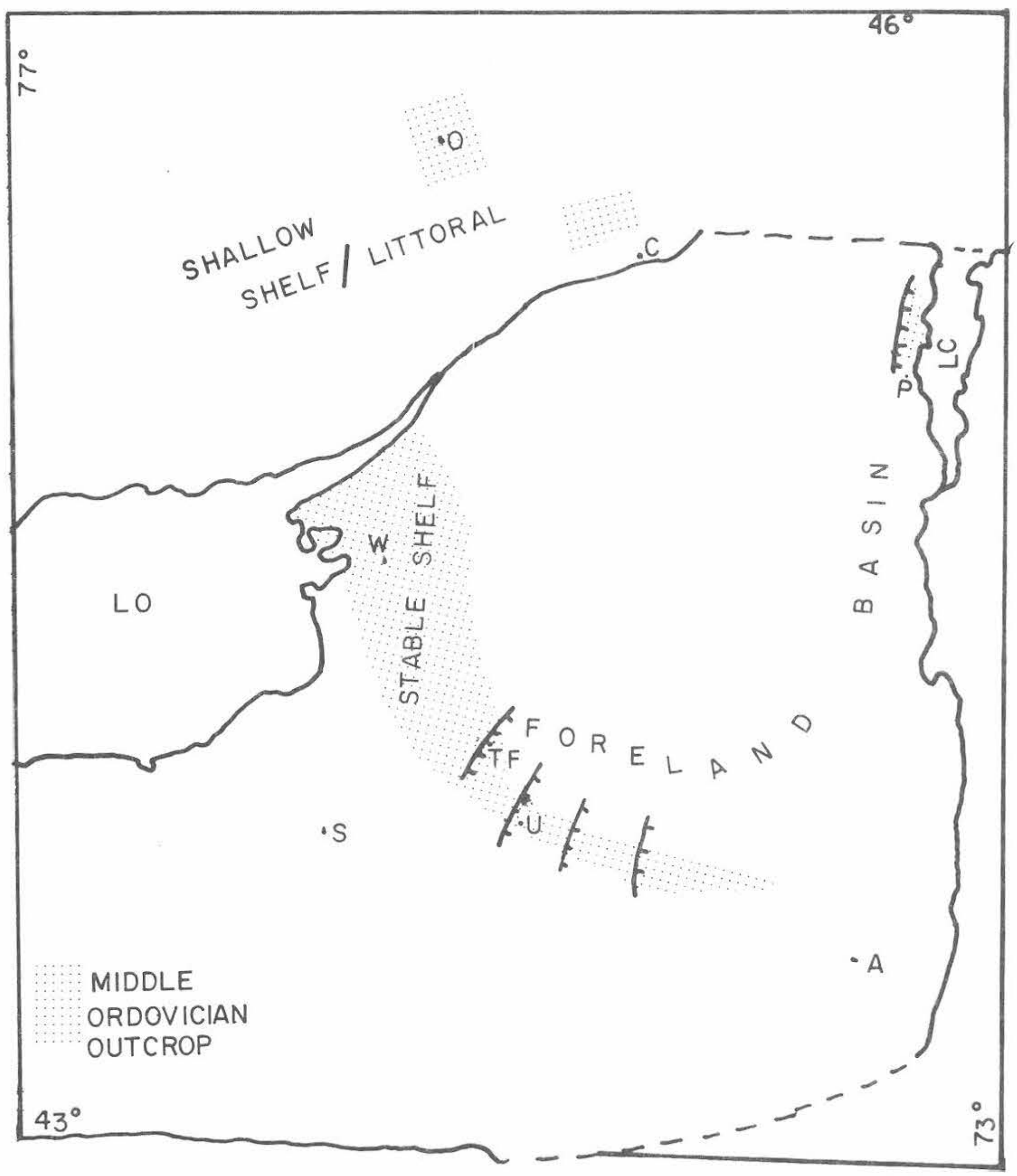

Figure 1. Paleogeographic map of the Trenton Group in New York and adjacent southern Ontario. Illustrated are the three main subdivisions of the depo-tectonic environment: the inner shelf or shallow shelf/littoral; the stable shelf; and the foreland basin. LO = Lake Ontario; LC = Lake Champlain; A = Albany; S = Syracuse; U = Utica; TF = Trenton type section at Trenton Falls Gorge; W = Watertown; C = Cornwall; O = Ottawa/Hull.

for the evolution of the Taconic Orogeny described by Bird and Dewey (1970) was refined by Rowley and Kidd on the basis of detailed petrographic and stratigraphic studies of the flysch associated with allochthon emplacement. Although the major contribution of their study is in the refinement of the timing and mechanism of allochthon emplacement, it also provides a concise summary of the tectonic settings of other portions of the continent-arc collisional belt.

Cisne, et al. (1982a) have also recognized that a continent-arc collisional model explains the stratigraphic sequence and facies succession of Middle Ordovician units in the Mohawk Valley, central New York. They compared this stratigraphic sequence and tectonic setting to that of the Australian flank of the Timor Trough, in other words, a continental shelf to outer trench slope setting. Their study, based on the detailed stratigraphy provided by bentonite horizons, generated paleobathymmetry and paleotopography of the cratonward portion of the shelf to trench transition.

The works of Cisne and Rabe (1978) and Cisne, et al. (1982) are important because they provide a major advance in our understanding of the sedimentary and biofacies of the Middle Ordovician sequence of the Mohawk Valley. In particular, it explains the origin and significance of: 1) numerous unconformities within the sequence; (2) attenuated and compressed stratigraphic sequences; (3) numerous syndepositional block faults; (4) major facies changes over short distances of the outcrop belt; (5) apparent anomolous juxtaposition of shallow and deep water sediments and sedimentary structures. These features have all been explained by recognition that the Middle Ordovician sediments were deposited on an actively fragmenting shelf in a foreland basin, and that each fault block within the shelf was accumulating a unique stratigraphic sequence. By using bentonite horizons to correlate fault blocks, Cisne and his coworkers constructed paleotopographic maps which illustrated the existence of an overall slope into the outer trench, superimposed on local topographic highs and lows. The extensional tectonics needed to generate this type of faulting in a compressional margin was described by Chapple (1973) as resulting from the passage of the shelf through the peripheral bulge. Similar syn-depositional extensional faults were described from the Middle Ordovician of southern Quebec by St. Julien and Hubert (1975) and their significance in producing localized stratigraphic sequences in the Middle Ordovician was mentioned by Mehrtens (1979).

The analogy of the Australian carbonate platform/Timor trench transect with that of the Trenton Group depotectonic setting is important. It suggests that there will be significant changes in paleoenvironments in the outcrop belt. Hypothesizing on what paleogeographic changes might be seen in the Trenton outcrop belt (Figure 1), the more cratonward exposures of the Trenton Group (west and northwest around the

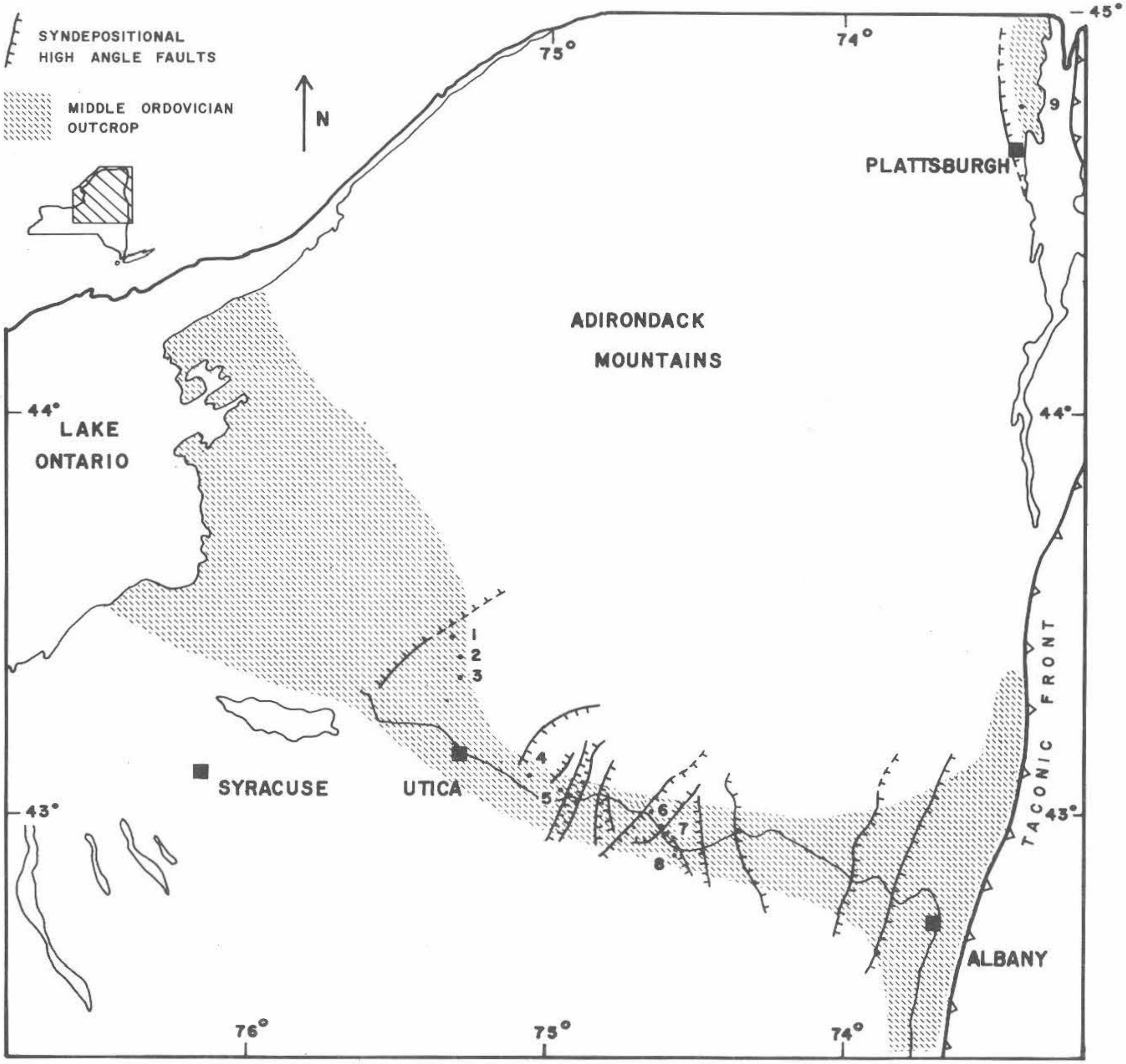

Figure 2. Locality map of northern New York State illustrating the outcrop belt of Trenton Group rocks. Key locations cited in the text include: 1 -Trenton Falls Gorge; 2 - Buttermilk Creek; 3 - City Brook; 4 - Herkimer; 5 - Little Falls; 6 - Caroga Creek; 7 - Palatine Bridge; 8 - Canajoharie Creek; 9 - Beekmantown.

