The Trenton - Utica Problem Revisited: New Observations and Ideas Regarding Middle - Late Ordovician Stratigraphy and Depositional Environments in Central New York

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INTRODUCTION

The Middle to Upper Ordovician Trenton Limestone and Middle to Upper Ordovician black (Utica-type) shale which overlies it in New York State and Southern Ontario have been of considerable interest to geologists since the time of James Hall. This attention is due to the paleontological richness of the Trenton carbonates and early recognition of the facies equivalency of part of the Trenton with black shale deposits in the Mohawk Valley. More recently, heightened interest in Trenton-Utica stratigraphy, sedimentology, paleoecology, and tectonic processes reflects recognition that these sediments are synorogenic. The closely associated Taconic Orogeny represents an arc collision event involving subduction-related emplacement (overthrusting) of an accretionary prism (Taconic Allochthon) over the margin of the Laurentia craton. This emplacement was followed by orogenesis associated with collision, suturing, and uplift of the Vermontia Terrane (Bird and Dewey, 1970; Rowley and Kidd, 1981; Lash, 1988). This paleosetting is believed to be analogous to the present day subduction of the Australian Sahul Shelf under the Banda Arc with the Taconic basin correlating to the foredeep south of Timor. In this context, the Trenton to Utica transition records the collapse of a cratonic platform owing to subduction and thrust load-related down-bending of the craton as the orogeny proceeded. Evidence for this downbuckling is manifest in the Middle-Upper Ordovician succession in central and eastern New York as an upward- and eastward facies change from carbonate platform deposits to basinal facies.. Furthermore, numerous normal faults cross-cut the Trenton, which are believed to have been active mainly as synthetic (down to the east) and antithetic (down to the west) displacements reflecting lithospheric responses to subduction (Bradley and Kidd, 1991). Many of these faults are believed to have been active during the tectonic foundering of the Trenton shelf, resulting in a complex "patchwork" stratigraphy for upper Trenton and lower "Utica" units in the Mohawk Valley (see Cisne and Rabe, 1978; Cisne, *et al.*, 1982; Bradley and Kidd, 1991).

Ruedemann (1925), Ruedemann and Chadwick (1935), and Kay (1937, 1953) mapped Trenton and Utica deposits across this region and recognized that uppermost Trenton units (Rust, Steuben, and Hillier limestones) progressively disappeared to the east and southeast of Lowville, NY. Medial Trenton strata (Denmark Limestone) distinctly grade from richly fossiliferous carbonates at Trenton Falls (Poland and Russia members) through a belt of fossil-poor thin-bedded calcilutite facies (Dolgeville Member) to predominantly dark gray or black fissile Utica-type shale (Canajoharie Shale) near Canajoharie, New York. Lower Trenton units (Napanee, King's Falls, Sugar River Formations) were observed to remain fossil-rich across central New York. However, there is an eastward thinning of these lower strata east of Dolgeville, NY, possibly due to submarine erosion. West of Canajoharie, NY the Trenton Limestone is locally missing (see Kay, 1953; Fisher, 1977; Cisne, and Rabe, 1978).

In two important publications, Cisne and Rabe (1978); and Cisne *et al.* (1982), presented results of highly refined paleoecologic work on Trenton and Canajoharie deposits using volcanic ashes (metabentonites) as correlation isochrons (Figure 1). In so doing, they were able to subdivide the Trenton into thin, time-constrained divisions which could be followed eastward into black shale. Quantitative gradient analysis of fossil associations indicated that this was no steady eastward-sloping ramp; normal faults were believed to have been active in latest Trenton time such that a horst and graben topography was developed and submarine fault scarps existed locally (Cisne and Rabe, 1982).

Controversies concerning Trenton, Canajoharie, and Utica stratigraphy in New York arose early in the study of these units. Although some divisions can be correlated over long distances, abrupt facies changes, losses of units, and appearances of units over small distances have long been noted (see discussions in Ruedemann, 1925; Ruedemann and Chadwick, 1935; Kay, 1937, 1953; Cisne, *et al.*, 1982; Titus, 1986, 1988). The most prominent problem involves Trenton and lower Utica Shale stratigraphy in the interval between Trenton Falls and Middleville, a 16 km-wide region northeast of Utica characterized by thick surficial cover and incomplete sections. Another problem is the meaning of sharp lithologic contacts in sections where bioclastic Trenton carbonates are abruptly overlain by dark argillaceous strata (Canajoharie Shale, Utica Shale) or by sparsely fossiliferous ribbon limestones (Dolgeville facies). The presence of such contacts has long been noted, but there is disagreement concerning their extent, age, and significance (see discussions in Kay, 1953; Riva, 1969; Fisher, 1977, 1979; Cisne *et al.*, 1982; Titus, 1990). Very recently, parts of the metabentonite correlation scheme of Cisne and Rabe (1978) have been called into question owing to new "fingerprinting" correlation techniques for ash identification. This problem, coupled with the unstable existing stratigraphies of Kay (1953), Fisher (1977), Cisne *et al.*(1982), and Titus (1990), poses the need for continued field study of these rocks but with the application of new approaches and perspectives.

The interest of the present authors of the Trenton-Utica problem stems both from our interest in the relationships of black shales in foreland basins to surrounding facies and from our use of stratigraphic event-horizons in establishing refined correlations in the Silurian and Devonian as well as for Upper Ordovician strata of Ontario and northcentral New York. Important to this approach is the recognition of sedimentary cycles of varying magnitude in these younger deposits which owe their origin to eustatic sea level changes (Brett and Baird, 1985; Brett *et al.*, 1990b). Also relevant to Trenton mapping is the discovery of widespread submarine discontinuities of varying magnitude which define mappable stratigraphic packages of great lateral extent (Brett and Baird, 1986a; Brett *et al.*, 1990a, b). It is our goal to define, firstly, the widespread major discontinuities both within- and bounding the Trenton, Canajoharie, and Utica, and secondly, the sedimentary cycles and distinctive cycle-capping condensed units within these large discontinuity-bounded packages. Preliminary results of this work are presented below.

We are particularly attracted to the sharp erosional bases of the Ordovician black shales. Our work on Late Ordovician, Silurian, and Devonian black shale-roofed erosions contact shows that they reflect erosional processes occurring predominantly under basinal conditions of prevailing near-anoxia (Baird and Brett, 1986a, b; Baird *et al.*, 1988; Baird and Brett, 1990; Lehmann and Brett, 1991a, b). Preliminary work on Dolgeville, Canajoharie, and Utica discontinuities is presented herein; it shows that these contacts are mappable and significant. A very large and widespread discontinuity herein informally designated the "Sub-Utica Disconformity" may be an Ordovician analog of an erosional overlap surface which floors Middle and Late Devonian black shale deposits across numerous eastern states.

STRATIGRAPHIC NOMENCLATURE UTILIZED ON THIS TRIP

On this trip, we will examine primarily "middle" Trenton strata. Unfortunately, a plethora of stratigraphic nomenclature has been applied to these rocks by various workers (see Fisher, 1977; Kay, 1968, for overview). Stratigraphic schemes of different workers--and in some cases, in different publications by the same worker--are typically contradictory. Furthermore, some proposed lithostratigraphic units were based solely on biostratigraphic marker horizons, while

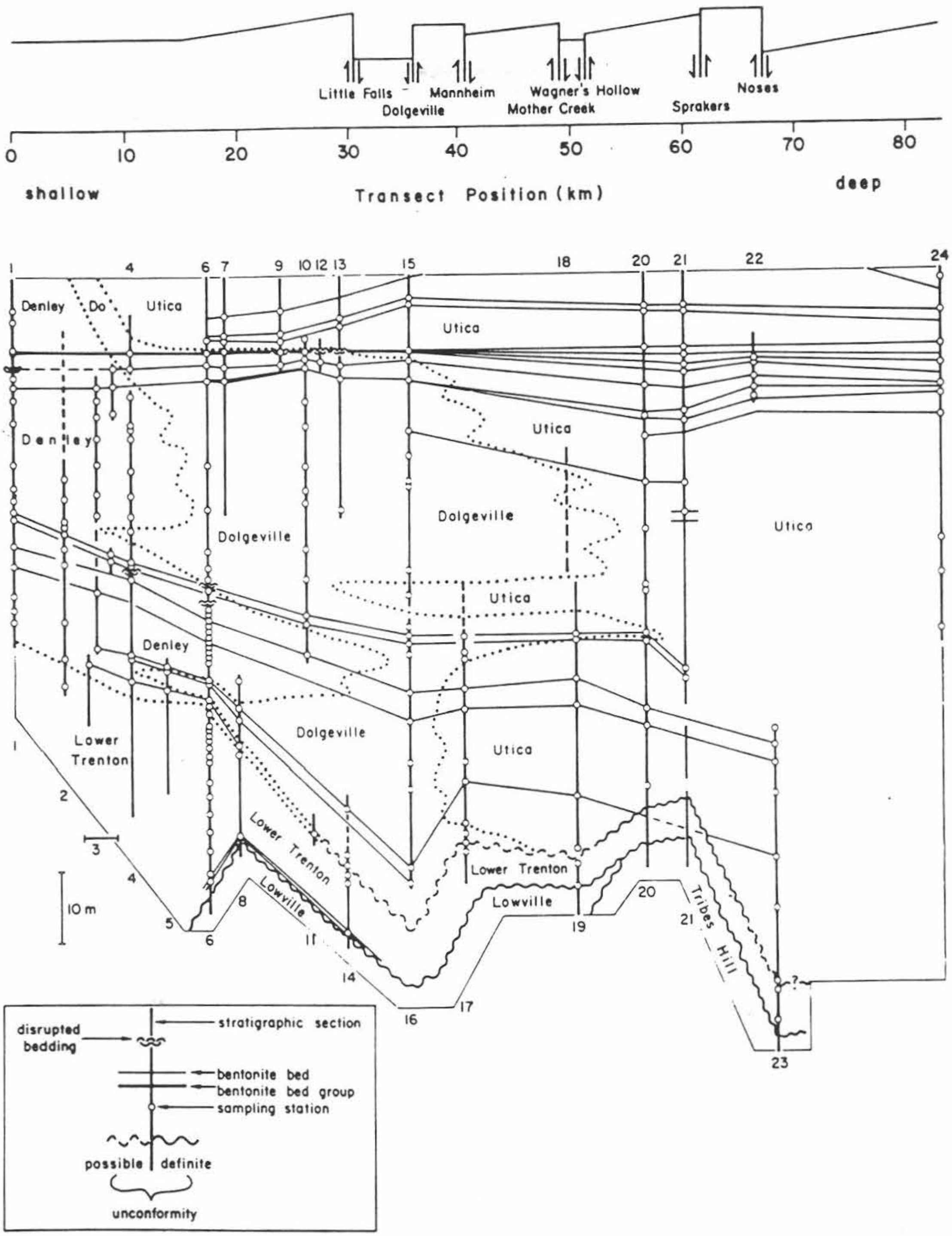

Figure 1. Stratigraphy of the Trenton Group and equivalent basinal facies based on work of Cisne and Rabe, 1978. Trenton sections as well as those for overlying and underlying units are represented by: 1 - Trenton Falls; 2 - Gravesville-Mill Creek; 3 - Poland; 4 - Rathbun Brook; 5 - Shedd Brook; 6 - Buttermilk Creek, Wolf Hollow Creek ("City Brook"), and creeks near the County Home; 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 - Canajoharie Creek; 21 - Flat Creek; 22 - Currytown Quarry; 23 - Van Wie Creek; 24 - Chuctanunda Creek. From Cisne and Rabe, 1978. Note absence of discontinuities in upper Denley and Dolgeville as well as abrupt Denley - Utica facies transition west of Rathbun Brook (see upper left).

some others have not been recognized outside of very localized regions. The net result of this medusoid intertwining and confusion of nomenclature is that many workers no longer attempt to recognize or utilize highly resolved lithostratigraphic units: Titus and Cameron (1976), Titus (1982, 1986, 1988), and Mehrtens (1988) do not recognize members of Trenton formations in their contributions to Trenton stratigraphy; Bradley and Kidd (1991) generally treat the Trenton Group as an undifferentiated stratigraphic unit.

We feel that a refined, unified Trenton stratigraphy, in which stratigraphic units are bounded by key event beds and lithologic deviations is essential for two reasons. First, correlation of refined stratigraphic units, along with recognition of facies changes within those units, is vital for precisely timing and understanding major tectonic and eustatic events. Second, a unified Trenton stratigraphy will enable our colleagues and us to more easily communicate ideas concerning the dynamics of the Middle/Late Ordovician foreland basin of New York and Ontario. On this trip, we apply a modified version of Kay's (1968) stratigraphic nomenclature. Definitions and descriptions of formal and informal "middle" Trenton stratigraphic units (see Table 1) follows.

Rathbun Member of the Sugar River Limestone: The Rathbun Member includes massive, ledge-forming, packstones and grainstones with few, thin shale interbeds. The lowest packstone beds of this interval contain numerous large (>10 cm) specimens of the domal bryozoan, *Prasopora*. The Rathbun is bounded at its base by more shaley Sugar River wacke- to packstones and at its top by the stratigraphically condensed City Brook bed (discussed below and under Stop 4). The Rathbun Member is 2 m thick at its type locality (Kay, 1953) and can be traced southeastward to the Little Falls area and northwestward to Gravesville. Although Chenowith (1952) did not recognize the Rathbun Member in the Black River Valley, massive upper Sugar River strata, probably correlative with the Rathbun Member, crop out in numerous stream sections in the Lowville area (66 km northwest of Gravesville). In the Lowville area, the Rathbun grainstones are approximately 2 m above a distinctive horizon of large slump folds, suggesting that the abrupt change from typical Sugar River lithology to calcilutites of the Poland may reflect tectonic deepening (see below). Southeast of Little Falls, the Rathbun is absent; these strata have probably been removed by submarine erosion.

Poland Member of the Denley Limestone: The Poland Member includes calcilutites and interbedded dark shales. These calcilutites contain fossil faunas dominated by the trilobites *Isotelus* and *Flexicalymene*, as well as orthocerid nautiloids. Tops of beds show variable degrees of burrowing. An intensely bioturbated pack- to wackestone, the City Brook bed (*Trocholites* Bed of Kay, 1953), defines the base of the Poland and is exposed from the Trenton Falls area to the vicinity of Countryman, New York. Observations by the present authors show that the supposedly diagnostic coiled nautiloid *Trocholites* is rare. As a result, we herein informally designate this layer as the City Brook bed for the excellent exposure on Wolf Hollow Creek (City Brook) just above City Falls (see Stop 4). Southeast of Little Falls, the City Brook bed suffers the same fate as the Rathbun Member: it is cut out by erosion. The City Brook bed is apparently correlative with the Camp Member (basal Denley Limestone) of Chenowith (1952). If this is true, the Camp Member (which would have precedence over the name "City Brook bed") retains a uniform thickness (0.7 m) from City Brook to Lowville but then thickens to 3.5 m at Sackets Harbor (Chenowith, 1952), 55 km northwest of Lowville. The City Brook bed is abruptly overlain by variably fossiliferous micrites and interbedded dark shales, the more typical Poland lithology. This lithology is laterally persistent; an abrupt "kick" into Poland calcilutites is easily recognized in outcrops from Lowville to Little Falls, a distance of 97 km. Northwest of the Lowville area however, the calcilutites grade into bioclastic limestones (Chenowith, 1952). This abrupt vertical transition from storm-dominated shelf deposits (Sugar River Limestone) to deeper shelf deposits (Poland Member) may record an episode of tectonically-induced subsidence which was accommodated by movement along faults in the Lowville - Copenhagen region (Lehmann and Brett, 1991b). From

<table>
<tr><th colspan="2">Kay, 1953</th><th colspan="2">Kay, 1968</th><th colspan="3">This paper</th><th>Key markers</th></tr>
<tr><td rowspan="2">Cobourg</td><td>Steuben Mbr.</td><td colspan="2">Steuben Ls.</td><td colspan="3">Steuben Ls</td><td>Abrupt facies change</td></tr>
<tr><td>Rust Mbr.</td><td rowspan="7">Denley</td><td>Rust Mbr.</td><td rowspan="7">Denley</td><td colspan="2">Rust Mbr.</td><td>Erosional contact</td></tr>
<tr><td rowspan="6">Denmark</td><td rowspan="4">Russia Mbr.</td><td rowspan="4">Russia Mbr.</td><td rowspan="4">Russia Mbr.</td><td>High Falls Tongue</td><td>Abrupt facies change</td></tr>
<tr><td>Brayton Corners Div.</td><td>Discontinuity/ erosional contact</td></tr>
<tr><td>Wolf Hollow Div.</td><td></td></tr>
<tr><td>North Gage Rd. Bed</td><td>Discontinuity</td></tr>
<tr><td>Poland Mbr.</td><td rowspan="2">Poland Mbr.</td><td colspan="2">Poland Mbr.</td><td>Lag debris</td></tr>
<tr><td>Trochelites Bed</td><td colspan="2">City Brook Bed</td><td>Abrupt facies change/ discontinuity</td></tr>
<tr><td rowspan="2">Shoreham</td><td>Rathbun Mbr.</td><td rowspan="2">Sugar River</td><td>Rathbun Mbr.</td><td rowspan="2">Sugar River</td><td colspan="2">Rathbun Mbr.</td><td>Abrupt facies change</td></tr>
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Table 1: Stratigraphic nomenclature utilized on this field trip and correlative nomenclature of Marshall Kay.

Gravesville to Kast Bridge, the calcilutitic Poland is capped by the North Gage Road bed, which marks the base of the overlying Russia Member.

Wolf Hollow Division, Russia Member of the Denley Limestone: The Wolf Hollow division includes nodular calcilutites to wackestones. It is marked by intervals of poorly bedded, conspicuously nodular, muddy carbonate which contain abundant three-dimensional nautiloid and endocerid steinkerns, as well as the trilobites *Isotelus* and *Flexicalymene*. The basal North Gage Road bed forms a 0.2 m ledge in its type locality (Rathbun Brook). This bioturbated packstone is recognizable from Gravesville to Middleville. However, correlation of this bed to Trenton Falls is only tentative. At Trenton Falls, a 0.7 m thick, shale-poor interval of wacke- to packstone crops out just above Sherman Falls. This resistant interval occupies approximately the same stratigraphic position as the North Gage Road bed, although, admittedly, the facies relationship between the resistant interval in the lower high falls of Trenton Falls and at Rathbun Brook (see Stop 3) is not entirely convincing. From Trenton Falls to Rathbun Brook, the Wolf Hollow division retains a uniform thickness (approximately 16 m) of cyclical progressions of tabularly to nodularly-bedded limestones. At Wolf Hollow Creek (City Brook); however, these strata are only 5.5 m thick. We attribute this thinning to stratigraphic condensation and submarine erosion. Two particularly nodular horizons thin dramatically between Rathbun Brook and Wolf Hollow Creek; the lower of these nodular horizons is capped by a carbonate conglomerate at the latter locality, supporting a submarine erosion hypothesis.

Brayton Corners Division, Russia Member of the Denley Limestone: In the Trenton Falls-to-Newport area, Wolf Hollow strata are disconformably overlain by an interval of well sorted calcisiltites to calcarenites and interbedded shales. We refer to this interval as the Brayton Corners division. It is 6 m thick at Trenton Falls and thins to 3.0 meters by Rathbun Brook. At Trenton Falls the the upper 3 m of this interval differs somewhat from the typical Brayton Corners lithology containing thin calcilutites, a few thin grainstones, and a 1 m thick amalgamated bed of nodular packstone. At Wolf Hollow Creek, the Brayton Corners division is represented by a 1.5 m interval of graded calcisiltites to calcilutites which contain phosphatic sand at their bases.

High Falls Tongue of the Dolgeville, Russia Member of the Denley Limestone: At Trenton Falls, the Brayton Corner lithology grades into a 4 meter interval of predominantly calcilutites and interbedded shales (Dolgeville lithology). The uppermost 0.5 m of the High Falls Tongue is calcarenitic and shows soft sediment deformation. This High Falls Tongue of the Dolgeville is disconformably overlain by basal Rust strata.

Rust Member, Denley Limestone: In the Trenton Falls-to-Poland area, a distinctive soft sediment deformed horizon of the uppermost Russia is erosionally truncated and is overlain by a 15 cm thick stratigraphically-condensed, amalgamated bed. The lower 12 cm of this bed is graded but fairly well sorted calcarenite. The top of this calcarenite is irregular and pitted, suggestive of submarine erosion. Overlying this calcarenite, and also filling erosional pits and crevices, is rusty-weathering calcareous silty mudstone. Abundant large molds of the brachiopod *Onniella* mark the top of this bed, which is, in turn, overlain by a 3 cm thick metabentonite. This volcanic ash is overlain by a 1 m thick interval of Dolgeville facies. Unlike typical Dolgeville, however, these calcilutites contain large vertical burrows. The interbedded calcilutites and shales are overlain by 22 m of more typical Rust lithology: nodular, bioturbated pack- to wackestones, intercalated with shales and rich in the brachiopods *Onniella* and *Rafinesquina? deltoidea*. Although Rust strata are typically poorly bedded, wave-rippled tabular beds are present and indicate sediment deposition within storm wave base. Three meters above the base of the Rust, strata are brecciated and slump folded; this is the "lower disturbed zone" of Prosser and Cummings (1897). Above the 22 m interval of typical Rust lithology is a 2.5 m interval of tabular, fossiliferous calcilutites and calcisiltites with interbedded shales. These somewhat Dolgeville-like strata contain exceptionally well preserved crinoids and trilobites and are probably correlative with the famed Rust Farm quarry beds of Walcott (1875 a, b, c, 1876, 1881). These finer-grained carbonates are overlain by 11.5 m of typical Rust lithology; the middle third of these upper Rust strata show severe slump folding ("upper disturbed zone" of Prosser and Cummings, 1897). Slump folding in the lower and upper disturbed zones are other possible correlatives of slump-folded upper Dolgeville seen at Stops 5, 6, and 7. At Stop 1, we will examine the fossiliferous calcilutites and the upper disturbed zone. The Rust strata are overlain by Steuben calcarenites, which lack interbedded shales. To the northwest of Trenton Falls, Rust shales die out, and differentiating Rust and Steuben strata is more difficult. However, the disturbed zones, as well as some distinctive fossil beds, carry through to at least Lowville, allowing correlation of these strata.

Steuben Limestone: The Steuben Limestone comprises thick beds of crinoidal grainstones. Nine meters of these strata are exposed at Trenton Falls; 18 m are exposed northwest of Booneville, where the strata have not been erosionally truncated. Some bed tops show two-dimensional wave ripples and interference ripples indicating sediment deposition near or above fairweather wave base. In the Trenton Falls area (and at South Trenton, Stop 1), Steuben grainstones are disconformably overlain by upper Utica black shales.

THE RATHBUN BROOK PROBLEM: THE RUST MEMBER VANISHING ACT

In the vicinity of Trenton Falls near Prospect, New York, the Middle Ordovician Trenton Limestone Group is approximately 130 meters thick, of which the upper 60% of the total succession is actually exposed at the falls (see Stop 1). In this region the lower 45 meter interval (Napanee, King's Falls, Sugar River Limestones) is dominantly calcilutites grading upward to tempestitic grainstones and packstones. The middle 70 meter interval is represented by the Denley which is subdivided into three members: Poland, Russia, and Rust (see Table 1). At Trenton Falls, 40 m of Poland and Russia strata are exposed (Kay, 1953). These shaley, nodular strata are dominantly a lower energy distal tempestitic wackestone to lime mudstone facies. The top five meters of the Russia Member contains a thin-bedded calcilutite interval recording low energy deeper subtidal conditions. The Russia, in turn, is overlain by the Rust Member which comprises 30 m of rubbly fossiliferous wackestones, packstones, and grainstones.

The upper regressive part of the Trenton Group (Steuben Limestone) is represented by up to 18 m of massive, high energy packstones and grainstones. Still higher Trenton deposits (Hillier Limestone) are present above the Steuben in the Watertown-Boonville area, but these beds are overstepped to the southeast by a discontinuity flooring the black, laminated and organic-rich Utica Shale and stratigraphically higher flysch. At South Trenton (Stop 1) the black Utica Shale yielding the Upper Ordovician graptolite *Climacograptus pygmaeus* directly overlies a largely-beveled Steuben section (Figures 7, 9).

Further southeast, near Poland, New York, the Steuben is apparently absent, but at least 25-30 m of Rust Member is recognized in sections north of the village. The lower units, although poorly exposed, appear little changed. Even to the south of Poland (1.5-2.5 km northwest of Rathbun Brook), some Rust is seen in sections. However, at Rathbun Brook (Stop 2) and at all sections southeast of there, none of the Rust Member is observed (Figure 2). On Rathbun Brook 33 m of Denley Limestone (17 m of Poland Member, 16 m of Russia Member) are followed by a 10 meter concealed interval. The concealed interval, in turn, is followed by 21 m of black Utica-type shale which contains numerous calcilutitic limestone bands in the lowest 5 to 7 m of the section (Figure 2). This black shale unit,which yields graptolites of the upper *C. spiniferus* zone (see zonation of Riva, 1969), is distinctly older than basal Utica to the west,.

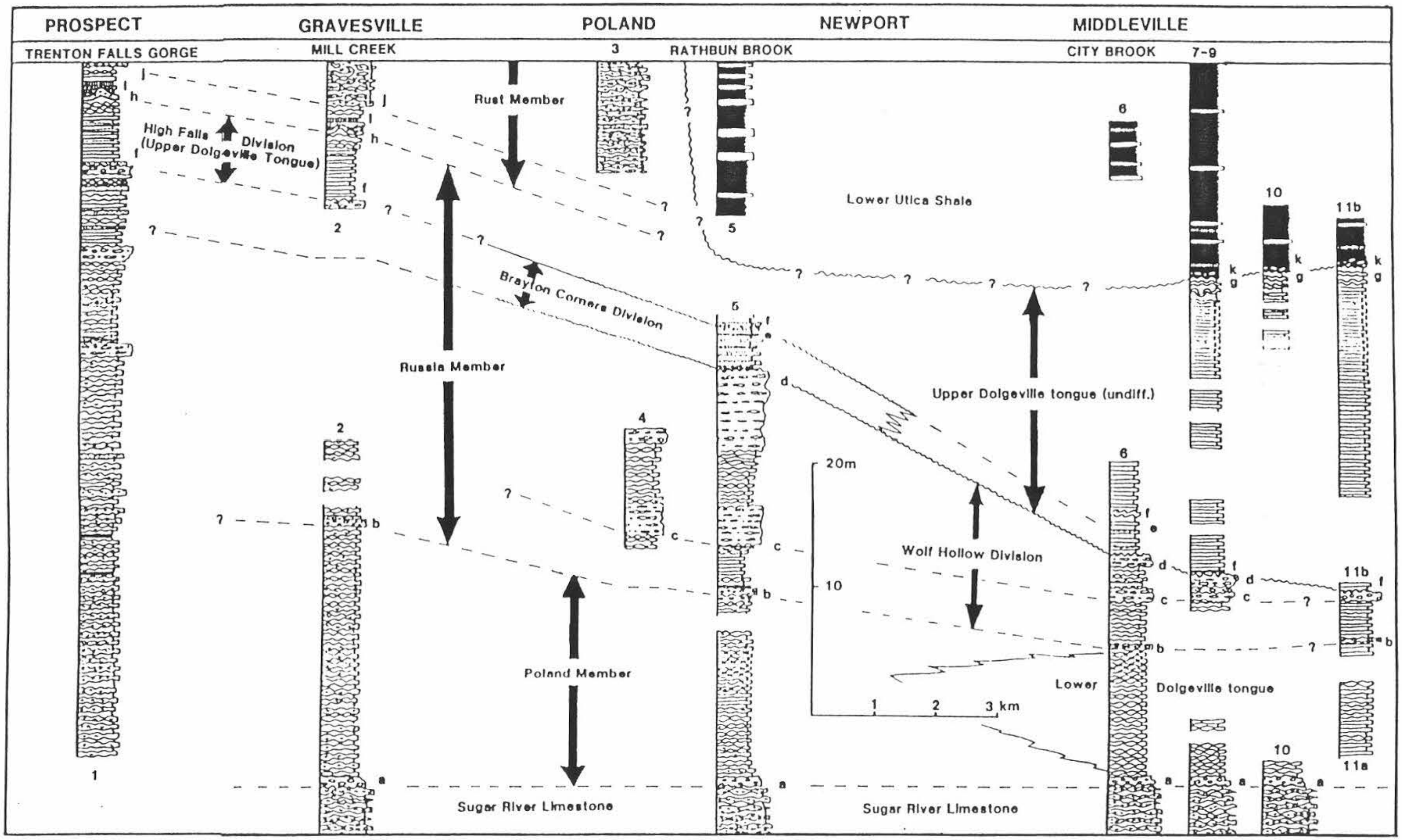
Southeast of Rathbun Brook is a 9 km wide region of concealed Trenton deposits which ends at the classic "City Brook" section at the southwest end of Wolf Hollow Creek (Stop 4) north of Middleville, New York. At this locality, a 12 m Poland section is abruptly overlain by 8 m of sparsely fossiliferous "ribbon limestone" deposits of the Dolgeville Member with a distinctive corrosional discontinuity at the contact (Kay, 1953: Figure 2). At this section, upper Dolgeville and higher units are concealed. However, at the "County Home-South" section of Kay (1953) south of Middleville, approximately 18 meters of Dolgeville are observed above 17 meters of "Poland Member" and below black shale of the lower/middle Utica ("Upper Canajoharie Shale" of Kay, 1953 (see Figure 3) which yields the graptolite *C. spiniferus* (Kay, 1953; Riva, 1969). At this section, a conspicuous debris layer containing Dolgeville-type micritic intraclasts is observed at the base of metabentonite-rich and phosphatic hash-rich lower Utica beds. Riva (1969) believes a discontinuity is present here (Figure 4), although other authors (Kay, 1953; Cisne *et al.*, 1982; Titus, 1988) do not show any at this level (Figures 1, 3). This contact will be seen on this trip at Stops 5, 6, and 7.