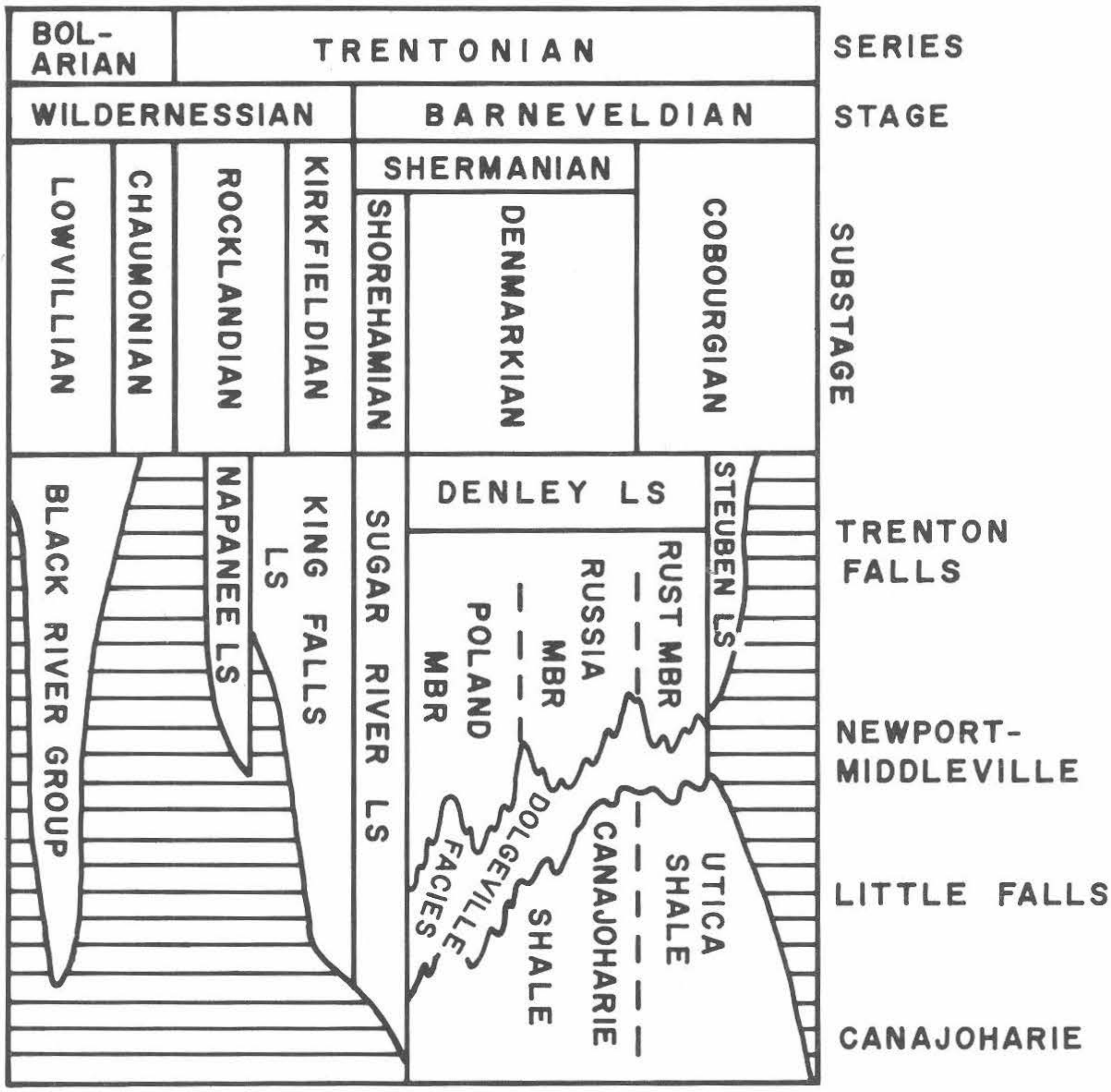

Figure 3. Correlation chart for Black River and Trenton Groups in central New York, modified from Titus and Cameron (1976).

Adirondacks) should be more removed from the trench setting, and therefore exhibit lithofacies that are shallow shelf in origin (ex. calcarenites and calcirudites exhibiting sedimentary structures diagnostic of wave-reworking) throughout the bulk of their stratigraphic sequence. Those portions of the outcrop belt which runs west-east in the Mohawk Valley are within the shelf to trench transition (Cisne and Rabe, 1978) and will exhibit features diagnostic of being below wave base and on a slope (slumps, turbidites, etc). A critical juncture then, would be the area of the outcrop belt where the transition from the stable, unfragmented shelf to that of the shelf/outer trench slope occurs. The most cratonward high angle fault in the outcrop belt occurs immediately to the northwest of the Trenton type section at Trenton Falls Gorge. This should also be the position of the stable shelf to foreland basin transition. It should be stressed that even within the foreland basin, shallow shelf (wave reworked) sediments will be deposited until the fault block founders. It is not unlikely then, to find shallow shelf sediments overlain by deeper water deposits. In this field trip we will be viewing outcrops that are all well within the fragmented foreland basin.

Stratigraphy

Pre-Trenton: The sedimentology of the Cambrian to Lower Ordovician siliciclastic and carbonate sequence (Little Falls Dolomite, Tribes Hill Dolomite, Beekmantown Dolomite) in the Mohawk Valley region of New York has been presented by Braun and Friedman (1969) and Mazzullo and Friedman (1975). These units represent peritidal to shallow shelf sediments and are, in the Mohawk Valley, unconformably overlain by the shallow shelf sandstones, dolostones, and limestones of the Black River Group. The nature of the Black River-Trenton contact is not diffinitive, and is thought by Cisne and Rabe (1978) to be a minor unconformity in central New York.

Trenton Group: The outcrop belt of Trenton Group rocks in central New York State extends through the Mohawk and Black River Valleys (Figure 2). This field trip will visit localities from northwest (Prospect, N.Y.) to southeast (Canajoharie Creek, N.Y.). The Trenton outcrop belt continues to the northwest and southeast direction (Figure 2), with isolated outcrops also present in the Champlain Valley of northern New York and western Vermont.

The stratigraphy of the Trenton Group was presented by Titus and Cameron (1976) who updated earlier versions by Kay (1937, 1953). The general stratigraphy of the Trenton Group is presented in Figure 3, which is modified from Titus and Cameron (1976).

The sedimentology of the basal units of the lower Trenton Group, the Selby and Napanee Limestones, have already been

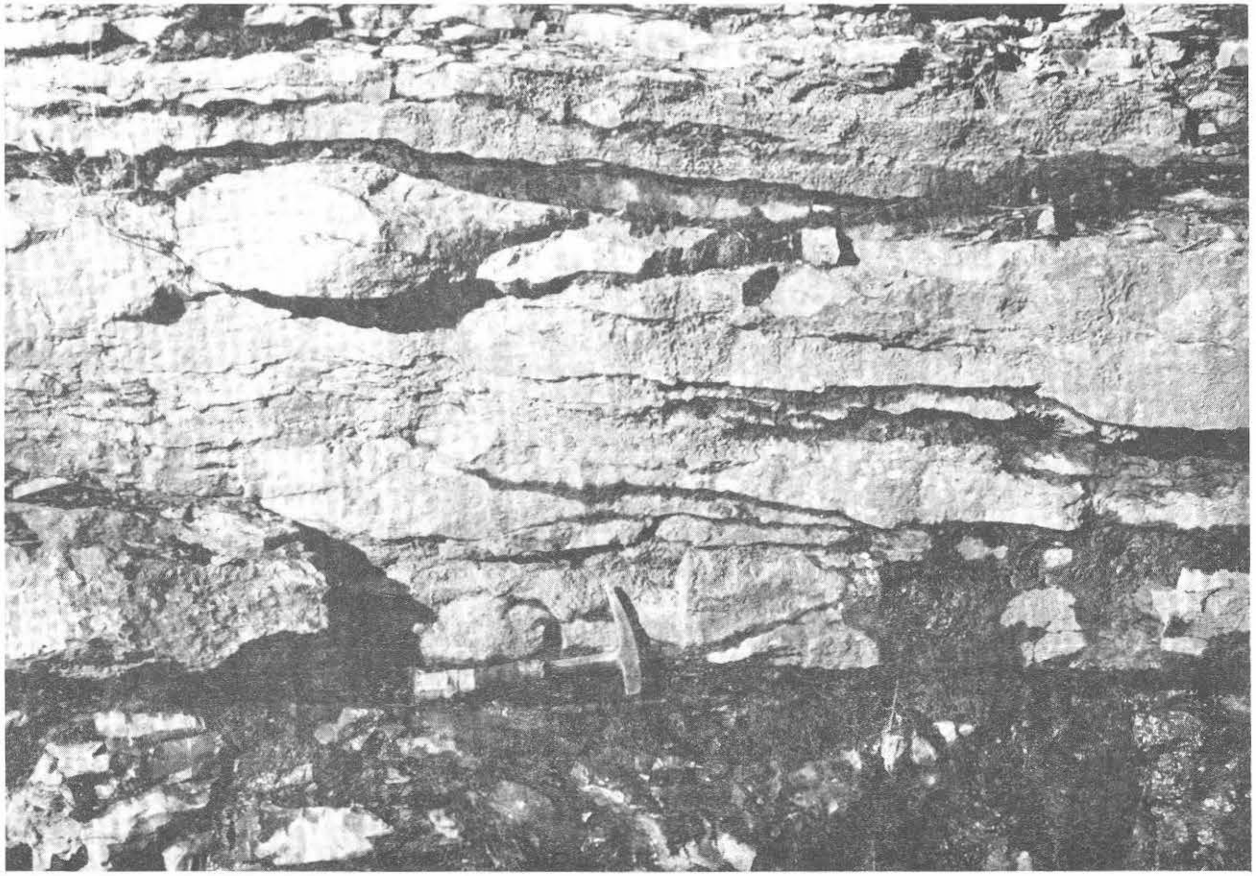

Figure 4. Outcrop photograph illustrating the typical bedding styles and textures of upper Kings Falls lithologies. Note the irregular bed thicknesses (lateral thickening and thinning) and wavy or hummocky bedding surfaces.

described in detail by Titus and Cameron (1976) and were the subject of previous NYSGA field trips (Cameron, Mangion and Titus, 1973 and Cameron, 1972). They are only briefly reviewed here. Essentially, they form a continuum of environments representing progressively increasing water depth from "lagoonal facies" (Napanee and Selby) to "offshore shoal facies" (lower Kings Falls), "shallow shelf facies" (middle and upper Kings Falls) and "deep offshore shelf" (lower and middle Sugar River) facies (Titus and Cameron, 1976, pp. 1211-1212). The lithofacies represented by these units include, for the Napanee and Selby, "relatively thick bedded calcilutites and calcsiltites with shale interbeds, horizontally and inclined current laminae and ripples, mudcracks, birdseye and vertical burrows". The shoal facies of the Kings Falls is a "thick bedded skeletal calcarenite" with "coquinal calcirudites, calcsiltites and interbedded calcareous shale" also present. The shallow shelf facies of the Kings Falls is a thinner bedded "sparry coquinal calcarenite" while the deep offshore shelf facies of the lower and middle Sugar River is a "thin bedded calcarenite with thin calcareous-shale interbeds" (Titus and Cameron, 1976, pp. 1211-1212). The typical bedding styles of the Kings Falls and lower Sugar River Limestones are shown in Figure 4. Note that the beds are laterally discontinuous, exhibiting lensing. This hummocky bedding style is a characteristic of wave reworked substrates, and has been noted by Aigner (1982) as diagnostic of storm reworked sediments. The Kings Falls and lower Sugar River lithologies will be seen at Shedd Brook (Stop 3) and Buttermilk Creek (Stop 1). The transition from this amalgamated bedding style to the more planar beds of the upper Sugar River and Denley, is significant and is interpreted as representing the transition from near wave base to below-wave base depths. Compare the relative thicknesses of the lithologies exhibiting amalgamated bedding among outcrops. Another characteristic of the Kings Falls and lower Sugar River Limestones is the relative absence of shale. This feature distinguishes the lower Sugar River from the upper Sugar as the contact with the Denley Limestone is approached.

The Denley Limestone overlies the Sugar River Limestone and is divisible at the type section in Trenton Falls Gorge (locality 1, Figure 1) into three members: Poland, Russia and Rust. The Denley/Sugar River contact is completely gradational in nature. On this field trip it will be seen at Stop 3 (Shedd Brook), Stop 1 (Buttermilk Creek) and Stop 2 (City Brook). The basal Denley differs from the Sugar River in that it: (1) contains a lower ratio of calcarenite to calcilutite (is finer-grained); (2) has slightly thicker shale interbeds; (3) contains horizons of barren, unfossiliferous, bioturbated micrite; (4) contains micrite beds with planar bases, bioturbated tops and a sequence of sedimentary structures recognizable as Bouma sequences in between. It was the recognition of these beds as turbidites that led to a re-evaluation of the depositional environment for the Denley Limestone. Also present within the Denley Limestone are

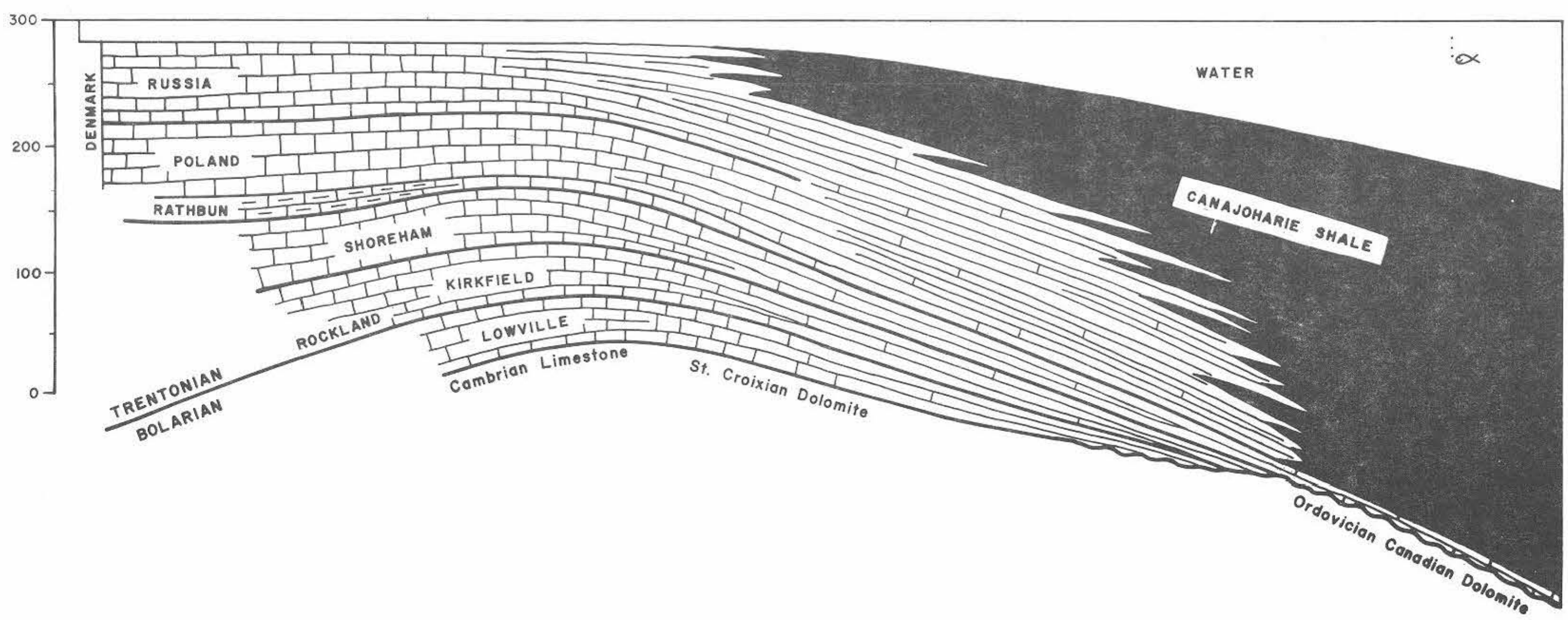

Figure 5. The restored section of the Trenton Group, after Kay (1965, Fig. 8.12). Essentially, Kay interpreted the Trenton units to be deposited on a shelf adjacent to a shale basin with a simple west to east transition from shallow shelf to transitional to deep water facies change. Compare this to Figure 6.

brecciated limestone horizons containing slump folds. The slump fold horizon visible in Figure 16 will be seen at Stop 4 (West Canada Creek).

Uppermost Trenton: Within the outcrop belt the Denley is overlain by a variety of units. East of the Trenton type section at Trenton Falls Gorge, the Dolgeville Facies was recognized by Kay (1953) as representing the transition between the Denley Limestone and the Canajoharie Shale. It is characterized by its fine-grained micritic composition, planar bases, laterally continuous beds and ubiquitous horizontal laminations (Figure 5). The Dolgeville will be seen at Stop 2 (City Brook). At the Trenton type section, the Steuben and Hillier Limestones overlie the Denley and have been described by Kay (1937, 1953) as a "thick bedded cross laminated calcite sandstone or calcarenite" and "argillaceous calcarenite and calcsiltite with interbedded shale", respectively (1953, p. 61). These limestones are conformably overlain by the Utica and Canajoharie Shales (Riva, 1972, fig. 16). The Steuben and Hillier Limestones are not present southeast of localities 1-3, Figure 2, and will not be seen in this field trip. In this region of the outcrop belt the shales of the Utica and Canajoharie overlie the Denley Limestone. The sedimentology of the Steuben and Hillier equivalents in the Trenton Group in Ontario have been studied by Brookfield (1983). Brookfield recognized lithofacies characteristic of supratidal, intertidal, lagoonal and shoal environments. Considering again Trenton paleogeography, the presence of these extremely shallow water environments in the most northwesterly portion of the outcrop belt is in keeping with the depositional model presented earlier.

To past workers it has always been somewhat problematical as to why the depositional environments represented by the lower to upper Trenton sediments should show a progressive deepening throughout most of the interval (Napanee and Selby Limestones), a shoaling (Steuben and Hillier Limestones) and ultimately, a rapid deepening (Utica and Canajoharie Shales). This oscillation was most recently attributed by Titus (1983) to be the result of facies mosaicing and oscillating eustatic sea level. As Cisne and Rabe's work demonstrates, extensional block faulting would explain why some of these facies (Steuben and Hillier, for example) are so localized in their occurence. The distribution pattern for Trenton units was incorporated into a model by Kay (1937, 1953), and is shown in Figure 5. As Figure 5 illustrates, the Trenton sediments were thought to have accumulated cratonward of the hinge of a subsiding shale basin. This model has persisted to the present day (Titus and Cameron, 1976). What differentiates Kay`s model from the one presented by Cisne and Rabe (1978) and adopted here, are the age relationships of the rock units from west to east. Kay`s (1937) use of the time-stratigraphic concept (rock unit=time unit) clouded the true chronostratigraphic relationships of the Trenton units. It is important to note that the bentonite stratigraphy presented by Cisne and Rabe demonstrates that the

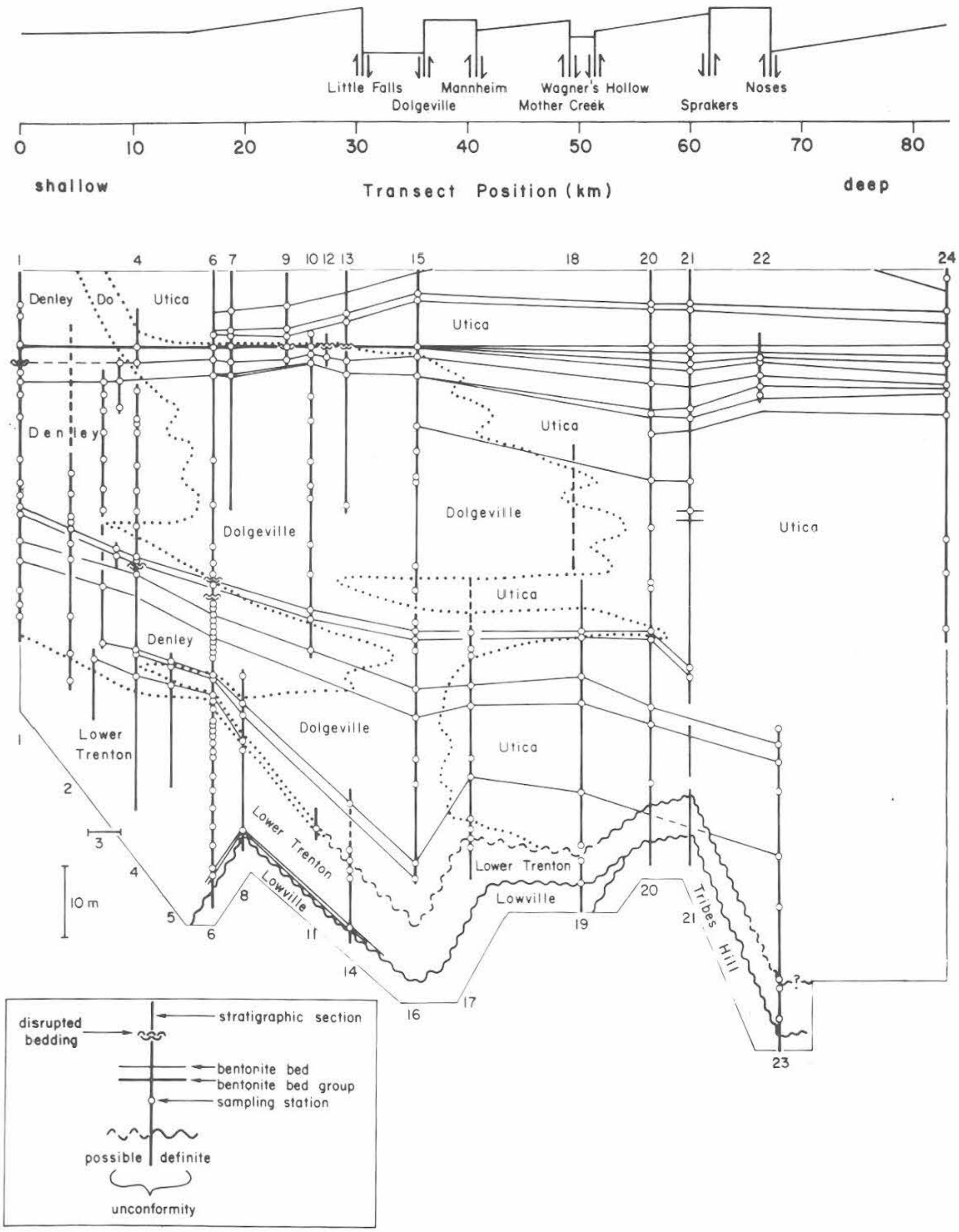

Figure 6. Stratigraphic sections of the Trenton Group and over- and underlying units are represented by vertical lines and have been correlated by bentonites (sub-horizontal lines). Sampling horizons for faunal studies are indicated by circles on the vertical lines. The structural cross section at the top of the diagram indicates that the Trenton strata thicken across basins and thin across basement highs, indicating that faulting is syndepositional. The sections are numbered: 1 - Trenton Falls; 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 & 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.

first appearance of a lithofacies in a stratigraphic sequence is not correlative with the first appearance in any other locality. Cameron (1972) also recognized the disachronous nature of formational contacts and attributed the rapid facies changes in an outcrop and the changes in thicknesses of units between outcrops to be the result of onlap resulting from transgression. These models differ primarily in the mechanisms invoked to explain the observed stratigraphic sequences. The foreland basin model presented by Cisne and Rabe (1978) and Cisne, et al (1982) suggests that foundering of the shelf was a more important factor than facies mosaicing associated with onlap. Their model is supported by the recognition of bioclastic turbidites from the Denley Limestone and Dolgeville Facies, suggestive of deeper water sedimentation characteristic of the outer shelf and slope environments.