The central problems posed by stratigraphic changes occurring near Rathbun Brook are: 1) the southeastward disappearance of 30 m of Rust strata across a distance of a few kilometers, 2) the southeastward appearance of the lower/middle Utica (*C. spiniferus*-bearing) black shale, and 3) the seemingly sudden appearance of significantly thicker "Russia-equivalent" Dolgeville facies at localities near Norway, City Brook, and Middleville (see Figures 2, 3, 7).

EXISTING INTERPRETATION OF DISJUNCT FACIES CHANGES

Kay's (1953) interpretation for this change is shown in Figure 3; he shows the Steuben disappearing to the southeast due to beveling below Utica. Furthermore, his correlations suggest an abrupt southeastward facies change from Rust bioclastic limestone at Poland to a "Dolgeville-Utica" facies at Rathbun Brook (the micritic "ribbon" limestone-bearing, Utica-type shale above the 10-meter covered interval). This Dolgeville-Utica facies, in turn, grades to black shale (his "upper Canajoharie Shale") further southeast. Although the "Poland" interval at Rathbun closely resembles its "correlative interval" at City Brook, Kay (1953) shows the Russia part of the Denley as having dramatically transformed to Dolgeville facies at this latter section. Subsequent workers (Fisher, 1977, 1979; Cisne *et al.*, 1982; Titus, 1988) also retain some or all of these lateral facies

Figure 2. Generalized Trenton and lower Utica sections, Trenton Falls - Little Falls region based on preliminary correlations. Note the prominent eastward thinning (condensation) of the interval between Units b and d (Wolf Hollow division of present authors) between Rathbun Brook and North Creek as well as the problematic abrupt eastward disappearance of the Rust Limestone Member near Poland. Facies symbols correspond to those explained in Figure 6. Letter units include: a, City Brook bed ("*Trocholites* Bed"); b, North Gage Road bed marking top of Poland Member and base of Wolf Hollow division (see text); c, base of prominent Wolf Hollow condensed cephalopodenkalk facies; d, submarine discontinuity (corrosion surface) marking top of Wolf Hollow condensed facies and flooring Dolgeville deposits (or Brayton Corners' division at loc. 5); e, nodular phosphate-rich concentration marking top of Brayton Corners division at localities 5 and 6; f, base of ribbon limestone facies of upper Dolgeville Member; g, regionally widespread levels of contorted Dolgeville Strata below top - Dolgeville disconformity (Thruway Discontinuity); h, folded limestone bed which marks the base of the Rust Member (*sensu* Kay, 1953); this unit is partially beveled and is overlapped by grainstone beds; i, conspicuous metabentonite and 0.2 meter of overlying dark, graptolite-and-ash-rich shale; j, base of typical rubbly, fossiliferous Rust Limestone deposits; k, corrasional discontinuity (Thruway Discontinuity) flooring lower Utica Shale. Localities include: 1, Trenton Falls Gorge; 2, Mill Creek at Gravesville; 3, creek section south of Brayton Road; 4, creek section paralleling Strumlock Road north of Brayton Corners; 5, Rathbun Brook; 6, Wolf Hollow Creek ("City Brook") east of Old City; 7-9, composite section for east-flowing tributaries of West Canada Creek near the old County Home (loc. 7,8) and northwest of Countryman (loc. 9); 10, creek northeast of Norway; 11a, North Creek east of Kast Bridge, 11b, North Creek south of Dillenbeck Corners.



PROSPECT
GRAVESVILLE
POLAND
NEWPORT
MIDDLEVILLE
TRENTON FALLS GORGE
MILL CREEK
3
RATHBUN BROOK
CITY BROOK
7-9
Rust Member
High Falls Division
(Upper Dolgeville Tongue)
Lower Utica Shale
Brayton Corners Division
Russia Member
Upper Dolgeville tongue (undiff.)
Wolf Hollow Division
Poland Member
Lower
Dolgeville tongue
Sugar River Limestone
Sugar River Limestone
20m
10
1
2
3 km
1
2
3
4
5
6
10
11a
11b

Figure 2

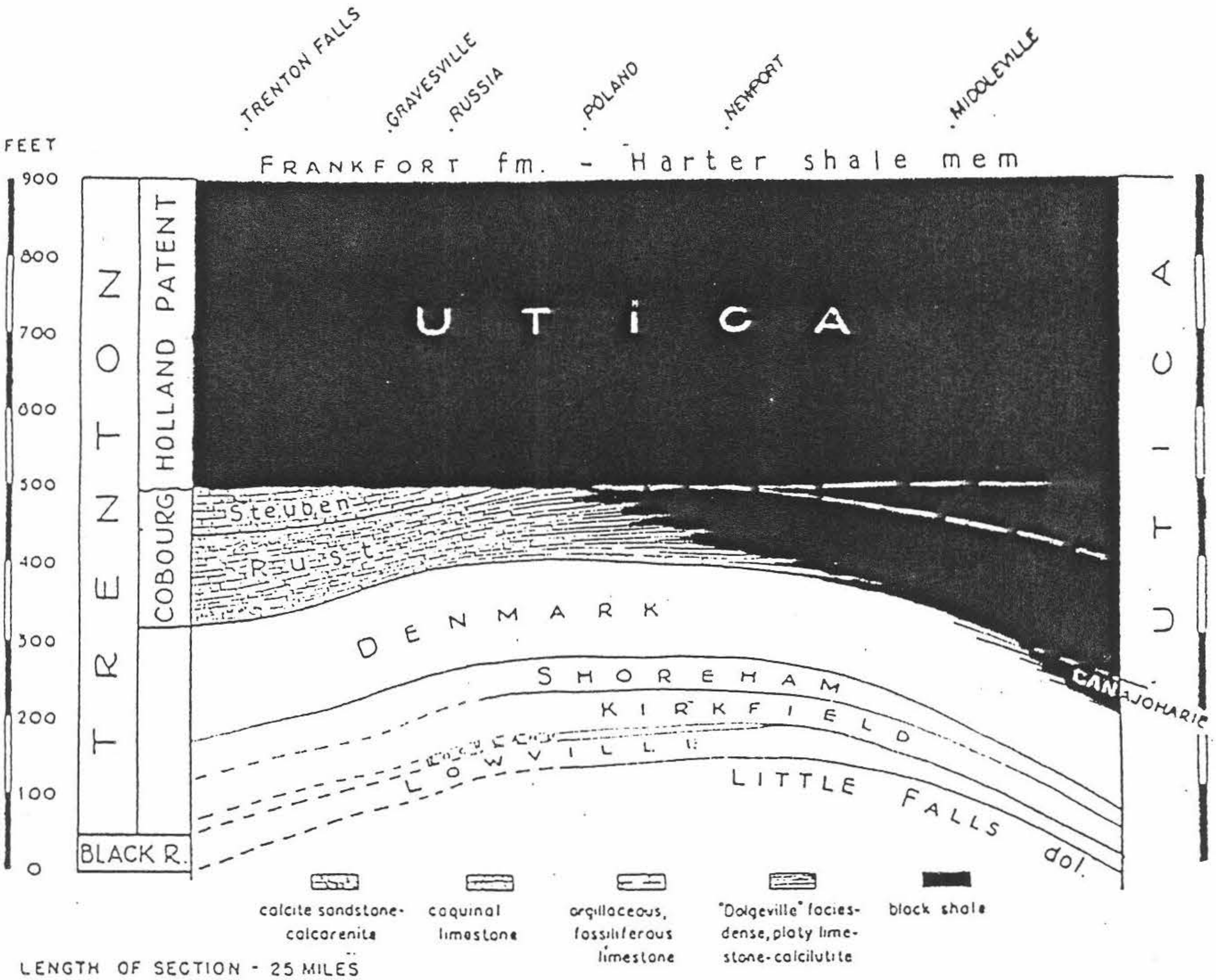


Figure 3. Inferred stratigraphic relationship of Trenton and Utica deposits based on work of Marshall Kay (from Kay, 1953). Note that uppermost Denmark Limestone (Russia Mbr.) and "Rust Limestone" grade eastward into black Utica facies across a very narrow Waltherian facies transition. Note also that the top-Trenton (Steuben-Utica) disconformity is shown to project cryptically into the Utica.

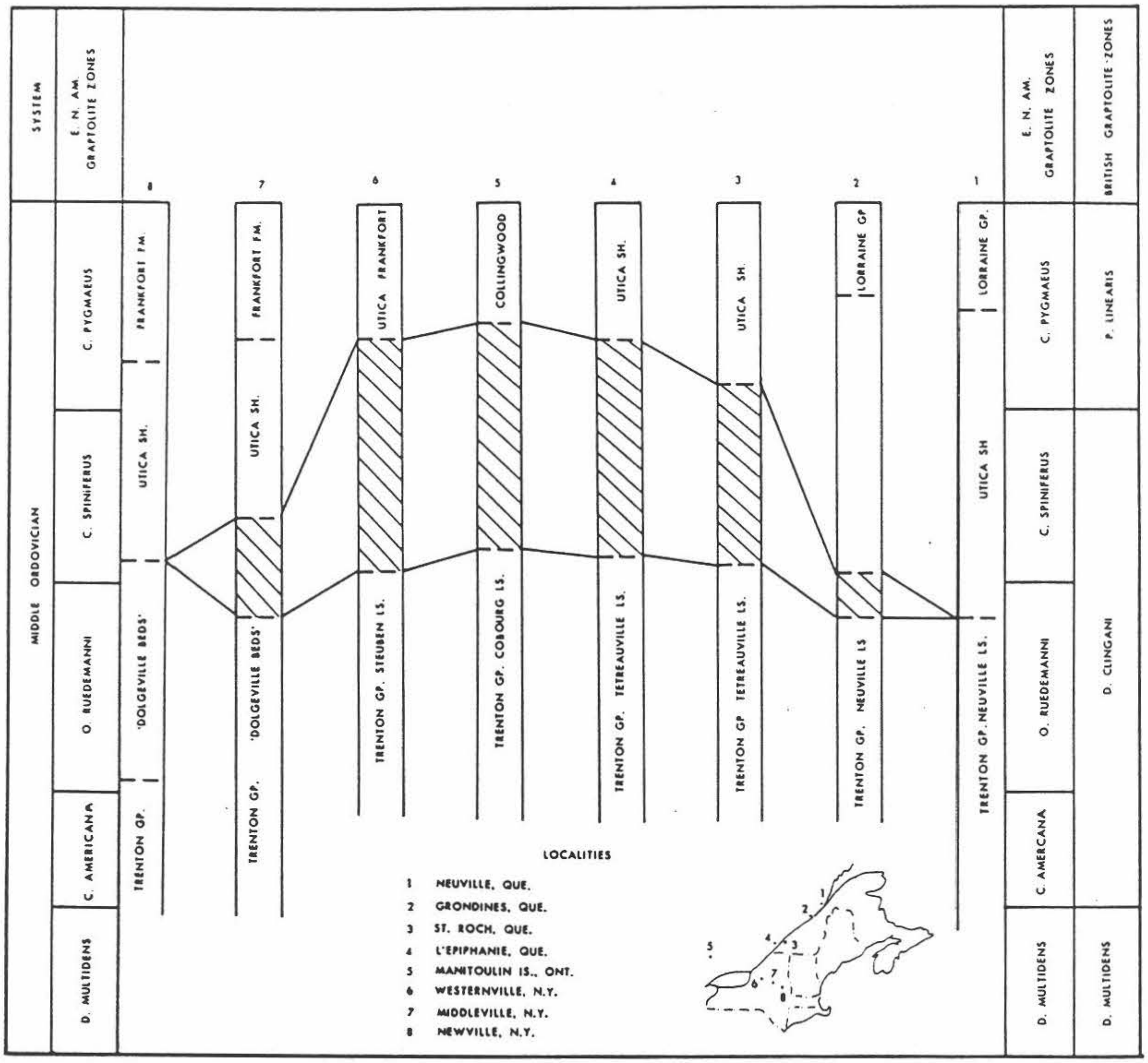


Figure 4. Chronostratigraphic diagram from Riva (1972a) illustrating a major hiatus separating Trenton carbonate deposits from basinal siliciclastic facies which overlap it. Note that this disconformity closes to continuity both northeastward across Quebec and eastward down the Mohawk Valley with the greatest gap separating the top Cobourg Limestone (upper Hillier carbonates) and the Collingwood Shale in Ontario. Yet, interestingly core and outcrop sections from the Toronto, Ontario region display an apparent gradation of facies between the Cobourg and overlying Collingwood strata; we have not recognized a Cobourg-Collingwood unconformity. This disconformity corresponds to our "Thruway Disconformity" and "Regional Sub-Utica Disconformity" discussed herein.