The revised stratigraphy presented by Cisne and Rabe (1978) is based on the measurement of 24 stratigraphic sections in the Mohawk Valley. Examination of Figure 6 reveals several important features: (1) most of the 24 measured sections have a unique stratigraphic sequence; (2) that although there is a general eastward increase in water depth (as recognized by the Dolgeville and Utica Shale facies) there are exceptions to this patter (note Dolgeville tongues in sections 5-8 and Denley tongue in sections 8-14; (3) within any one stratigraphic section there is not a uniform increase in water depth; (4) note in Figure 6, the irregular topography of the underlying surface; (5) some stratigraphic sections are significantly thinned (example section 23 in Figure 6 where the upper Trenton is missing and the lower Trenton is immediately overlain by Utica). We will be visiting several of these exposures on this field trip. We will see: (1) section 5 on Figure 6, Shedd Brook (Stop 3), where the upper Kings Falls, entire Sugar River and Denley Limestones, and lower Dolgeville Facies are exposed; (2) section 6 on Figure 6 (Buttermilk and City Brooks, Stops 1 & 2), where the Black River/Lower Trenton contact, all of the Lower Trenton, Sugar River and Denley Limestones, and the base of the Dolgeville Facies are exposed; (3) section 1 on Figure 6, West Canada Creek (Stop 4), where the upper Denley Limestone exhbiting slump fold horizons can be seen; (4) section 16 on Figure 6, Dolgeville (Stop 5), where the best exposures of Dolgeville Facies can be seen; (5) section 20 on Figure 6, Canajoharie Creek (Stop 6), where the unconformity between the Lower Ordovician Tribes Hill Dolomite and the Lower Trenton is exposed, and the thinned Lower Trenton (Kings Falls) is immediately overlain by Utica Shale; (6) Caroga Creek (Stop 7), section 19 on Figure 6, another exposure of the Black River/Lower Trenton contact, thinned Lower Trenton lithofacies and overlying Utica Shale.

Turbidite Sedimentology

Research on the depostional environment of the Denley Limestone was begun as part of the data collection and

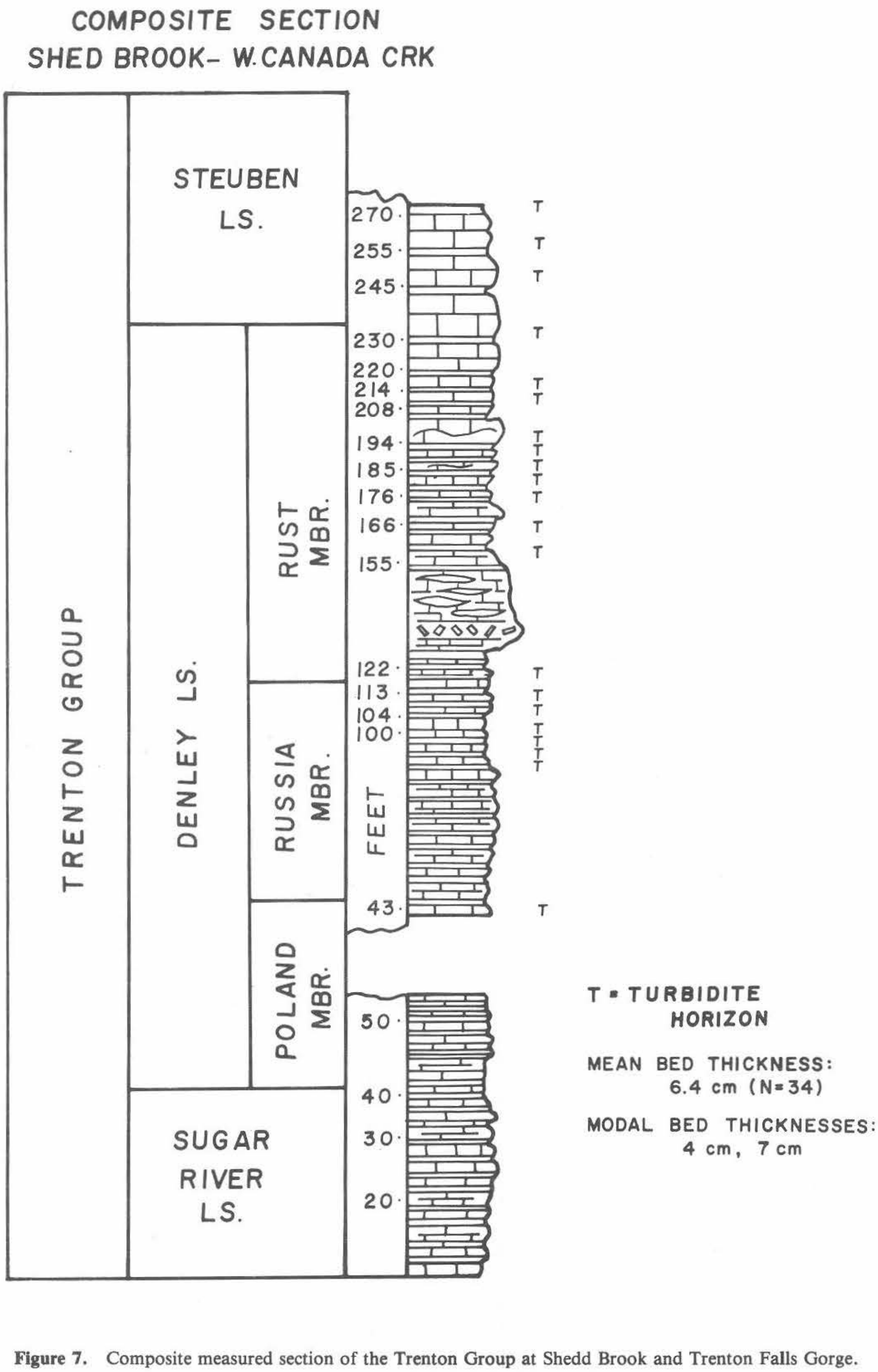

Figure 7. Composite measured section of the Trenton Group at Shedd Brook and Trenton Falls Gorge.

sampling for a study on the morphology and environmental preferences of the trepestome bryozoa, Prasopora (figure 7). Prasopora, a gum-droped shaped colony, covers bedding planes in the Sugar River and Denley Limestones, and is the index fossil for the Sugar River. Entire limestone beds below the colonies were collected and thin sectioned for petrographic analysis. The 250 foot thick Trenton type section at Trenton Falls Gorge (Denley Limestone: Poland, Russia,and Rust Members, Steuben and Hillier Limestones) was sampled in this fashion. Subsequent outcrops were sampled in a more methodical manner. Large thin sections (5 x 7 inch up to 5 x 14 inch) on 1/4 inch glass plates were made to preserve entire limestone beds and the upper and lower contacts with interbedded shale horizons.

The Denley Limestone is characterized by the repetitive interbedding of limestone and shale couplets. What is the origin of this cyclic bedding? Do the shale horizons represent episodic events of deeper water sedimentation or are they the result of dewatering and compaction of an original mixed carbonate-terriginous clay sediment? Are the carbonate beds resedimented and the shale autochtonous? These questions, orignally asked as part of the Prasopora paleoenvironment study, became important in their own right for the information they might contain on the origin of limestone-shale couplets in general. Mehrtens (in press) presented the evidence that 70% of the limestone beds sampled in the Denley Limestone at the Trenton Falls Gorge type section (Figure 7) were bioclastic turbidites. Subsequent studies of other stratigraphic sections in the Mohawk and Champlain Valleys indicate that bioclastic turbidites are a common occurence in the Denley Limestone, Dolgeville Facies and undifferentiated Trenton sediments. The bioclastic turbidites are recognizable by internal structures identifiable by Bouma Units. Comparison of the Denley Limestone turbidites to other examples of bioclastic turbidites cited in the geologic literature (Thompson and Thommasson, 1969; Cook and Taylor, 1977; Yurewicz, 1977; Scholle, 1971; Garrison and Fisher, 1975, among others) indicates that they share many characteristics: (1) division of beds into a lower graded and upper mudstone portion; (2) graded carbonate sand units capped by laminated or cross laminated units; (3) laterally extensive beds; (4) associated slump fold horizons; (5) planar bases with bioturbated tops; (6) ubiquitous grading and horizontal laminae. Figure 8 compares the internal structures of bioclastic turbidites to those of a clastic turbidite.

Although recognition of bioclastic turbidites is dependent on petrographic study it will be possible to see some features associated with turbidite sedimentation on this field trip. Examination of several of the large thin sections illustrates many of the features visible with petrographic study.

Examination of Figure 9 illustrates a typical bioclastic

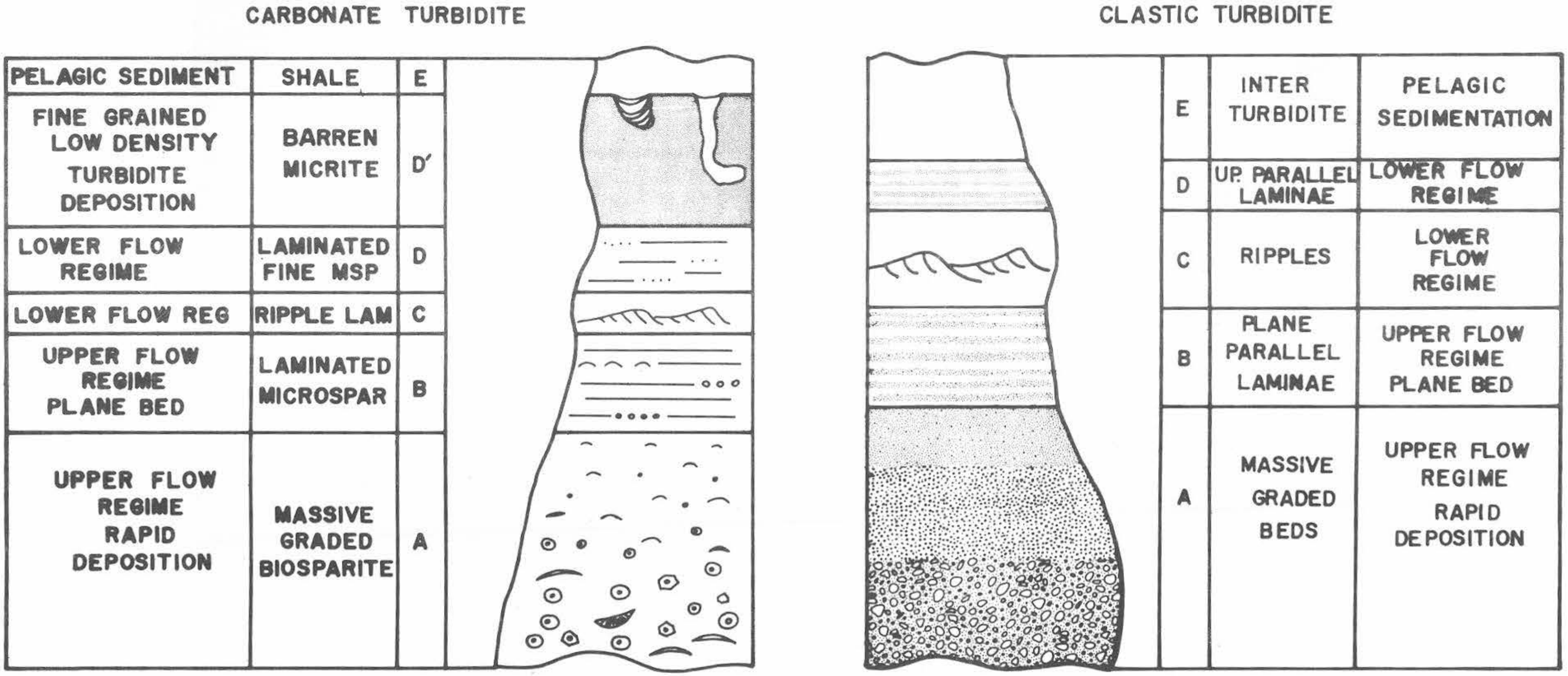

Figure 8. Comparison of the internal sedimentary structures and their hydrodynamic interpretations for clastic and carbonate turbidites. After Walker (1965).

Figure 9. A large (8 x 8 inches) thin section on a glass plate which illustrates a Tabd ' sequence. Note the descending burrows.

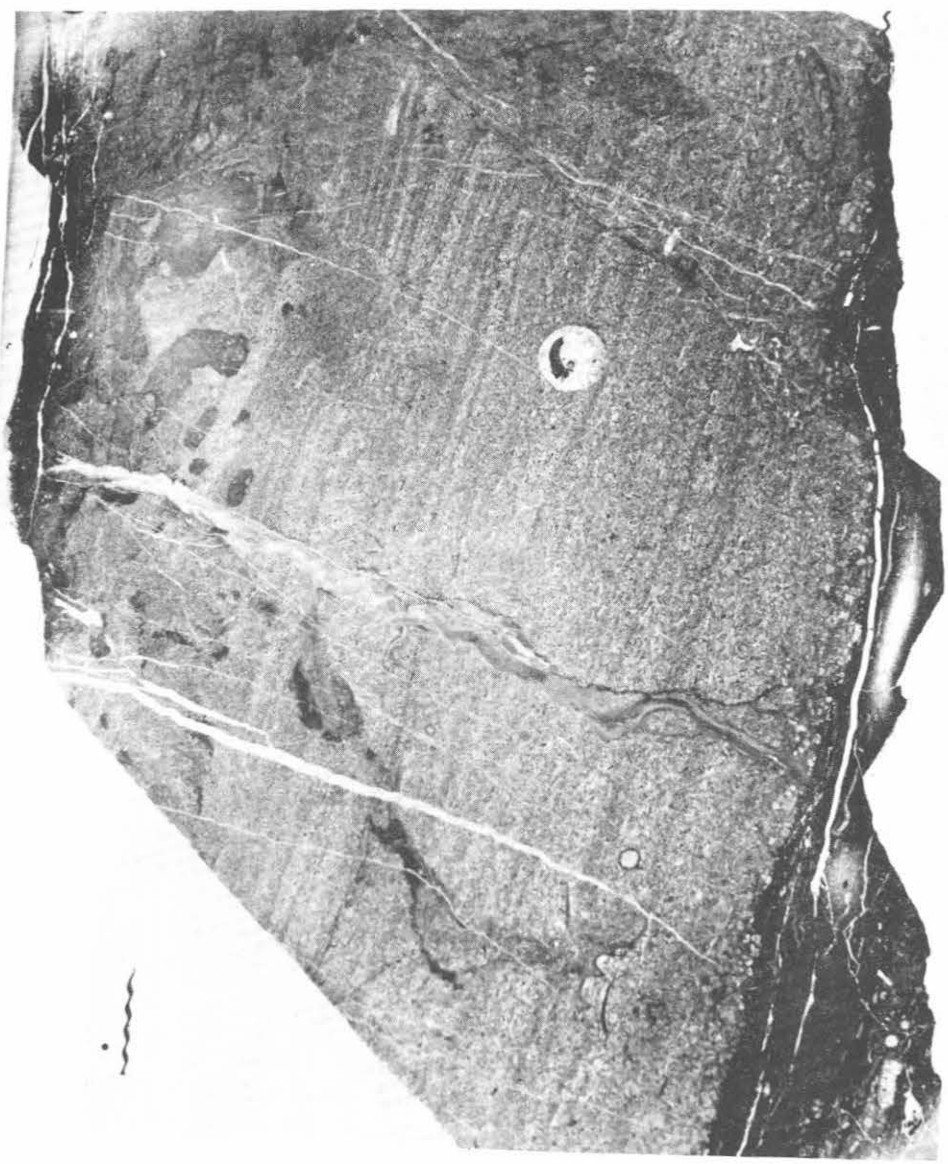

Figure 10. Another large thin section illustrating Tab Bouma Units.

turbidite from undifferentiated middle Trenton Group. This thin section, 9 x 10 cm in size, is bounded on top and bottom with calcareous shale units interpreted as interturbidite deposits, or Te units. The turbidite has at its base a 1 cm thick layer of disarticulated crinoid ossicles analogous to the traction carpet of coarse quartz sand of a clastic turbidite. This layer (Ta) gerades into a less fossiliferous laminated microspar (Tb). Close examination of Figure 8A suggests that the grading visible through the bulk of the thin section owes its origin to three processes, illustrated in Figure 10: (1) concentrations of ossicles at the base and a vertical diminuition in their size and abundance; (2) a vertical size change in highly fragmented silt-sized skeletal fragments; (3) vertical decrease in size of the interparticle spar between grains of the laminated micrite matrix. This size change in the spar is thought to reflect a vertical change in interparticle porosity (Choquette and Pray, 1970). The origin of the interparticle porosity grading and subsequent spar cement is thought to be related to the thickness of the current-laminated horizontal laminae, and is therefore primary in origin. The unit overlying the current-laminated Tb unit is a highly bioturbated barren micrite horizon (td'). Internal structures within the burrows confirms that they are descending from the overlying shale and thus reflects the recolonization of the emplaced sediment.

Figure 10 is a thin section of a 6 cm thick turbidite horizons from the Denley Limestone (Russia Member). This thin section contains a poorly sorted and poorly graded biospar at its base (Ta). Numerous fragmented, unidentifiable pelmatozoan debris is visible. This 2 cm thick basal unit grades up into the horizontally laminated unit (Tb) through an interval of 0.5cm. Within this interval the skeletal fragments decrease in the size and abundance vertically. There is an associated decrease inthe size of interparticle spar. The effects of shelter porosity are clearly visible beneath the trilobite fragment. The horizontally laminated Tb unit is 4 cm thick and composed of current-laminated micrite, terriginous silt and microspar cement.

Figure 11 is a thin sectio of a 9cm thick turbidite horizon from the Denley Limestone (Poland Member). This thin section exhibits a thin (1 cm) basal lag of poorly sorted, fragmented skeletal debris and spar cement (Ta). Grading is not well developed. This basal lag is immediately overlain, without any gradational interval, by 8 cm of barren micrite (Td'). Except for a few small worm burrows, this micrite horizon is structureless. This is a very characteristic turbidite occurence. Examination of Table 1 indicates that turbidites composed of a basal lag overlain by barren micrite (Tad')makes up 11% of the Trenton turbidites at Trenton Falls Gorge and 40% of the turbidites from undifferentiated Trenton near Beekmantown. This turbidite is very important because it is the most likely sequence to be overlooked or misidentified as being the result of resuspension and settling due to storms.

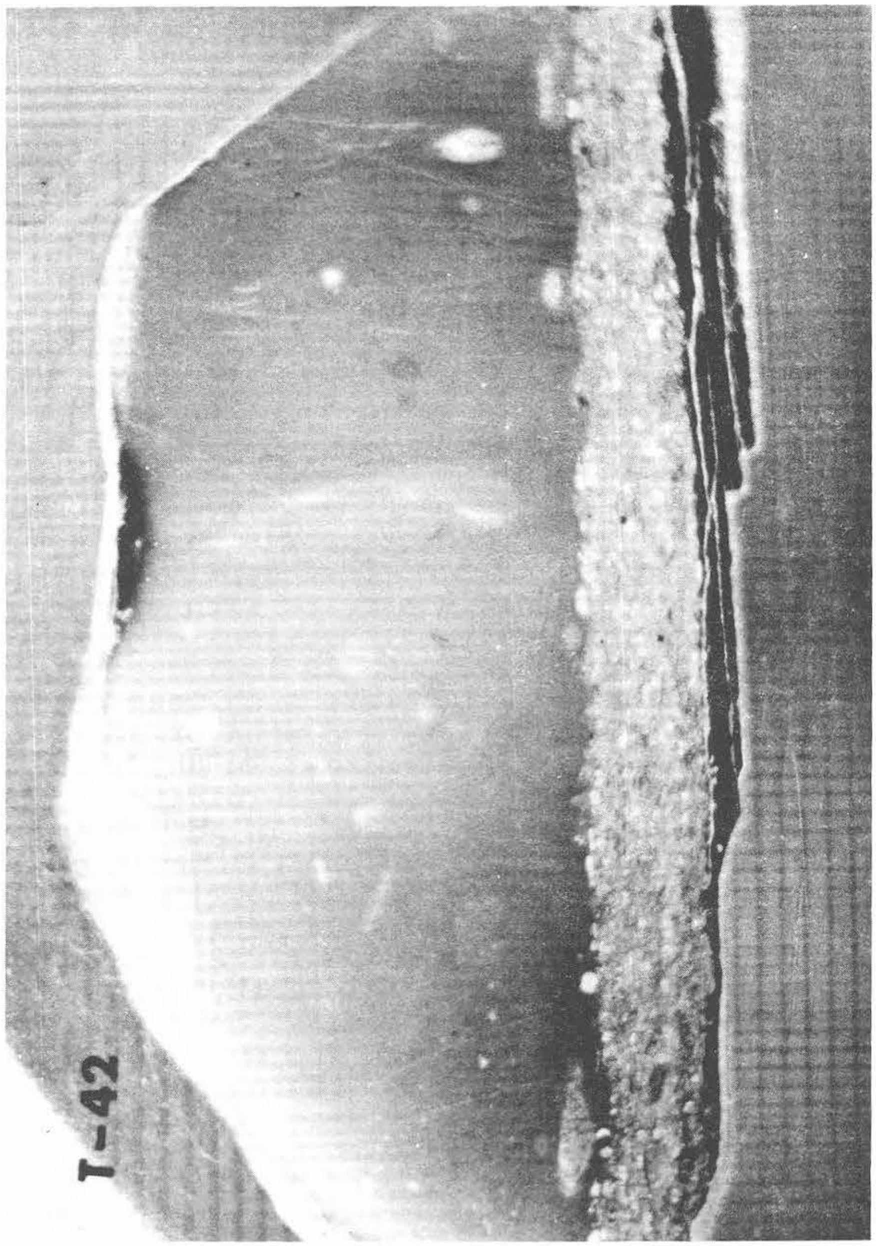

Figure 11. Another large thin section illustrating Tad′ sequences, a common turbidite occurrence.

These two mechanisms can be differentiated by a simple statistical measure, a plot of grain size (measured by crinoid ossicle diameter) vs graded bed thickness (illustrated in Figure 12). The rationale and threoretical basis for this relationship was discussed by Mehrtens (in press). Basically, sediment that is simply resuspended and allowed to settle as a function of its settling velocity will produce a graded bed. The size of the grains within this graded layer will not however, be related to the hydraulics of flow, and will therefore not show size sorting. A correlation between bed thickness and grain size exists in turbidites, however, because the hydraulics of flow control not only the size of the particles moved, but the thickness of the bed. This relationship (bed thickness and grain size) has been described for modern bioclastic turbidites (Crevallo and Schlager, 1980).