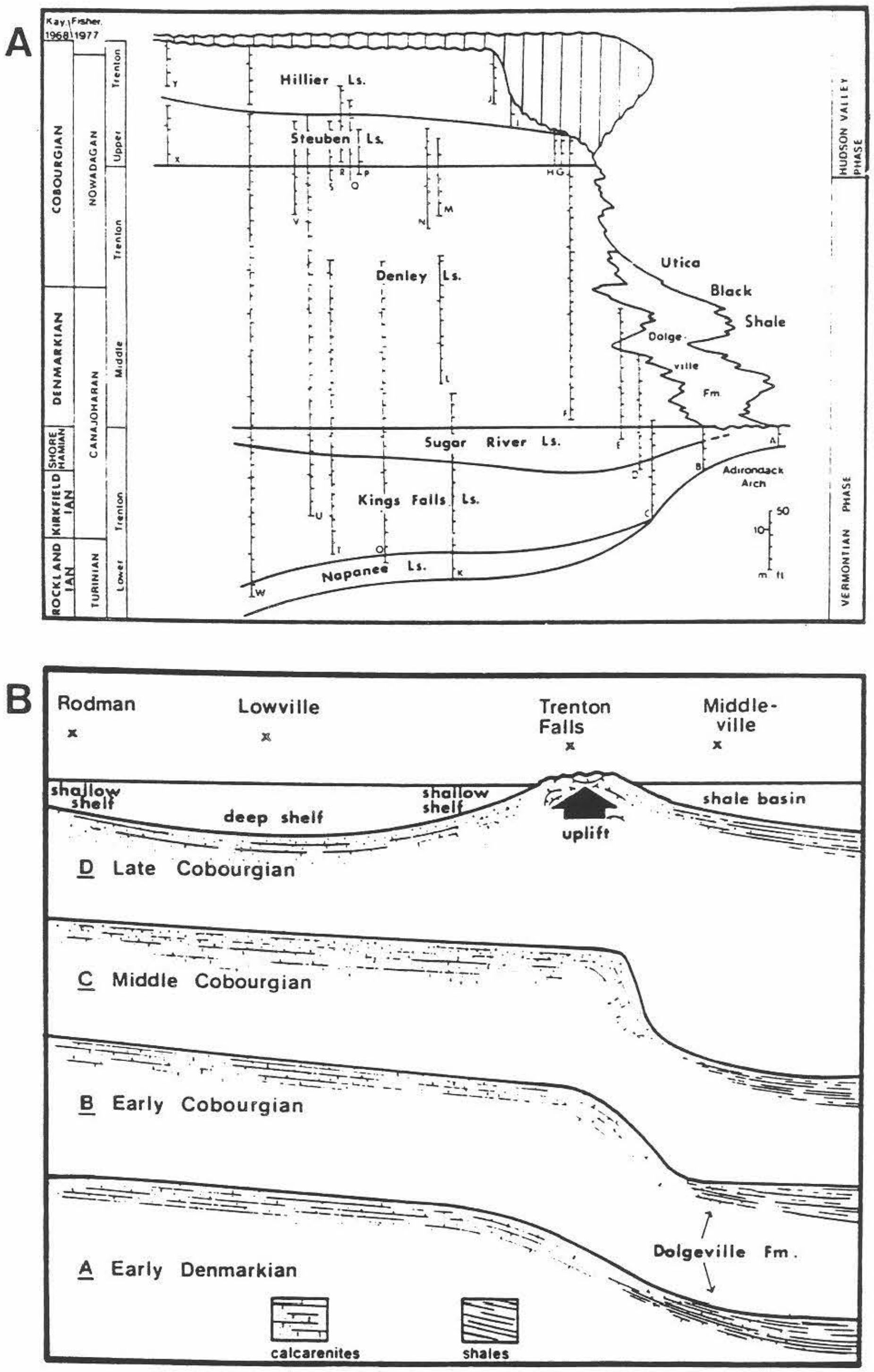


Figure 5. Late Trenton tectonism based on model of Titus (1986). a) Stratigraphy of Trenton Group; outcrops are as follows: A) Canajoharie Creek; B) Ingham Mills; C) Buttermilk Creek; D) Rathbun Creek; E) Mill Creek, Gravesville; F) Trenton Falls; G)Prospect quarry; H) Barnevald quarry; I) Big Brook, Frenchville; J) Pixley Falls; K) Sugar River, Booneville; L and M) Moose Creek; N) Roadcut, Talcotville; O) Mill Creek, Turin; P) Douglass Creek; Q) Whetstone Gulf; R) Atwater Creek; S and T) Roaring Brook; U) Mill Creek, Lowville; V) Black Creek; W) Deer River; X) Gulf Stream, Rodman. From Titus (1988). Note abrupt Denley-Utica facies boundary east of Trenton Falls (loc. F) and maximal development of top Trenton hiatus in same area. b) Evolution of the Trenton carbonate bank margin during Denmarkian (Poland-Russia) and Cobourgian (Rust-Steuben) time. From Titus (1988).

"jumps" in their stratigraphic reconstructions (see Figures 1, 5). If this correlation were correct, the width of the transition Russia into Dolgeville facies would be constrained to a few kilometers at most, and the Rust lower/middle Utica transition would be even more abrupt (Figures 2, 5).

It is possible that these abrupt "facies changes" may reflect synthetic "down-to-the-east" faulting of the type discussed by Bradley and Kidd (1991); such faults would have oversteepened the eastward-sloping submarine ramp through listric displacement, generating submarine escarpments over which storm-turbidite debris would have poured. Cisne and Rabe (1978), Cisne *et al.* (1982) as well as Mehrtens (1988) also evoke faulting as a mechanism for rapid and/or disjunctive facies changes.

Titus (1986) shows the upper Denley (Rust) to lower/middle Utica "transition" west of Rathbun Brook as a sharp facies jump with the implication that it represents a lateral shift from platform margin to basinal settings. (For an alternate platform model, see Surlyk and Ineson, 1992.) He argues that the Rust interval records regressive carbonate aggradation on this platform which culminated in the shallow Steuben platform. Titus (1986) envisions a subsequent episode of localized folding, uplift, and erosional beveling of the Steuben limestone prior to shelf drowning during Hillier time followed by deposition of Utica black muds across the entire region (see Titus, 1988: Figure 4).

PRELIMINARY OBSERVATIONS FROM CURRENT MAPPING PROJECT

Middle Trenton-Canajoharie Shale

The present authors have identified and traced the basal Poland marker bed (City Brook bed) from Lowville southeastward to a ravine near Countryman, north of Kast Bridge. This 0.7 to 0.2 m thick unit is a micritic nobbly limestone, rich in cephalopods and trilobites. The City Brook bed contrasts strongly with the tempestitic grainstones and packstones of the underlying Sugar River Limestone.

Beginning in the vicinity of Norway, Middleville, and Countryman (Figure 11), a thin, trilobite debris-and pelmatozoan-rich hash layer appears above the City Brook bed and below normal Poland Member micritic beds. At the creek northeast of Norway, this layer is sandy. At Countryman, it yields quartz granules and sand, as well as abundant phosphatic bioclasts. Southeast of Countryman, this hash layer yields abundant phosphatic debris and reworked limestone clasts; it marks a discontinuity which has beveled through the City Brook bed and into the Rathbun Member of the Sugar River Limestone. This discontinuity has now been traced from the vicinity of Little Falls (Rt. 5S roadcut east of Jacksonburg, NY) eastward to the vicinity of Cranesville, east of Amsterdam, New York. We will see the City Brook bed at Wolf Hollow Creek (Stop 4).

Herein, we present tentative revisions of Russia and Rust strata (Table 1; Figures 2, 6, 7). The basal Dolgeville corrosional discontinuity recognized at City Brook by Kay (1953) has now been traced southeastward to Gun Club Road, west of Little Falls, through three intervening outcrops. More significantly, this boundary is now traceable westward to Rathbun Brook (Figures 2, 6). At Rathbun Brook, this horizon is represented by a corrosion surface which is littered with phosphatized nautiloid steinkerns; this horizon is 3 m below the top of the visible Trenton section. At Trenton Falls, however, this contact is difficult to place.

These observations indicate that the Dolgeville Member of the Norway-Countryman area is equivalent to deposits no older than the Brayton Corners division, although the upper part of the Dolgeville may be Rust-equivalent (see discussion below). It also means that the Poland through Brayton Corners interval thins from approximately 37 m at Trenton Falls to 16.5 m at Wolf Hollow Creek. This occurs through southeastward stratigraphic condensation with most condensation occurring in the post-Poland part of the section (Wolf Hollow and Brayton Corners divisions; see

Figures 2, 6). Careful mapping of marker beds and sedimentary cycles in the Russia Member shows that stratigraphic units converge southeastward. In particular, the Wolf Hollow division grades southeastward from predominantly bedded bioclastic packstones and wackestones at Trenton Falls to predominantly nodular, cephalopod-rich, shaley micrites at Wolf Hollow Creek. These observations, thus, obviate the need for an abrupt Russia to Dolgeville facies change between Rathbun Brook and Wolf Hollow Creek (Stop 4) as inferred by Kay (1953); (compare Figure 3 and Figures 2, 6, 7).

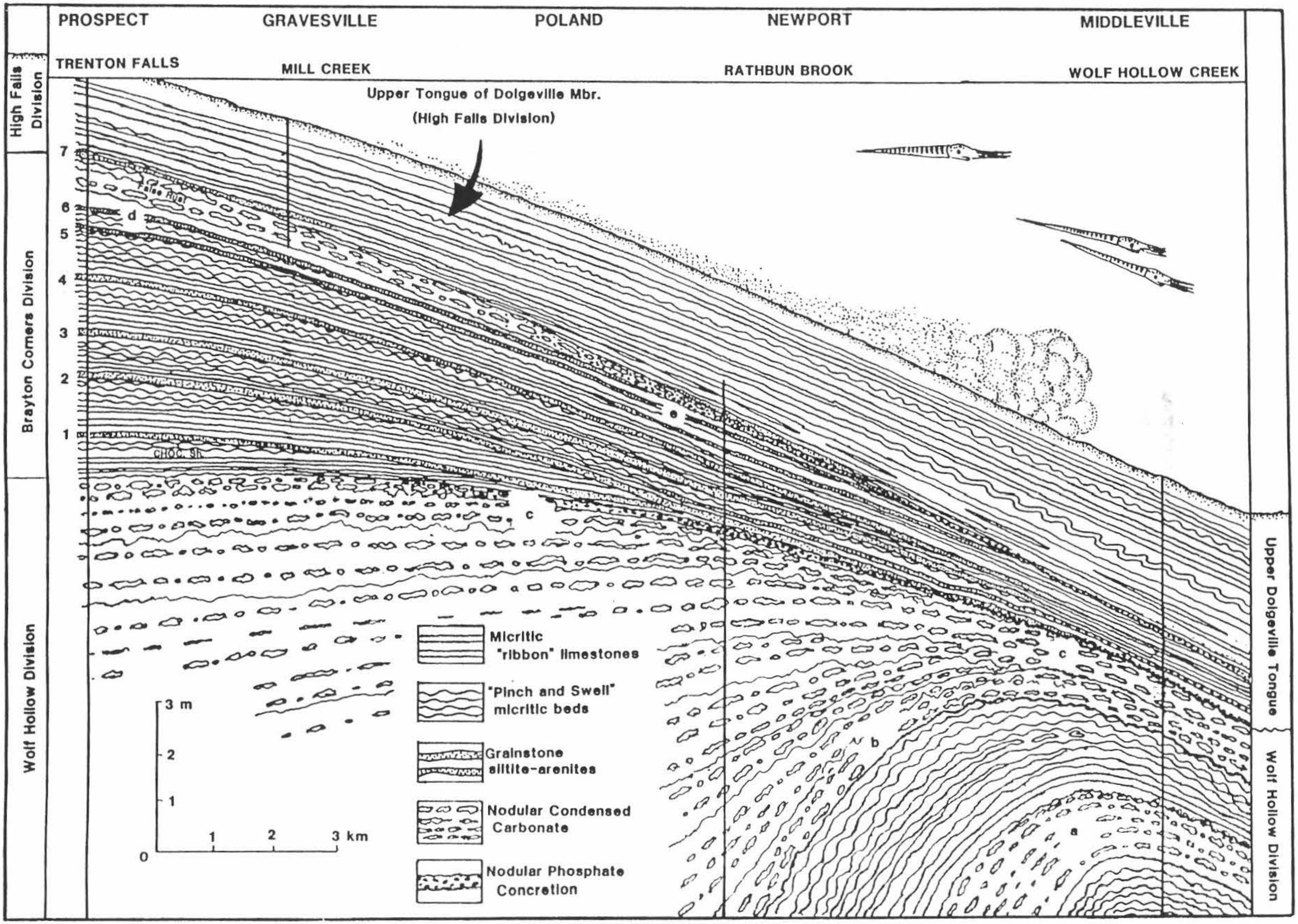
Conspicuous in the Poland - Russia interval are cyclic alternations of bedded biomicrites and nodular cephalopod-rich deposits. These constitute 4th or 5th order-scale sedimentary cycles which might record relative changes in water depth (Figure 8). Condensed nodular limestones record conditions of sediment-starvation and aggradation, possibly related to initial deepening episodes followed by early highstands, respectively. Overlying tabular calcilutites and metabentonite-bearing dark shales pass upward into burrowed and sediment-winnowed lowstand deposits. Lowstand deposits, in turn, pass upwards back into nodular, cephalopod-rich limestones. The North Gage Road bed, two higher condensed levels within the Wolf Hollow division, a condensed bed at the top of the Brayton Corners division, and a similar bed marking the base of the Rust Member constitute the caps of five such sedimentary cycles. These cycles, critical to correlation and facies interpretation, are the subject of ongoing study.

In addition to the pattern of southeastward thinning of the Poland through Brayton Corners deposits, we observe that the upper Dolgeville interval thickens from 5 meters at Trenton Falls to approximately 22-24 meters in the Middleville-Kast Bridge area with no overlying Rust Member visible. We do not know if this thickening is entirely due to stratigraphic expansion within Dolgeville or to eastward appearance of progressively higher Dolgeville beds from beneath a sub-Rust or sub-Utica unconformity. This question cannot be answered at present because no exposures of the Dolgeville-Rust contact exist southeast of Gravesville. Close study of the Dolgeville-Rust contact is needed at Trenton Falls and to the north of there (see "REMAINING PROBLEMS").

Upper Trenton Unconformity

The Steuben is definitely overstepped by Utica towards the southeast, and the underlying Rust probably suffers the same fate (Figures 2, 7). Although the Trenton-Utica contact is nowhere exposed between South Trenton (Stop 1) and sections near Norway and Middleville, 17 km east of there, visible Rust sections appear to thin dramatically southeast of Poland, and no Rust lithology is observed at Rathbun Brook. We believe that this loss of Rust is a continuation of southeastward overstep of Trenton beds, beginning with the Hillier "chop out" near Boonville and the Steuben overstep southeast of South Trenton. It is significant that a nearly complete 30-meter Rust section,

Figure 6. Inferred downslope facies change within upper Russia Member (Wolf Hollow division into upper Dolgeville stratigraphic interval) across West Canada Creek region (see Stops 3,4). Note prominent eastward-southeastward thinning (condensation) of nodular, cephalopod-rich Wolf Hollow division with appearance of top-Wolf Hollow discontinuity (corrosion surface) at Rathbun Brook (Stop 3) and Wolf Hollow Creek (Stop 4). The overlying Brayton Corners division, displaying a repetitive alternation of micritic limestone beds and tabular grainstone layers at Trenton Falls, thins southeastward through a stacked succession of ribbon grainstones at Rathbun Brook to a 1.3 meter interval of Dolgeville-type ribbon micrites with associated grainstone to calcisiltite layers and nodular phosphate concentrations. Lettered units include: a, lower condensed, cephalopod-rich interval in Wolf Hollow division; b, base of upper condensed, cephalopod-rich interval in Wolf Hollow division; c, phosphate-rich zone at top of Wolf Hollow which changes southeastward to a conspicuous corrosion surface near Middleville; d, recurrent condensed nodular limestone bed which marks top of Brayton Corners division; e, nodular, shaley limestone bed rich in nodular phosphate and phosphatized nautiloid steinkerns. This correlates upslope to unit d and downslope of phosphorite-rich micritic ribbon limestone bed in Dolgeville Member at Wolf Hollow Creek. Numbers correspond to possible 6th-order minor cycles in Brayton Corners division.