Figure 13 illustrates the nature of the vertical changes visible within the Trenton trubidites. From bottom to top there is a progressive decrease in allochem abundance and associated interparticle cement. Accompanying this decrease is the expected increase in carbonate mud. The effects of varying source area on turbidite composition is seen by comparing the Bouma Units present in the Denley versus the Dolgeville Facies. The Dolgeville, as described earlier, consists of barren, horizontally laminated micrite with planar bases and thick shale interbeds (Figure 5). Horizons of coarse graded skeletal debris (Ta) and horizontally laminated skeletal fragments and carbonate mud (Tb) are much less common than in the Denley Limestone turbidites, and when present, contain an overall higher percentage of micrite. Tc units are more commonly preserved in the Dolgeville turbidites, probably because the lack of crushed allochems in Td limited the reworking which subsequently removes Tc. Based on these differences, the turbidites of the Dolgeville Facies could be interpreted as being more distal than those of the Denley. However, as Scholle (1971) and Welch (1978) demonstrated, the same features which distinguish "distality" (overall fine-grained size, Tcd) could represent deposits derived from a dominantly fine-grained source. The Dolgeville turbidites could be quite proximal in origin, having been derived from portions of the shelf which had already foundered sufficiently to have accumulated a supply of carbonate mud. Alternately, they could represent the distal portion of a Denley turbidite. If the latter were true we might expect to see a change in bed thickness from the proximal Denley turbidites to the more distal Dolgeville turbidites. In fact, the opposite is seen. The Denley turbidites average 7 cm in thickness while those of the Dolgeville average 8-10cm in thickness.

Mehrtens (in review) discussed the criteria for distinguishing turbidites from storm generated ebb currents. Many recent papers have described the internal structures generated by storm processes (see Nelson, 1982; Kriesa, 1981, Seilacher, 1982 and Aigner, 1982 for examples). The following

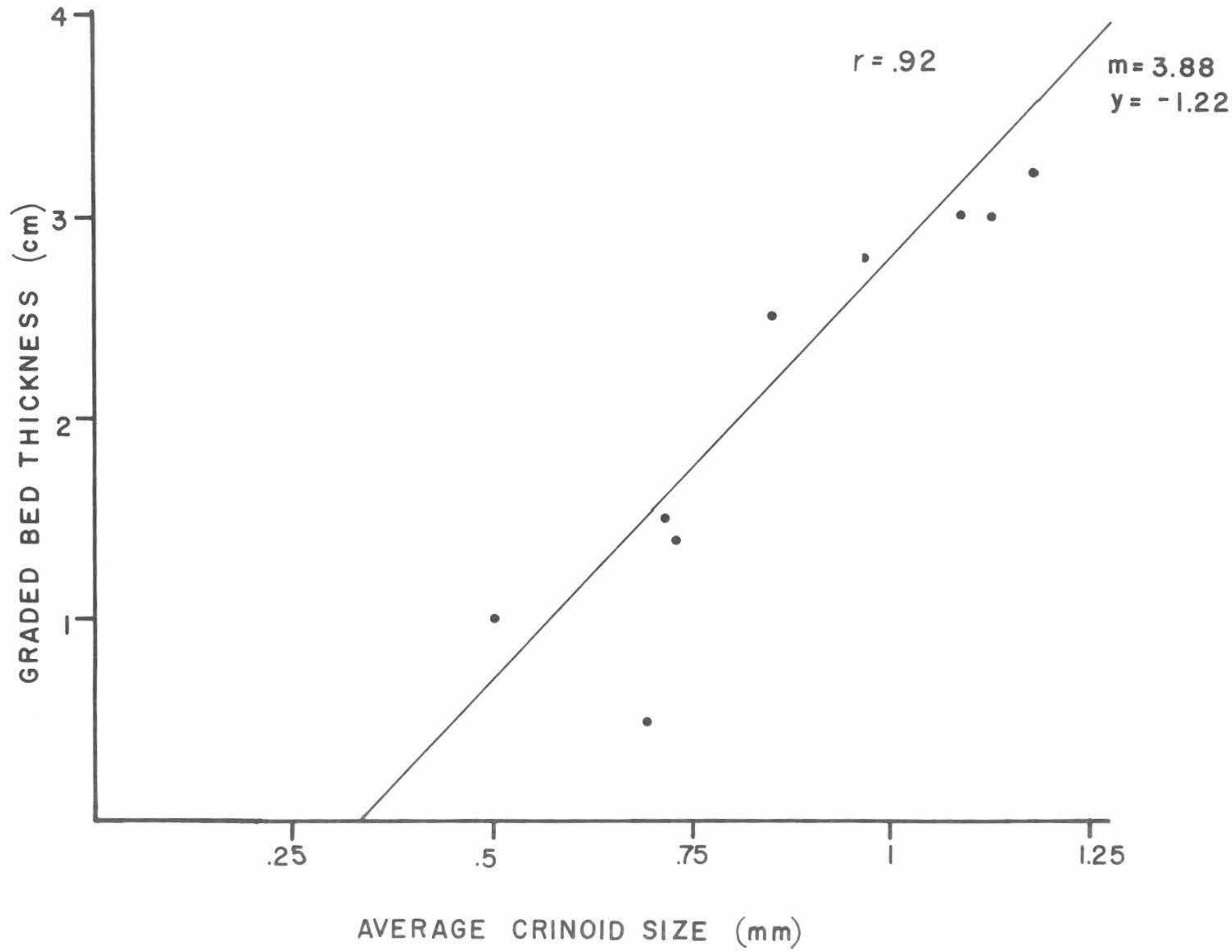

Figure 12. "Best fit" line and correlation coefficient (0.92) produced by linear regression analysis. This plot indicates a statistically valid positive relationship between the size of the fossils being deposited and the hydraulic conditions of the flow regime. Because there is a correlation between the size and the velocity of a turbidite, this observed relationship between grain size and bed thickness is characteristic of a turbidite.

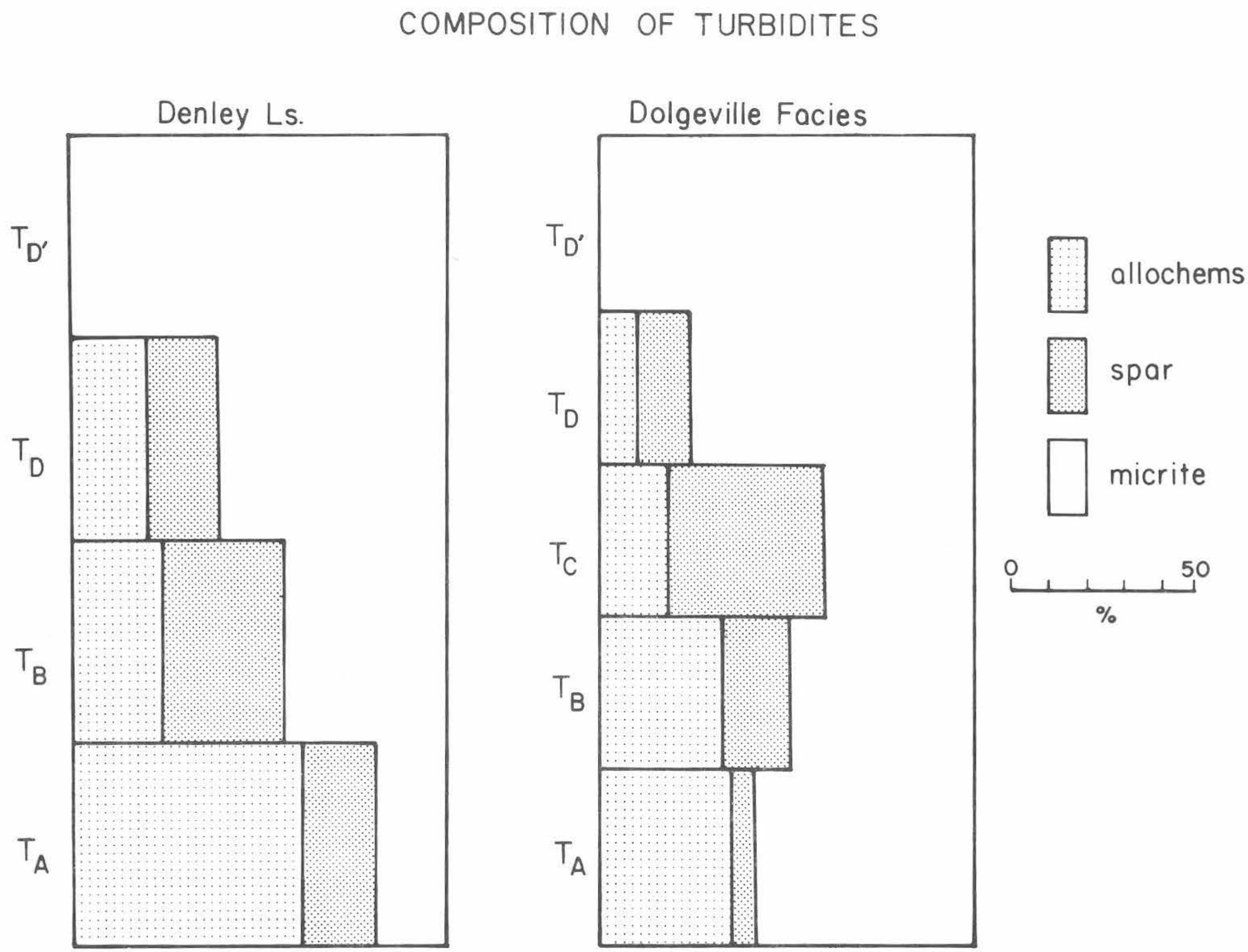

Figure 13. Graphic representation of the vertical changes which occur within the Denley and Dolgeville Turbidite beds.