PROSPECT
GRAVESVILLE
POLAND
NEWPORT
MIDDLEVILLE
TRENTON FALLS
MILL CREEK
RATHBUN BROOK
WOLF HOLLOW CREEK
High Falls Division
Brayton Corners Division
Wolf Hollow Division
Upper Dolgeville Tongue
Wolf Hollow Division
Upper Tongue of Dolgeville Mbr.
(High Falls Division)
7
6
5
4
3
2
1
a
b
c
d
e
3 m
2
1
0
1
2
3 km
Micritic "ribbon" limestones
"Pinch and Swell" micritic beds
Grainstone siltite-arenites
Nodular Condensed Carbonate
Nodular Phosphate Concretion

Figure 6

including Walcott's "zone of trilobites" and two characteristic zones of deformation (see Stop 1), is still present northwest of Poland. South of Poland one can observe small sections of characteristic Rust lithology which, presumably, represent lower Rust strata, but these outcrops are too poor to confirm this. In short, lines of evidence for southeastward overstep of Rust are circumstantial but strongly suggestive; these include: aforementioned overstep of Hillier and Steuben, lack of significant southeastward facies change within Rust to different facies, and rapid disappearance of Rust sections between Poland and Rathbun Brook (Figures 2, 7).

Utica Shale Divisions

It has long been known that an erosional contact floors Upper Ordovician black shale and siltstone deposits between Watertown and the vicinity of South Trenton (Stop 1). Similarly an aforementioned sharp contact above folded Dolgeville beds and below Utica-type facies has been noted for sections between Middleville and the New York State Thruway south of Little Falls (see Stops 5 and 6), but it has been relegated to greater or lesser significance by different authors (see discussions in Kay, 1953; Riva, 1969; Fisher, 1979; Cisne *et al.*, 1982). This latter contact which floors Utica facies yielding the zonal graptolites *Dicranograptus nicholsoni* and *Clmiacograptus typicalis* is now traceable from the small creek northeast of Norway to East Canada Creek and Nowadaga Creek 16-20 km to the southeast (Figures 2, 7). In most localities it overlies a conspicuous zone of penecontemporaneously deformed Dolgeville beds (see discussion: Stops 5, 6, and 7) and it is characterized by a phosphatic lag deposit with conspicuously shingled, corroded, and reworked Dolgeville micrite fragments.

This contact, herein informally designated the "Thruway discontinuity" for the long New York State Thruway section south of Little Falls (see Stop 6) is a major disconformity which marks a hiatus encompassing one or more graptolite zones (see Riva, 1969). Its eastern and western limits are unknown; we presently recognize it as extending from Newville and Dolgeville in the Mohawk Valley northwestward to the Watertown area (Figures 4, 7, 9).

At Rathbun Brook and in gullies to the southeast of it, the basal exposed Utica is a somewhat calcareous, laminated black shale characterized by buff-weathering micritic "ribbon" limestones which vary greatly in thickness and spacing within the black shale. The associated shale is rich in graptolites of the upper *Climacograptus spiniferus* zone, and bedding planes

Figure 7. Inferred relationship of Trenton and Utica stratigraphic divisions in region between Prospect and Kast Bridge. Eastward loss of Upper Trenton deposits (Rust and Steuben strata) is attributed to erosional overstep prior to deposition of Utica black muds. Anomalously abrupt overstep of Rust Member west of Rathbun Brook (Loc. 6) is problematic; thick ribbon limestones in lower/middle Utica deposits at Rathbun Brook may indicate the presence of a steepened east-facing, erosional ramp west of that locality which fed thick carbonate turbidites into the Utica basin as the ramp was being buried. A higher erosion surface within the Utica (Honey Hill Discontinuity) is shown to truncate both lower/ middle Utica beds as well as part of the upper Trenton (see text). This submarine erosion scenario for explaining the abrupt eastward loss of the upper Trenton is favored by the present authors (see text) but an alternative, fault-based explanation is presented in Figure 10. Lettered units include: a, City Brook bed *("Trocholites "* Bed); b, corrosional discontinuity marking top of Wolf Hollow division; c, folded and partly truncated limestone bed marking base of Rust Member; d, prominent metabentonite in basal Rust interval; e, zones of structurally deformed strata in Rust Member; f, zone of disturbed beds in uppermost Dolgeville Member - this disturbance may correlated with units c, d, or e; g, unusually thick ribbon limestones observed at Rathbun Brook. Localities include: 1, Trenton Falls Gorge; 2, Ninemile Creek at South Trenton (Stop 2); 3, Mill Creek at Gravesville; 4, east fork of creek east of Beecher Road, 2 km southeast of Russia; 5a, creek section south Brayton Road; 5b, creek section paralleling Strumlock Road north of Brayton Corners; 6, Rathbun Brook; 7, second gully north of Honey Hill Road; 8, Wolf Hollow Creek ("City Falls"); 9, creek northeast of Norway; 10a, creek north of the County Home; 10b, creek south of the County Home; 11, east-flowing tributary of West Canada Creek at Countryman. Unpatterned= Trenton bioclastic limestones. Loose stippling= turbiditic ribbon limestone facies. Dense stippling= black shale deposits.

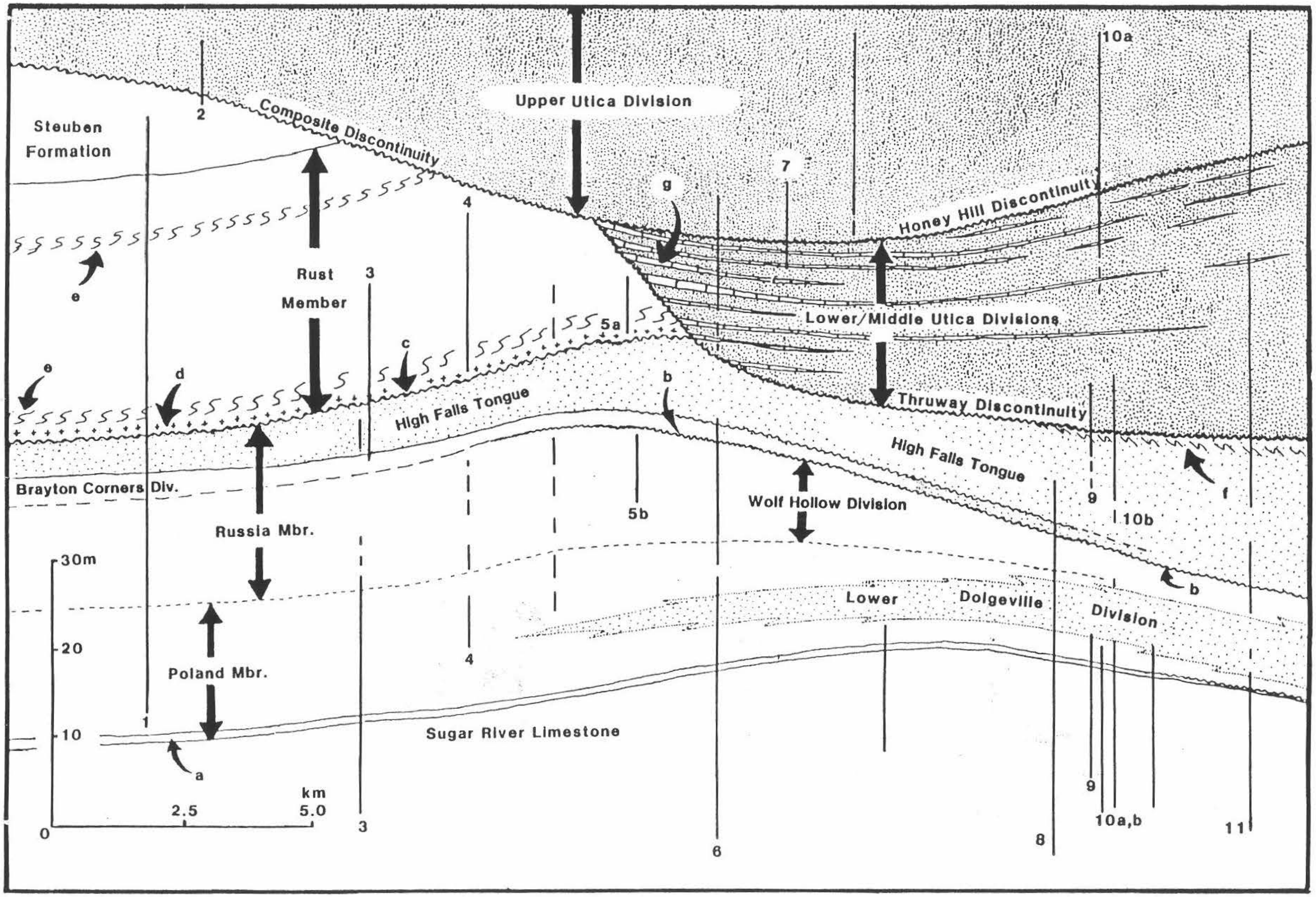

Upper Utica Division
Steuben Formation
Composite Discontinuity
Rust Member
Honey Hill Discontinuity
Lower/Middle Utica Divisions
Thruway Discontinuity
High Falls Tongue
High Falls Tongue
Brayton Corners Div.
Wolf Hollow Division
Russia Mbr.
Poland Mbr.
Lower Dolgeville Division
Sugar River Limestone
30m
20
10
0
2.5
5.0
km
1
2
3
3
3
4
4
5a
5b
6
7
8
9
9
10a
10b
10a,b
11
a
b
b
b
c
d
e
e
f
g

Figure 7

are often coated with phosphatic fossil hash. At Rathbun Brook the micritic limestones are anomalously thick and numerous, but thinner, equivalent beds can be seen in the Utica southeastward to the Little Falls area. At South Trenton, the Utica Shale yields the younger graptolite *Climacograptus pygmaeus* and it distinctly lacks ribbon limestones (see Stop 1).

The top of the ribbon limestone-bearing lower Utica division is now found to be marked by an erosion surface and an associated lag deposit which we informally designate the "Honey Hill Road bed" for exposures on an unnamed creek north of Honey Hill Road and northeast of the Newport Golf Course (Figures 7, 9). The Honey Hill Road bed is notable for locally thick lag concentrations of problematic phosphatic rod-like structures which are similar to those observed in the top-Trenton lag deposit at South Trenton (see Stop 1). The associated discontinuity is of unknown temporal magnitude but it may mark the *C. spiniferus* - *C. pygmaeus* zonal change. At Rathbun Brook this contact is probably 15-18 meters above the Thruway discontinuity which we believe is concealed under the 10-meter covered interval on that creek (Figures 2, 7, 9).

Above the Honey Hill Road bed at Rathbun Brook and along creeks near Middleville and at Countryman, the upper Utica is typically lacking in ribbon micrites; hence it is lithologically distinct from the lower/middle Utica succession below this contact. At the northern "County Home" section near Middleville and at the creek at Countryman, the lower/middle Utica interval is at least 30 m thick (Figure 7). Still further east it progressively thickens above the Thruway discontinuity. We believe that the micrite ribbon-bearing lower Utica division is overstepped by the Honey Hill Road discontinuity west of Rathbun Brook such that the regional sub-Utica disconformity at South Trenton reflects the additive merging of both hiatuses (Figures 7, 9).

INFERRED MIDDLE TRENTON AND UTICA EVENTS: UTICA-CANAJOHARIE REGION

Medial Trenton stratigraphy is suggestive of an eastward-sloping carbonate ramp which, at times, was oversteepened. Within the field trip area, conditions recorded by the Poland Member and the Wolf Hollow division of the Russia Member indicate a relative deepening of Trenton seas and increased steepening of the carbonate ramp from the earlier higher energy Sugar River shelf conditions. This sea level deepening brought on sediment-starvation, recorded by the condensed City Brook bed and the discontinuity which removed this bed in downslope areas. Many higher Russia strata resemble the City Brook bed and record similar processes. These nodular limestones are analogous to cephalopodenkalk facies present in younger systems (Tucker, 1973; Jenkyns, 1971; Baird and Brett, 1986a) Cephalopodenkalk facies typically record slow sediment accumulation, intense bioturbation, and cephalopod accumulation under predominantly quiet, minimally oxic to dysoxic conditions below storm wave base. Poland and Russia strata grade downslope to tabular micrites and interbedded dark shales (Dolgeville Member). For example, lower (Poland-equivalent) Dolgeville deposits east of Little Falls are turbidites of lime and siliciclastic mud which accumulated in a more basinal dysoxic environment. Further east, equivalent black shales (lower Canajoharie Shale) record dysoxic to anoxic basinal conditions presumably still further downslope. A similar facies gradation is present in lower Wolf Hollow-equivalent Dolgeville deposits. The presence of mildly bioturbated mudstone and muddy limestone beds yielding a sparse fossil benthos above Canajoharie Falls suggests that the lower strata of the Wolf Hollow division may have a lithologic signature in the Canajoharie Shale.

The vertical change from Wolf Hollow deposits through Dolgeville facies records an episode of relative sea level rise with consequent northwestward (up-ramp) advance of dysoxic bottom conditions. It is significant that a condensed interval of nodular phosphate, ribbon calcarenites and calcisiltites (Brayton Corners division) marks the boundary between Dolgeville facies and the Wolf Hollow interval at Rathbun Brook (Stop 2). In the Little Falls area, a corrosional-abrasional, phosphate-coated discontinuity underlies true Dolgeville facies at this horizon, and the Brayton Corners division is absent (Figures 2, 6, 7).