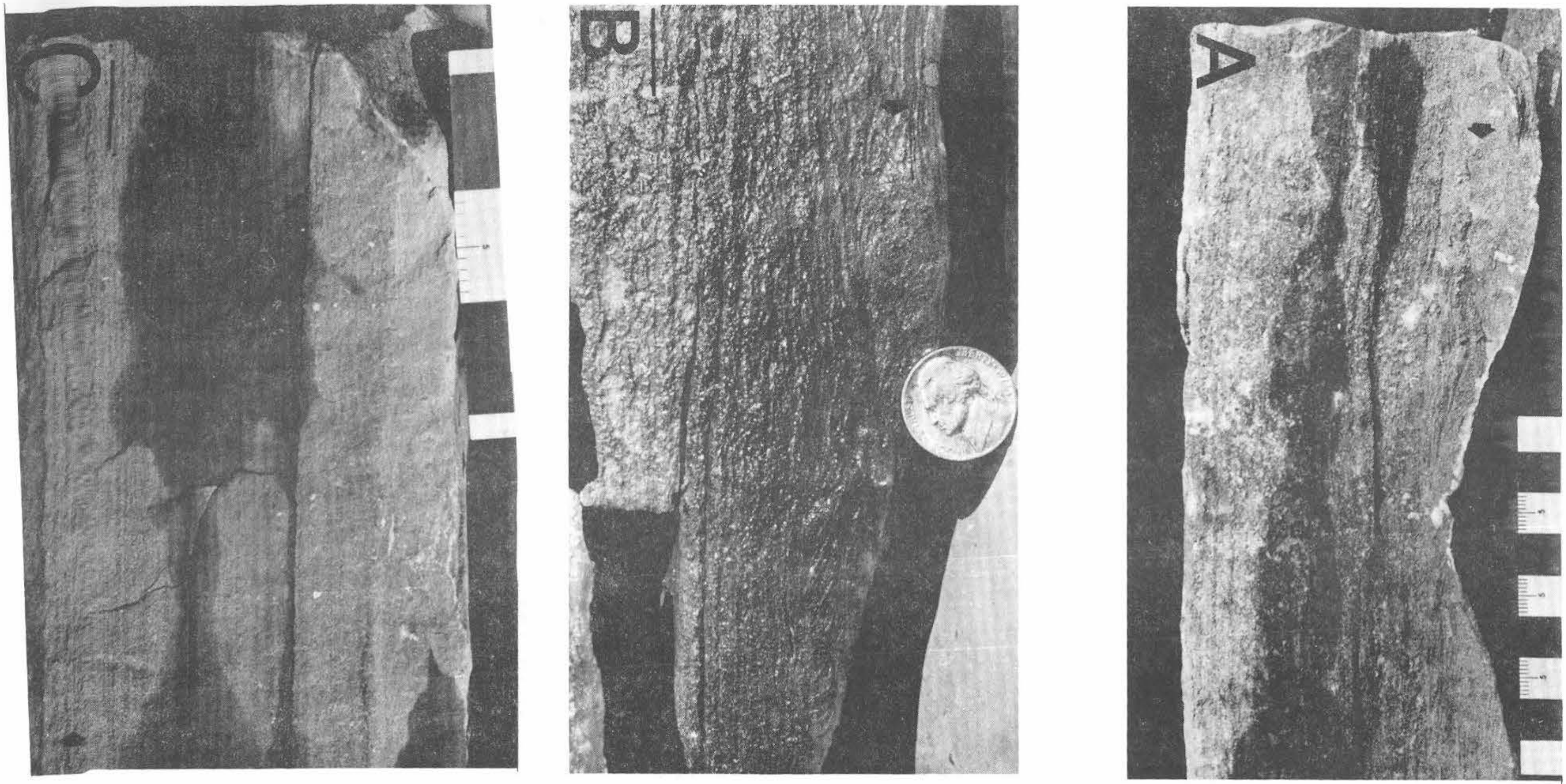

Figure 14. Photographs of the weathered surfaces of outcrops where cross laminations are most visible. **A.** Cross lamination of Tc is well developed over a horizontally laminated Tb. **B.** Laminations of Tc distorted into convolutions. **C.** Basal concentration of crinoid ossicles (lower arrow) of Ta is overlain by horizontally laminated Tb, and at upper arrow, cross laminated Tc.

characteristics for storm-generated deposits were frequently cited: (1)internal structures, although similar to Bouma Units, lack the repetitive consistency of turbidites; (2) association with Skolithos burrows; (3) lateral continuity on the order of 10's of meters; (4) strongly lenticular bedding is present; (4) multiple paleocurrents, one fairweather and another storm in origin; (5) association with trough cross lamination from wave oscillation; (6) association with hummocky cross stratification; (7) lateral facies grading into normal (fairweather or below wave base) marine shallow water litho- and biofacies; (8) escape burrows; (9) high degree of post-storm bioturbation.

Based on this list of criteria, the turbidite origin for the limestone/shale couplets is clear: (1) the internal structures occur with regular frequency throughout a stratigraphic sequence (see Figure 7); (2) Skolithos burrows are not associated with the Denley Limestone or Dolgeville Facies; (3) beds exhibit lateral continuity on the order of 100's meters; (4) the same paleocurrents are derived from measurement of ripple cross lamination (Figure 14) within the limestone beds as is obtained from graptolite and cephalopod orientations in the shale horizons (Cisne and Rabe, 1978); (5) trough cross-laminations associated with wave oscillation are absent in the Denley and Dolgeville; (6) hummocky cross stratification is also absent; (7) facies changes are abrupt and rarely gradtional; (8) escape burrows are not seen, rather all burrows are recolonization burrows, the result of repopulation of the resedimented limestone; (9) frequency of turbidite emplacement was sufficient to restrict post-emplacement bioturbation (a criteria cited by Dott, 1982, as a means of distinguishing storm and turbidite generated graded beds). Based on this evidence, association with slump fold horizons, statistical analysis and hydraulic interpretation of textural data, and consistency with the depo-tectonic model presented by Cisne, et al (1982), the limestone and shale couplets of the Denley Limestone and Dolgeville Facies can be interpreted as bioclastic turbidites.

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ROAD LOG

This Road Log starts at Thruway Exit 30, Herkimer, New York

Mileage

0.0	From Thruway, follow signs for Rt. 28N, through Herkimer to Middleville and intersection with Rts. 29 and 167.
1.7	Make left and continue north on Rt. 28 for 1.7 miles to Castle Rd. Turn right.
2.0	Go 0.3 miles up Castle Rd. to road coming in sharply on left.
2.1	Take sharp left, descending hill, and passing lower portion of City Brook on right.
2.6	Continue 0.5 miles to T junction. Take sharp right onto White Creek Road.
3.1	Go 0.5 miles to small bridge over Buttermilk Creek. Park immediately beyond bridge. STOP 1.

STOP 1 Buttermilk Creek

Park immediately beyond the bridge and descend to Buttermilk Creek. The section downstream of the bridge is part of the Black River Group (Gull River), consisting of calcareous limestone. Underneath the bridge and a short distance upstream are ledges of coarsely crystalline limestone alternating with massive calcareous sandstone beds. These are the lagoonal sediments of the Napanee and Selby Limestones. These rocks have been described by Titus and Cameron (1976) and are characterized by their aphanitic texture, birdseye structures, massive bedding, and disseminated quartz sand. This facies continues in a series of benches going upstream. The contact of the Napanee and Selby with the Kings Falls occurs immediately above the pool below the first waterfall. The Kings Falls is differentiated from the underlying facies by the first appearance of fossiliferous calcarenites that are thinner bedded and exhibit lateral thickening and thinning of individual beds. The Kings Falls continues upstream to the larger waterfall, consisting of beds of calcarenite and bioturbated calcilutite. The lateral lensing of the beds, so characteristic of the Kings Falls is readily visible.

Mileage

STOP 1 (cont'd)

While at this stop you should: (1) examine the Napanee and Selby (lagoonal) facies as this is the only stop where they will be seen on this trip; (2) examine the Kings Falls, noting in particular the features which may suggest that it accumulated near wave base. Are there any internal structures within the limestone beds? How much shale, if any, is present? Are the beds laterally continuous? How frequent was bioturbation? Where are the fossils - within limestone beds or on bedding planes?

3.6 Return to cars and retrace steps on White Creek Rd., going 0.5 miles to road coming in on left.

4.2 Make sharp left. Go 0.6 miles (passing lower City Brook on left) to junction with Castle Rd.

4.6 Make sharp left onto Castle Rd., ascend hill 0.4 miles to Farrington Rd. (dead end).

4.7 Take left onto Farrington Rd. and immediately park near bridge crossing City Brook. STOP 2.

STOP 2 City Brook

After disembarking from the cars, descend to City Brook upstream of the bridge. The section downstream is one of the most beautiful exposures of the Black River, Selby, Napanee and Kings Falls Limestones in the Mohawk Valley but is off limits. Under the bridge, and continuing up section, are small benches of the Sugar River Limestone. These bedding planes are distinguished by their abundant Prasopora colonies, along with the typical Sugar River benthic fauna described in Titus and Cameron (1976). Compare the Sugar River Limestone to the Kings Falls Limestone seen at STOP 1. How does it differ? What is the evidence that it might have accumulated at slightly deeper depths? How laterally continuous are these beds? Do they exhibit the same degree of lateral lensing? Is there a change in the relative percentage of calcarenite versus calcilutite beds? The contact of the Sugar River and the Denley Limestones occurs in the small waterfall. The basal Denley seen here is similar to the basal Denley seen at the next stop (Shedd Brook) but is very different than the basal Denley at Trenton Falls Gorge.

Figure 15. An example of a compressed stratigraphic section, this one at Canajoharie Creek. The observer's feet are on the Lower Ordovician dolomites, which are unconformably overlain by limestones of the Trenton Group. The color change from light to dark marks the contact with the overlying Canajoharie Shale.

Mileage

STOP 2 (cont'd)

Here the Denley is much less fossiliferous and much finer-grained. Note the nodular limestone bedding. Bedding planes are not littered with fauna, except for an occasional trilobite and cephalopod. Continuing up the stepped benches note the abundance of calcilutite, mostly all barren. The dominant two lithologies of the Denley here are: (1) a barren calcilutite with planar bottoms and reworked (bioturbated) tops and (2) a nodular, more argillaceous calcilutite. These lithologies continue upstream until the waterfall is reached. Here, on the cliffs above the stream, the contact with the overlying Dolgeville Facies is seen. The Dolgeville is characterized by the interbedded planar calcilutite with thick interbeds of shale (see Figure 15). This City Brook section is interesting because it records a very rapid, non-gradational facies change in the Sugar River/Denley contact. It also is unusual in that the Denley here is such a deep water deposit. Examination of the limestone beds reveals a dominance of planar laminations interpreted as Td and structureless, bioturbated micrite interpreted as Td'. While at this stop you should ponder the nature of the facies change from the Sugar River to Denley. Do you think it's the result of lateral facies mosaicing accompanying gradual transgression, or, could it be the result of a rapid drop of the fault block, drowning the shelf?

5.2 Return to cars and retrace steps, descending Castle Rd. 0.5 miles to Rt. 28.

7.8 At intersection of Castle Rd. and Rt. 28, turn right towards Newport, going 2.6 miles to flashing light in town of Newport.

7.9 Turn left at flashing light, going 0.1 miles and crossing West Canada Creek.

8.0 At T intersection, go left.

9.2 Go 1.2 miles and ascend hill.

9.4 Park car over crest of hill. STOP 3.

Mileage

STOP 3 Shedd Brook

After parking at the top of the hill, cross the road and descend to the stream bed. Walk down to the base of the section. Exposed at the base of Shedd Brook is the upper Kings Falls Limestone. It should look similar to the upper part of the section at Buttermilk Creek, that is, coarse calcarenite to calcirudite beds which exhibit lensing. All of the Sugar River Limestone is exposed in this stream cut, and comparisons can be made between the Kings Falls and Sugar River. Study the Sugar River lithologies and bedding styles to draw some conclusion about environment of deposition relative to wave base. This is an important point because the Sugar River is interpreted to represent "normal" carbonate accumulation below wave base. If this is what "normal" below-wave base sedimentation looks like, what interpretations can be made about the overlying Denley Limestone? The contact of the Sugar River and the Denley Limestone occurs at the top of the waterfall. Examine the upper horizons of the Sugar River. Note the abundance of relatively unfossiliferous calcilutite beds with shale interbeds. How gradational are the Kings Falls to lower Sugar River to uppermost Sugar River facies? The top of the waterfall represents the last of the fossiliferous calcilutite and calcarenite beds in this section. The percentage of interbedded shale is also increasing. A bentonite horizon is present in the bushes on the left side of the stream. There is a long bench in the stream bed of the nodular barren calcilutite beds with thick shale interbeds of the Denley Limestone. This should look similar to the Denley seen at the previous stop. Up stream at the bend in the brook, Dolgeville beds of planar carcilutite and shale are seen. Passing under the road you continue to walk on nodular bedded, calcilutite horizons of the Denley Limestone. About 50 feet above the road on the right side of the stream, there is a small exposure of interbedded nodular calcilutite and planar calcilutite beds with bioturbated tops, also of the Denley Limestone. Two more bentonite horizons are located in this small cliff. The stratigraphic section seen along Shedd Brook is very similar to that in City Brook but it is worth walking this section to demonstrate:
(1) the gradational Kings Falls to Sugar River section;
(2) interbedded bentonite horizons.