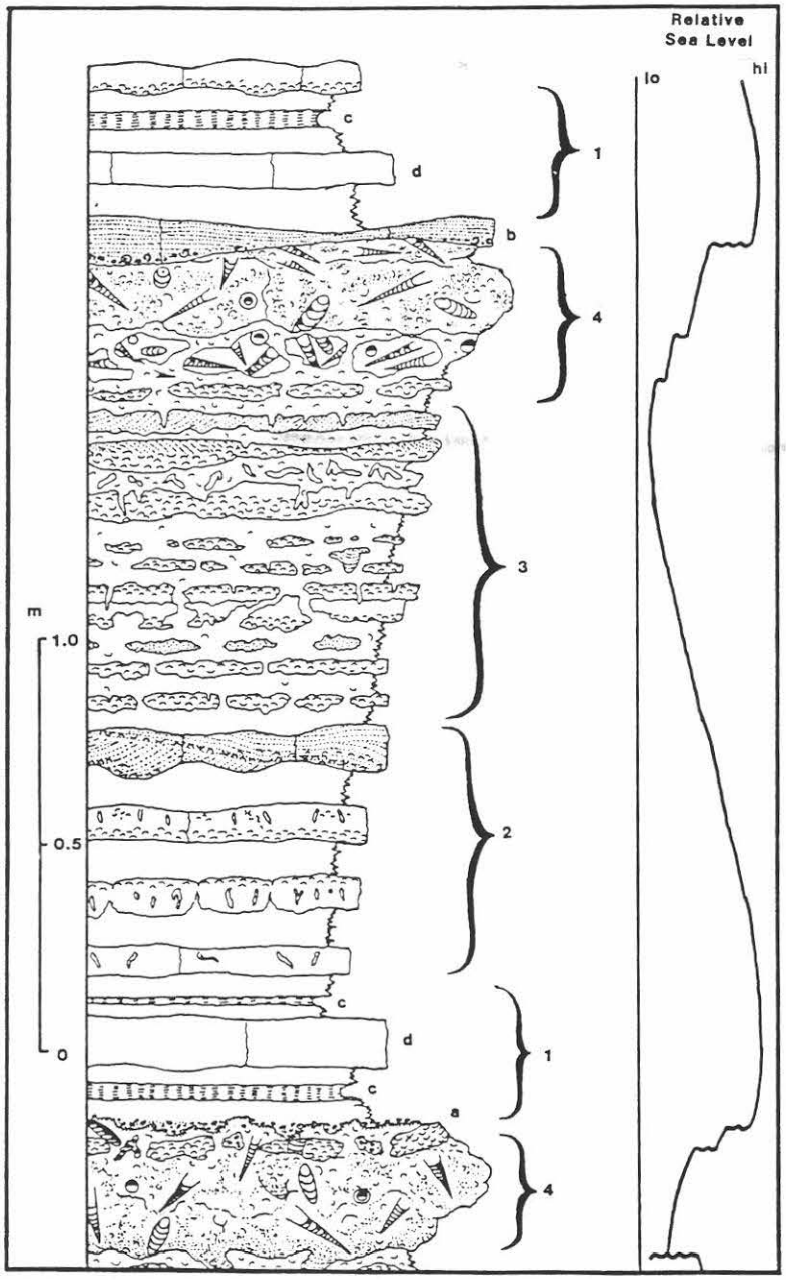


Figure 8. Generalized sedimentary cycle typical of the Wolf Hollow division and overlying Brayton Corners division (see Stops 3,4). Cycle magnitude shown is 5th order but complex larger-scale cycles show a similar facies spectrum. Sea level is relative; both eustatic and tectonic factors probably controlled cycle motif during Trenton deposition. Depth-related facies include the following: 1, early highstand, micritic limestones and dark shales yielding volcanic ashes and low diversity benthos (dysoxic conditions below storm wavebase); 2, late highstand - early sea level fall deposits showing greater evidence of benthonic activity; 3, late sea level fall - to - lowstand interval recording influence of storms, extensive bioturbation, richer benthos, and increased condensation due to sediment bypass; 4, condensed limestone facies recording relative sea level rise and associated conditions of sediment starvation. Erosion (and corrosion) surfaces capping condensed limestones correspond to surfaces of maximum flooding in cycle. Note that condensed limestones record a complex internal history of winnowing, erosional scour episodes, and multiple diagenetic events. Lettered units include: a) Phosphate - cemented corrosion surface littered with phosphatic nodules and phosphatized fossil steinkerns; b, grainstone - siltite - arenite lag bed on discontinuity which contains phosphatic gastropod steinkerns; c, metabentonites (volcanic ash units); d, prominent tabular calcilutite bed which is often observed above the maximum flooding surface.

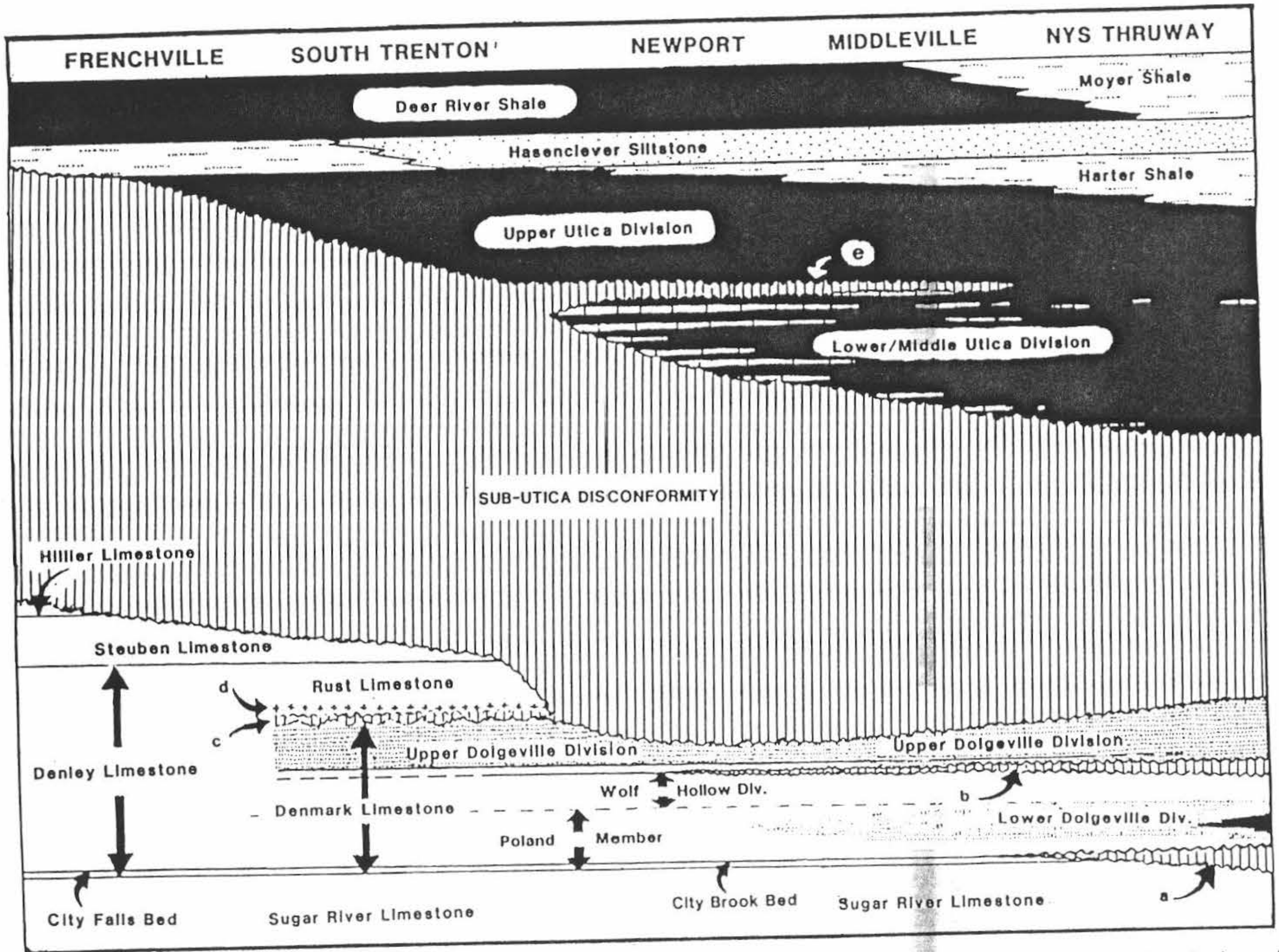


Figure 9. Middle Trenton to "Utica" chronostratigraphy, central New York region. Inferred time-magnitude of sub-Utica disconformity is conjectural but is believed to be large in this region. Note abrupt eastward erosional loss of upper Trenton deposits near Poland and progressive westward overlap of Utica deposits over progressively younger Trenton units across the region (see text). Hiatus associated with Honey Hill Discontinuity probably thins eastward to continuity into the foreland basin. Horizontal stipple pattern denotes turbiditic ribbon limestone facies of Dolgeville Member. Non-patterned area corresponds to bioclastic limestone deposits of Trenton Group. Black denotes laminated, organic-rich, black facies of Utica Shale. Discontinuities labeled as follows: a, sub-Denley discontinuity; b, Brayton Corners discontinuity; c, sub-Rust discontinuity; d, previously undescribed metabentonite in lower Rust; e, Honey Hill Discontinuity.

The downslope thinning of the Brayton Corners beds, followed by their truncation beneath basinal facies further downslope, is similar to phenomena we have observed in the Devonian Genesee Formation (Baird *et al.*, 1988). Our observations suggest that submarine erosion on Devonian sediment-starved slopes is most pronounced in the lower slope regime where dysoxic and anoxic basinal waters impinge upon the bottom. Downslope truncation of Devonian Wolf Hollow carbonate analogs--the Fir Tree and Lodi limestones--apparently occurred under conditions of transgressive sediment-starvation, carbonate undersaturation and consequent carbonate dissolution, as well as episodic current (storm- or internal wave-generated) impingement on substrate (Baird *et al.*, 1988; Baird and Brett, 1990). Contacts such as the Wolf Hollow - Dolgeville contact, the Trenton - Canajoharie discontinuity, the Thruway discontinuity, and the Honey Hill Road discontinuity probably all owe their origin to these processes.

The change from Dolgeville through Rust and into Steuben lithology marks a significant interval of marine shallowing from dysoxic conditions below storm wave base (Dolgeville) to oxic conditions within the reach of storm waves but below fair weather wave base (Rust) into high energy marine shoal facies (Steuben). This was not a uniform regression; in late Rust time, deposits resembling the proximal Dolgeville and some parts of the Wolf Hollow interval reappear within the normally rubbly, diverse-fossil facies of normal Rust. These beds, which were "mined" for trilobites by Walcott (1875a, b, c) and later workers, mark a minor transgression within the overall shallowing succession.

The eastward erosional loss of upper Trenton units across the study area leaves to speculation the character of the upper Trenton strata in eastern New York. We suspect that the Rust would have graded into downslope Dolgeville- and Canajoharie-type black shale facies reflecting persistence of the Albany Basin to the east. However, recent mapping by one of us (Lehmann) indicates that the Steuben becomes more grainstone-rich toward that unit's southeastern erosional limit. This opens up an interesting speculation that an epeirogenic upwarp (peripheral bulge?) may have developed in the western Mohawk Valley region at this time prior to its later collapse or corrasional beveling during late Hillier and early/middle Utica time. A variation of this theme is presented by Titus (1986, 1988) who argues that a discrete Trenton platform margin formed during Steuben time and that this margin was mildly folded during a disturbance timed with the Hudson Valley phase of the Taconic Orogeny. He argues that folded Steuben beds underlie flat-lying Utica shale at the Holland Patent locality on Nine Mile Creek west of Stop 2.

The problem of assessing the fate of upper Trenton strata east of the Poland - Newport area may be partly solved through future identification and location of Rust-, Steuben-, and lower Hillier-equivalent beds where they emerge beneath the Thruway discontinuity. Riva (1969) shows Trenton through Utica strata as nearing continuity at Nowadaga Creek, southeast of Little Falls (Figure 4). Yet, the discontinuity is still physically manifested on that stream, suggesting that discontinuity closes still further east. In any case, where continuity is approached, regressive shoal facies of the Steuben should perhaps be expressed as a tongue of Dolgeville facies which extends eastward into otherwise undifferentiated Canajoharie Shale.

The Thruway discontinuity is characterized by westward overlap of lower/middle Utica beds suggesting that the erosion surface was a gently sloped east-facing ramp, which was progressively buried by black muds as the basin evolved. Sediment-starvation, episodic current activity, and pervasive anoxia and/or carbonate undersaturation sustained bottom erosion and corrosion to produce the distinctive lag of phosphatic debris and micrite intraclasts common this surface. Presumably this corrasion would have removed variable portions of the Upper Trenton over millions of years of time. Unusual steepness of this ramp near Rathbun Brook could explain both the rapid disappearance of lower/middle Utica beds west of that creek and the unusual development of thick ribbon micrites in the lower/middle Utica at that locality (Figures 2, 7); such thick beds would record turbiditic carbonate "wash off" into the Utica basin from the steeper slope. However, for an alternative tectonic explanation for the abrupt stratigraphic changes near Rathbun

Brook, see "REMAINING PROBLEMS" and Figure 10.

Overlap of lower/middle Utica muds advanced for an unknown distance to the northwest of the Utica area before a later episode of erosion (associated with the Honey Hill discontinuity) removed them as well as additional Steuben beds (Figures 7, 9). This second discontinuity surface was then overlapped to the northwest by younger black muds of the lower part of the *Climacograptus pygmaeus* zone (upper Utica). This overlap is dramatic, continuing northwestward past the Watertown area such that siltstones equivalent to the Frankfort Formation lap onto the top-Trenton contact at Frenchville, NY, and even younger Utica-type facies of the Deer River Shale (upper *Climacograptus pygmaeus* zone) and the Blue Mountain Shale (*Climacograptus manitulinensis* zone) lap onto this surface still further northwest (Lehmann and Brett, 1991a). It is, as yet, unknown as to where the regional sub-Utica disconformity closes to continuity, but core and outcrop data suggest continuity in the Toronto, Ontario region, with closure occurring within the upper Hillier Limestone (upper Lindsay of Ontario) or above it.

In summation, the overall cratonward drift and facies succession from middle Trenton to upper Utica reflects the behavior of a peripheral foreland basin during orogeny; successive emplacement of allochthon slices and later thrust masses in the Hudson Valley region as well as synchronous filling of the basin with flysch would have led initially to sinking of the Trenton shelf from east to west. This was followed by progressive overlap of basinal muds (Canajoharie-Utica Shale facies) in the same direction. The development of a sediment-starved east-sloping ramp would have led to dissolution and abrasion of exposed Trenton carbonate as water depth, carbonate undersaturation, and depth-related anoxia increased; this would have produced the discontinuities discussed herein and it may have led to the removal of much of the upper Trenton strata. This mirrors the Taghanic onlap event of Middle to Late Devonian age where foreland basin migration and deltaic progradation were key responses to the Acadian Orogeny (Ettensohn, 1987). This makes the "Utica Shale" with its subjacent unconformities a close analog to the Devonian Geneseo, Ohio, Antrim, and Chattanooga black shale complex with its subjacent overlap surfaces (Baird and Brett, 1986a, 1986b, 1990).

Figure 10. Alternative model for explaining abrupt eastward disappearance of upper Trenton deposits (Rust Mbr.) by evoking movement of linked synthetic-antithetic faults (*sensu* Bradley and Kidd, 1991). Fault movement is purely conjectural as no fault system has yet been found between Poland and Rathbun Brook, but stratigraphic changes within the upper Trenton (see text) could be explained by the sense of fault movement depicted. Fault motion is shown to have commenced during deposition of the basal Rust disturbed layer and overlying thick metabentonite with ensuing shelf collapse and development of a southeast-facing submarine escarpment. Laminated black lower Utica deposits are shown as time-equivalent with Rust platform deposits; they accumulated under anoxic conditions along with turbiditic ribbon limestones and inferred olistostromes in the graben and with only minor allodapic carbonate further east in the foreland basin. Corrosion and abrasion of Dolgeville deposits on the southeastern upthrown block would have occurred under sediment-starved, oxygen-deficient conditions to produce an intraclast-littered rubble hardground; diachronous overlap of this surface would have produced the Thruway Discontinuity. This model explains both the abrupt eastward "replacement" of Rust by lower Utica and the seemingly thin 10-meter covered interval between the Brayton Corners division and lower Utica deposits at Rathbun Brook. Lettered units include: a, transitional Denmark - Dolgeville deposits (Brayton Corners div.) east of graben; b, basal Rust folded and truncated bed, plus overlying metabentonite which is marked by +++ symbol - note that these beds intertongue with lowest olistostrome and that the ash hypothetically reappears under the Thruway Discontinuity at the lower right; c, two key levels of disturbed strata (deformed zones) in the Rust Member - these would be linked to seismic activity on the adjacent active fault both during or immediately following Rust deposition.

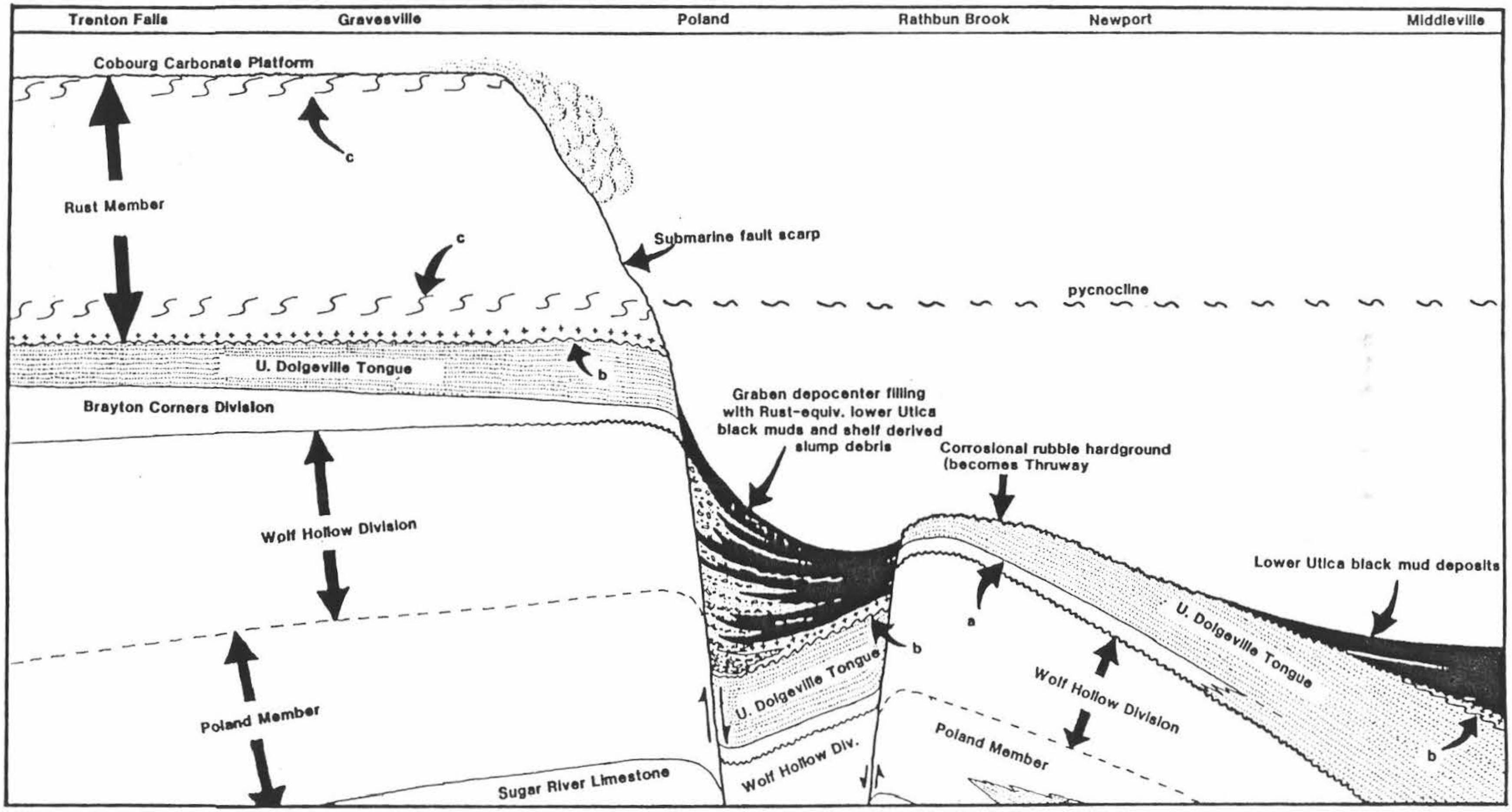

Trenton Falls
Gravesville
Poland
Rathbun Brook
Newport
Middleville
Cobourg Carbonate Platform
c
Rust Member
c
Submarine fault scarp
pycnocline
U. Dolgeville Tongue
b
Brayton Corners Division
Graben depocenter filling
with Rust-equiv. lower Utica
black muds and shelf derived
slump debris
Corrosional rubble hardground
(becomes Thruway
Wolf Hollow Division
Lower Utica black mud deposits
a
U. Dolgeville Tongue
b
U. Dolgeville Tongue
Wolf Hollow Division
Poland Member
Poland Member
Wolf Hollow Div.
b
Sugar River Limestone

Figure 10

REMAINING PROBLEMS

Several outstanding stratigraphic problems exist which constrain our knowledge of upper Trenton depositional events. These questions include the following:

What is the fate of the Rust Member southeast of Poland? Apparently this unit is overstepped to the southeast by the lower/middle Utica Shale (Figures 2, 7) but others have hypothesized a rapid lateral facies change from Rust through Dolgeville to Utica near Rathbun Brook. Moreover, this change may also have a structural origin (see Figure 10). Rust correlative strata may: 1) abruptly grade into Dolgeville facies near Rathbun Brook, 2) not be present between Rathbun Brook and Canajoharie, due to sediment bypass or erosion, or 3) correlate with some of the calcareous lower/middle Utica strata. The first alternative is appealing in that no major erosional cut-out is required. Furthermore, the Rust bioclastic sediments would have provided a source for the thick Dolgeville ribbon-limestones, and some Dolgeville-like calcilutites are present in the Rust. However, such a rapid facies jump does seem unlikely. If Rust-correlative strata are absent between Rathbun Brook and Canajoharie, the absence is most likely the result of sediment bypass following ramp over-steenening associated with the slump folding of uppermost Dolgeville beds; it seems highly unlikely that erosional removal of carbonate strata would consistently cease at the same stratigraphic level. The third hypothetical explanation of the "Rust problem" is shown and described in Figure 10.

To date, correlating some of the key event horizons in, and associated with, the Rust has not been entirely successful. Folding at the top of the Dolgeville (seen at Stops 5, 6, and 7) *might* represent the same slump event which resulted in either the upper or lower disturbed zone; however, even if the Dolgeville folds could be correlated with one of the disturbed zones in the Rust, we could not say with certainty whether or not Rust-correlative strata were present in the Dolgeville. The discontinuity at the top of the Russia in the Trenton Falls - Poland area *might* correlate with the Thruway discontinuity, but this in itself would not explain the disappearance of the Rust.

An appealing explanation of the "Rust problem" involves erosional bevelling of Rust and Steuben strata, as well as some of their downslope facies equivalents due to formation of a peripheral bulge. Such a mechanism is invoked by others (Jacobi, 1981; Lash 1988) to explain major localized truncation of sub-Trenton units in the Appalachian Basin. Such locallized upwarp could have removed a sufficient thickness of upper Trenton strata to leave platform facies on its west flank (west of the erosional cut-out) and Dolgeville-type ribbons or Canajoharie Shale on the east flank (east of the discontinuity closure) of the bulge.

Improved graptolite control both for Rust and the lower Utica could aid in understanding the "Rust problem." Furthermore, core drilling through the covered interval on Rathbun Brook should show if the Thruway discontinuity is present and, if so, whether or not any Rust is still present beneath it (see Figures 7, 10). Core drilling through the small Rust section immediately to the north of Rathbun Brook would give a thickness for the Dolgeville in this area, and it may show whether or not a discontinuity surface is present at the Dolgeville-Rust contact. Drill cores and geophysical logs could offer vital information for eliminating some of the possible fates of the Rust.

The Rust problem is but one area of Trenton stratigraphy that we are currently examining. Other key questions which we hope to help answer in the near future include:

> How far east does the Thruway discontinuity extend? Do Rust-, Steuben-, and Hillier-equivalent beds reemerge under it, and, if so, where and in what facies form? We are currently attempting these correlations and, as of this writing, has traced this contact eastward to Nowadaga and East Canada Creeks.

Can the Wolf Hollow Limestone- Dolgeville (mid-Denmark) erosional contact be traced eastward into the Canajoharie Shale of the St. Johnsville-Amsterdam region? Recent mapping suggests that the Wolf Hollow interval is expressed as a sequence of dilute calcisiltite bands above Canajoharie Falls on Canajoharie Creek, but the top erosional contact has not been observed east of the Little Falls - North Creek area.

Can the Dolgeville interval at Trenton Falls (High Falls tongue) be traced northwestward from that area towards Watertown? Again, this work is ongoing.

Can zonal equivalents of the carbonate succession of Rust, Steuben, Hillier, and Lindsay be confidently matched with appropriate Dolgeville, Canajoharie, and Utica beds to constrain the timing and placement of carbonate accumulation, submarine erosion, and black mud onlap in the Lake Ontario-Mohawk Valley region during the Taconic disturbance? Currently, graptolite control is better for the basinal shales than it is for the limestones. However, current work on graptolite zones (Mitchell *et al.* in prep) as well as refined fingerprinting of ash beds holds great promise of answers.

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ROAD LOG

(Also applies to field trip led by C. Mehrtens)

0	0	Thruway - Rt. 12 junction, Utica. Head north on Rt. 8/12.
5.8	5.8	Routes 8 and 12 split. Continue north on Rt. 12.
8.5	2.7	Cross Ninemile Creek. Continue north on Rt. 12.
13.5	5.0	Exit onto 365 North.
14.5	1.0	Turn right onto Church Street, heading into "downtown" Prospect.
15.4	0.9	Turn right onto State Street (which becomes Military Road).
15.7	0.3	Cross West Canada Creek.
15.8	0.1	Pull into parking on left. Walk down into gorge of West Canada Creek via path on the northeast side of the bridge.

Stop 1: West Canada Creek, Prospect: Slump folds and obrution deposits in the Rust Member, Denley Limestone.

A nearly continuous, although faulted exposure, of middle and upper Trenton strata crops out in the West Canada Creek gorge from the village of Trenton Falls to the Prospect Dam (approximately 3.5 km of exposure). At this stop, we will examine the upper 15 m of Rust bioclastic limestones and the lower 5 m of Steuben calcarenites. A number of interesting and enigmatic sedimentary and taphonomic features are present in this interval.

Note the prominent slump fold horizon (the "upper disturbed zone" of Prosser and Cummings, 1897) in the upper Rust, approximately 5 m above stream level along the east wall of the gorge. Disturbed strata occur as intermittent pods or lenses. Within lenses, strata are folded, brecciated, and--in some cases--over-thrusted. Lenses of disturbed strata are typically bounded by, and merge laterally into, shaley horizons, some of which contain slickensides. Some of these shales form rusty, micaceous recessions in the outcrop; they may be metabentonites. This interplay of ductile and brittle deformation suggests that strata were fairly well lithified when they were deformed (Mehrtens, 1984).

This disturbed zone is clearly continuous from Poland to Remsen, a distance of 12 km. Furthermore, "disturbed" strata occur at approximately the same stratigraphic position from Remsen to Lowville, 45 km to the northwest. This widespread occurrence of upper Rust disturbed strata, suggests that deformation reflects some sort of regional event--probably oversteepening of the Trenton ramp/platform.

The timing and nature of this oversteepening event is problematic. Unlike the slump folds in the uppermost Dolgeville (see Stop 6), these slump folds seem to indicate a down-to-the-east paleoslope (Cisne and Rabe, 1978). Although these slump features are clearly post-depositional, sediment was not completely lithified during deformation. Potentially, water released during compaction of clays accommodated the ductile behavior of the limestone beds; the disturbed zone incorporates a particularly shaley horizon of the Rust. Clearly, water content of the muds, amount of overburden, and angle of slope all played important roles in this slump deformation.