10.8 Return to cars, turn around carefully on hill, descend hill to intersection.

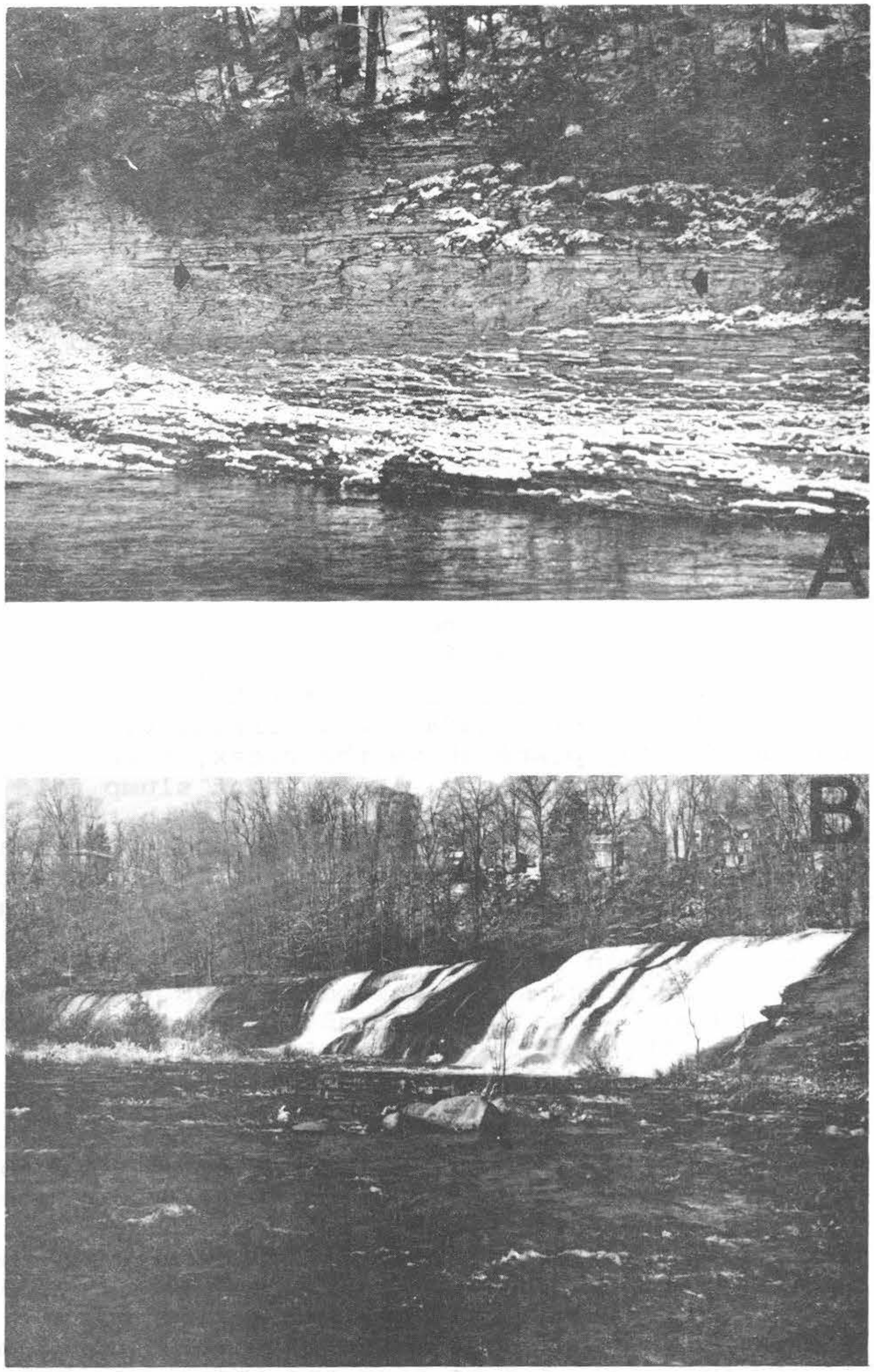

Figure 16. **A.** Exposure of a slump fold horizon (between arrows) in the Denley Limestone on West Canada Creek. **B.** Exposure of the Denley Limestone along West Canada Creek illustrating the large degree of lateral continuity of beds (houses above waterfall for scale).

Mileage

11.1 Turn left, recross West Canada Creek to flashing light.

14.8 Go left (north) on Rt. 28 to Poland.

21.5 Continue north on Rt. 28 to unmarked triangular intersection. Go straight off Rt. 28 to stop sign.

22.5 Make right and go 1 mile to intersection. West Canada Creek on right, access to Trenton Falls Gorge is ahead.

25.0 Go left, following paved road into Prospect.

25.2 At stop sign in village of Prospect, go right and descend hill to bridge.

25.3 Park on far side of bridge. STOP 4.

STOP 4 Prospect (needs special permission from Niagara Mohawk Power Corp.)

After parking the cars across the bridge, descend the cliff to West Canada Creek carefully. Standing on the bedding plane above the creek, turn around and examine the cliff face. A prominent slump fold horizon is visible (Figure 16). Note that the slump fold can be traced laterally to an undisrupted horizon of calcarenite. The nose of the fold is characterized by brecciated clasts of limestone so the sediment was fairly lithified at the time of emplacement. Paleoslope measurements on this and other slope indicators (aligned fossils) indicate a paleoslope of S80E (Cisne and Rabe, 1978). Note the sediment in which the slumping occured. This is the Denley Limestone, but a very different Denley than what has been seen at Stops 2 and 3. Note how fossiliferous some of the calcarenite and calcirudite beds are. The strophomenid Rafinesquina is especially abundant, as is Prasopora. Interbedded with this fossiliferous facies of the Denley are lithologies we have already seen: nodular, bioturbated calcilutite and calcilutite with planar bases and bioturbated tops (Td'). Also present are beds of graded skeletal debris (Ta), and horizontally laminated skeletal debris (Tb). Looking upstream a wide waterfall can be seen and individual beds can be traced across this exposure. Beds which exhibit this degree of lateral continuity, with negligible change in thickness could not have accumulated near wave base.

Mileage

25.6 Return to cars, turn around, return to intersection in village of Prospect.

28.2 Make left and return to intersection by West Canada Creek and Gorge access.

34.8 Go right and return to Rt. 28 south to Poland.

38.6 Continue on Rt. 28 to flashing light in Newport.

42.9 Continue south on Rt. 28 to Middleville and junction with Rts. 28, 29, and 167.

55.6 Turn left onto Rt. 29 and follow to Dolgeville.

55.7 At stop sign in Dolgeville, turn left (staying on Rt. 29) to bridge. Go straight across bridge and make immediate (poorly marked) right onto Dolgeville Extension Road.

56.1 Go along Dolgeville Extension Road, with East Canada Creek and the Daniel Green Factory on your right.

56.8 At T intersection, turn left onto Dolgeville Ave. and go 0.7 miles. Park on hill before guard rail. STOP 5.

STOP 5 Dolgeville

This stop along East Canada Creek in Dolgeville is made for examination of the basinal shales. Parking on the hill and descending to the stream below the dam, the calcareous turbidites and interbedded shale horizons of the Utica shale are exposed. The calcareous turbidites are identifiable by their buff yellow weathering. Tc and Td horizons are the only Bouma Units present. The thick shale interbeds contain numerous good graptolites. Based on the Bouma Units present within the turbidite horizons and the thickness of the interturbidite deposits, it is possible to interpret this section as representing a distal turbidite facies. The source of the calcareous horizons is the foundered shelf (Dolgeville Facies) intertonguing with the basinal terriginous muds. Continuing down to the pool at the base of the waterfall, drag folds associated with the Little Falls Fault are visible.

57.3 Return to cars. Ascend hill to turn around.

Mileage

58.5 Descend hill into Dolgeville.

58.9 Turn right onto Dolgeville Extension Rd. and return to bridge.

66.1 Turn left onto Rt. 167 and follow south. Lunch stop at roadside park. Stay on Rt. 167S through Little Falls until Rts. 5 and 167 divide.

68.3 Stay on Rt. 167S, crossing Barge Canal, to junction with Rt. 5S. Go east (left) on Rt. 5S.

69.2 Passing Kings Falls, Sugar River, and Utica lithologies on right and left of road (abandoned quarry on left).

83.8 Continue east on Rt. 5S to Fort Plain.

83.9 At junction of 5S and 80, take a dog-leg left, staying on 5S.

88.0 Continue into Canajoharie and junction of Rts. 5S and 10.

88.1 Go right into triangular square and traffic light. Go right at traffic light and make immediate right onto Moyer St.

88.5 Go up Moyer St. hill and make right onto Floral Ave.

88.7 Proceed to end of Floral St. and park. STOP 6.

STOP 6 Canajoharie Creek

Descend to the creek from the parking lot. The creek bed is Chuctanunda Creek Dolostone of Lower Ordovician age. The lower cliff face contains the unconformity between this dolostone and the interbedded limestone and shales of the Kings Falls Limestone. Looking up the cliff the Kings Falls is overlain by the Canajoharie Shale (Figure 15). In other words, all of the Lower Trenton is missing, with the exception of a thin section (15 feet) of Kings Falls, and all of the upper Trenton is missing. Cameron (1971) described this section of limestone as Sugar River, but noted that it represents a shallower water environment than the Sugar River seen to the northwest (Stops 2 and 3). This unit can be better described not by the fossil assemblage it contains,

Mileage

STOP 6 (cont'd)

but by the lithofacies present. The bedding style is identical to that of the Kings Falls seen earlier; laterally discontinuous beds exhibiting lensing and cross laminations. Looking at this section you can ask yourself: How can wave-reworked limestones and basinal shales be juxtaposed with no intervening deeper water limestones? Why are there no lower Trenton units between the Kings Falls and the Lower Ordovician dolomites? Do these abrupt facies changes represent lateral mosaicing produced by sea level changes or does it seem more probable that movement on a syn-depositional block fault could generate this type of sequence?

88.9 Return to cars. Drive out Floral St. to intersection with Moyer St. Turn left.

89.0 Descend Moyer St. hill. Make left into triangular square and traffic light. Make right onto Rt. 10.

89.3 Go to intersection of Rts. 10 and 5.

94.6 Go left (west) on Rt. 5 to a sign for the Palatine Church.

94.7 Take a right onto Old Mill Rd., cross Caroga Creek and part. STOP 7.

STOP 7 Caroga Creek

After parking, descend to the creek below the bridge under Route 5. The section below the bridge and downstream are undifferentiated Black River deposits. Depending on the height of the stream, variable amounts of rock are exposed here. At low stage, aphanitic dolostones with birdseye structures are visible. The section between the two bridges has many covered intervals but ledges of coarsely crystalline limestone outcrop and are interpreted as Kings Falls. Under the second bridge ledges of laminated calcarenites outcrop, exhibiting planar tops and bottoms and lacking fossils. Upstream of these are beds of the bioturbated, barren calcilutites. These last two lithologies are characteristic of the Denley Limestone as seen on City and Shedd Brooks. A covered interval occurs above this and below the cliff with Utica Shale. This section then, is another

Mileage

STOP 7 (cont'd)

thinned section of Trenton. Both the lower Trenton and upper Trenton units are missing or greatly reduced in thickness. Because the quality of this exposure is not equal to that at Canajoharie Creek, it is not as spectacular, but the significance of the facies changes is equally important. Note that as one progressed east for the last two outcrops, the magnitude of the variation in stratigraphic sections became more significant. This is in keeping with our moving further into the foreland basin from the stable shelf represented in the earlier outcrops.

95.0 Return to cars and continue down Old Mill Rd., past Palatine Church, to junction with Rt. 5.

108.0 Turn right (west) on Rt. 5 to Little Falls.

116.0 Continue west on Rt. 5 through Herkimer.

116.5 Take left on Rt. 28 south to Thruway.