How might this slumping have been influenced by tectonic activity? Cisne *et al*. (1982) and Mehrtens (1988) have suggested that middle Trenton sediments were deposited in a developing foreland basin in which subsidence was accommodated by movement along the numerous normal faults which are present in the Mohawk Valley region. One such fault, which displaces Trenton strata 35 m, is located 150 m upstream of the Prospect Bridge. A narrow gully occupies the

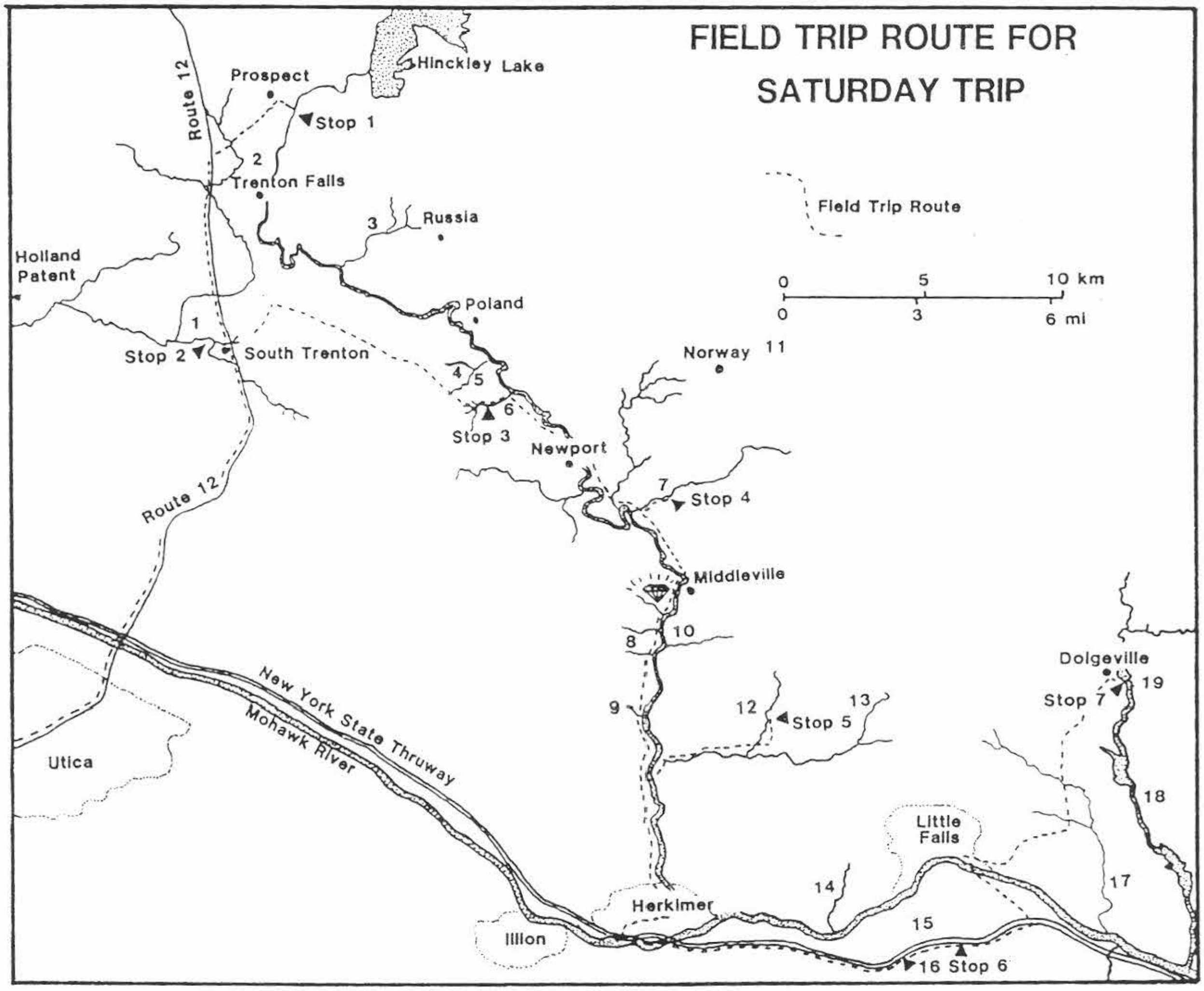

Figure 11. Study area showing field trip route. See road log for road and stop descriptions. Numbered localities include: 1, Ninemile Creek at South Trenton (Stop 2); 2, Trenton Falls Gorge (Stop 1); 3, Mill Creek at Gravesville; 4, creek south of Brayton Road; 5, creek parallel to Strumlock Road; 6, Rathbun Brook (Stop 3); 7, Wolf Hollow Creek (Stop 4); 8, creeks near the County Home; 9, creek northwest of Countryman; 10, Stony Creek; 11, creek northeast of Norway; 12, tributary of North Creek at Meyers Road (Stop 5); 13, tributary of North Creek south of Dillenbeck Corners; 14, creek at Gun Club Road; 15, Roadcut on Route 5s; 16, Roadcuts on New York State Thruway (Stop 6); 17, West Crum Creek; 18, East Canada Creek at Ingham Mills; 19, East Canada Creek below Dolgeville Dam (Stop 7).

surficial position of the fault. In the south wall of the gully, Steuben grainstones crop out. In the north wall of the gully, nodular limestones of the lower Rust are present. The northern exposure also contains abundant slickensides. The fault shows reverse polarity. However, drag folds associated with this fault indicate original normal, down to the east displacement; a net reversal of displacement apparently occurred at a later time (Bradley and Kidd, 1991). Tectonically-induced subsidence could have resulted in an oversteepened platform. Interestingly, the disturbed zone is cross-cut by a number of faults suggesting that either: 1) most motion along these faults occurred after slump folding, or 2) synchronous displacement along these faults--possibly related to thrust loading--resulted in widespread regional slumping.

Alternatively, Titus (1986) suggests that upper Denley (Rust) to Steuben deposition reflects upbuckling of the western Adirondack Arch region. In this scenario, oversteepening could accompany the basin modification. However, down-to-the-east slump features would suggest that the axis of uplift was to the west of Prospect.

Waltherian relationships suggest that the Rust strata at this outcrop represent deposition below normal wave base but possibly not below storm wave base. Lower Rust strata above High Falls at Trenton Falls contain wave ripple marks, while interference ripple marks and hummocky cross stratification occur in the Steuben grainstones at Cincinnati Creek (4 km to the northwest of here). Thus upper Rust strata are conformably bracketed by deposits representing storm-dominated shelf and wave base settings. Airy wave theory analysis of ripple marks of this stratigraphic interval at Booneville (25 km to the northwest) suggests sediment was deposited in water depths of between 1 and 27 m at that locality.

The occurrence of a diverse epibenthos and ichnofauna suggests well oxygenated seafloor and substrate conditions. The nodular bioclastic upper Rust Member contains abundant specimens of the brachiopods *Rafinesquina deltoidea*, and *Platystrophia sp*., the bryozoan *Prasopora orientalis,* and echinoderm plates. Nodular brachiopod- and trepostome-rich packestones and grainstones are typical Rust lithology. However, a 2 m interval of tabular bedded wackestones to fossiliferous lime mudstones are present below the disturbed zone. These limestones and interbedded shales--a tongue of deeper water carbonates, approaching Dolgeville facies--contain a distinctly different fossil fauna dominated by fenestrate and small ramose trepostome bryozoans, crinoids and the trilobites *Isotelus* and *Ceraurus*. These beds, probably correlative with the famed Rust Farm quarry beds of Walcott (1875a, b, c; 1876; 1881), contain abundant ceraurid trilobites at some localities. Brachiopods are much less common than in typical Rust strata. These tabular Rust strata include obrution deposits containing beautifully preserved specimens of *Glyptocrinus* and *Ectenocrinus*. These crinoids occur in both carbonate and siliciclastic mud tempestites/turbidites. Upright crinoid stems, up to 8 cm in length, attest to the severity of these sedimentation events.

15.8	0.0	Retrace route back to Rt. 12.
18.1	2.3	Head south on Rt. 12.
22.4	4.3	Take the Putnam Road/South Trenton exit.
22.6	0.2	Turn left at Putnam Road.
22.8	0.2	Turn left onto Old Rt. 12.
23.1	0.3	Turn right onto Church Street (at old white church).
23.4	0.3	Road forks. Stay to the left
23.5	0.1	Make a sharp turn to the right onto a private road (with multiple "No Trespassing" signs). Park. Follow path to below bridge. Walk upstream.

Stop 2: Ninemile Creek, South Trenton: Disconformity (regional composite unconformity) capping Steuben Limestone and flooring Utica Shale.

At this stop, we will examine a composite unconformity--the Thruway and Honey Hill discontinuities are superposed here--which separates Trenton carbonates from overlying Utica strata. This is the only outcrop between Frenchville (15 km to the northwest) and the Norway-Middleville area (15 km to the southeast) where the contact between Trenton carbonates and overlying siliciclastics (in this case, the upper portion of the Utica Shale) can actually be seen; near Holland Patent (2 km to the northwest), a mineralized Steuben top surface can be seen on this same creek, but the basal 0.5 m of Utica Shale is poorly exposed. Suprisinigly, although the Holland Patent stream section is commonly cited, the South Trenton section is not mentioned in most earlier reports--most notably Kay, 1953.

The South Trenton section results from a broad anticlinal fold which brings the Steuben Limestone up into view for a distance of 100 m along this stream; this fold is exposed 500 m downstream (west) of the private road bridge over the creek. Three beds (totaling 0.75 m) of Steuben are exposed at the breached fold axis, and over 10 m of Utica Shale are exposed in the stop vicinity.

Dark gray packstone facies of the Steuben is overlain by a 35 cm-thick interval of very dark gray bioturbated wackestone, rich in phosphatic nodules and small rod-like phosphatic bioclasts which forms the limestone bench above water on the creek bank. This is, in turn, overlain by a phosphate-cemented corrosion surface which is distinctly pitted and which contains infillings of Utica Shale and phosphatic debris in depressions between knobs and raised bosses. Locally, a 2 cm-thick micritic ledge is developed along the corrosion surface; it is distinctly perforated, roofing a horizontal crevice space which is filled with phosphatic lag debris. Note the complex pattern of burrow-infilling "let down" of lag debris into and under this uppermost Steuben carbonate bed. Resting on the mineralized surface is black laminated Utica Shale which yields the lower Upper Ordovician graptolite *Climacograptus pygmaeus*. At Stops 4, 5, and 6 (to the southeast), we will also view Utica Shale over the Thruway discontinuity, but in these latter sections, both the underlying carbonates and the overlying shales are distinctly older. At Frenchville (to the northwest), the Steuben carbonates are overlain by turbiditic siltstones and shales of the Frankfort Formation. In this respect, the South Trenton exposure offers a unique opportunity to see Utica Shale correlative with strata of the type section (Utica) in contact with underlying carbonates. Furthermore, these contact sections illustrate a pattern of northwestward overlap of black muds which continues from Canajoharie to near Toronto, Ontario: progressively younger siliciclastics disconformably overlie progressively younger carbonates (Lehmann and Brett, 1991a).

We interpret the contact displayed at this stop as a corrasional discontinuity produced by combined processes of corrosion and abrasion under conditions of sediment-starvation and dysoxic to anoxic bottom waters. Unconformities of this type typically underlie black shales in the Appalachian foreland basin; sediment-starvation, episodic impingement of deeper water current processes, carbonate undersaturation of bottom waters, and low pH conditions are all believed to contribute to the corrasion process (see Baird and Brett, 1990 for overview). Lag debris produced from the corrasion process consists of insoluble grains of pyrite, phosphate, and quartz. Middle and Upper Ordovician lags of this type are mainly composed of phosphatic nodules and bioclasts.

23.5	0	Retrace route back to Putnam Road.
24.4	0.9	Turn right onto Putnam Road. Continue on Putnam Road under Rt. 12 overpass.
25.9	1.5	Turn right onto road to North Gage.
27.5	1.6	Pass through intersection in North Gage (head straight).
28.7	1.2	Cross Rt. 8 (head straight).
29.9	1.2	Cross Herkimer County line.

30.6 0.7 Pass Strumlock Road. The furthest southeastern exposure of limestones of the Rust Member (Denley Limestone) occur along a small stream near this road.

31.5 0.9 Park at the old meat packing plant on the right.

Stop 3: Rathbun Brook: Key beds of the Medial Trenton succession.

We will examine bed succession from the top of the Poland Member, through a complete section of our informal Wolf Hollow division, to the lowest 3.5 meters of our Brayton Corners division. Above these strata is a 10 m-thick interval of concealed strata, which begins near the closed meat packing plant. This is one of the most critical and enigmatic sections with regard to the problems of southeastward disappearance of the upper Denley (Rust) strata, thickening of Dolgeville facies, and appearance of lower/middle Utica beds

Kay's (1953) Poland- Russia boundary on this creek is difficult to locate, as it is on several other creeks; he describes 33 m of "Denmark" at this section of which approximately half is Poland Member (which we will not examine) and half is Russia. We designate the base of Kay's (1953) Russia Member (and our Wolf Hollow division) as the base of a prominent 0.2 m-thick bioturbated packstone layer, herein designated the North Gage Road bed, which holds up a small waterfall on this creek and which will also be seen at Stop 4. This bed is approximately 12.5 m above the top of the Sugar River Limestone.

Above the North Gage Road bed is a 3.5 m interval of thin bedded, tabular to slightly nodular calcilutite beds which is, in turn, succeeded by a thick interval of nodular to massive shaly wackestone and lime mudstone which displays only weak bedding at many levels. This 15 m succession is rich in steinkerns of *Geisenoceras,* which are conspicuous on numerous bedding surfaces. Other common taxa include the trilobites *Flexicalymene* and *Isotelus*, the bryozoan *Prasopora*, and pelmatozoan debris. Two main zones of strongly nodular limestones in this interval are separated by more tabular-bedded calcilutites (Figures 2, 6); These intervals of nearly non-bedded Russia seem to correlate to two thinner massive intervals at City Brook (Stop 4) and correspond to times of sediment-starvation which produced a distinctive nodular, cephalopod-rich facies (cephalopodenkalk) that is thin (stratigraphically condensed) relative to correlative deposits.

Upstream from North Gage Road, nodular deposits give way to tabular bedded calcisiltites and calcarenites which display sharp bases, some with sole marks. This 3.5 m succession, best developed near the fork in the creek below the abandoned meat packing plant, is also characterized by nodular to sandy phosphorite concentrations both at its base and at higher levels. At its base is an irregular knobby contact overlain by a bioclastic debris layer yielding a profusion of nautiloid steinkerns as well as abundant phosphatic grains; this bed, in turn, is succeeded by a grainstone layer. This contact marks a submarine erosion surface that correlates to a corrasion surface at City Brook that Kay (1953) designated as the Poland-Russia boundary on that creek (Figure 3).

Herein, the strata between the top of the North Gage Road bed and the base of the 3.5 m-thick calcislitite/calcarenite interval are informally refered to as the Wolf Hollow division of the Russia Member (for the excellent exposure of strata which we will see at that creek), and the overlying 3.5 m interval is refered to as the Brayton Corners division. The Wolf Hollow beds are lithologically distinct and are roughly correlative with the lower 3/4 of Kay's (1953) Russia Member (Figures 2, 6, 7).

The phosphate-bearing, grainstone-rich interval (Brayton Corners division) capping the Wolf Hollow seen here is apparently the upslope facies equivalent of ribbon limestone deposits (upper Dolgeville tongue) which we will see at City Brook (Stop 4). The Brayton Corners division expands upslope to 6 or 7 m of tabular-bedded mixed grainstone-calcilutite facies at Trenton Falls and near Gravesville. In that region, the grainstones are overlain by a 3-6 m interval of thin calcilutites which we refer to as the High Falls Tongue of the Dolgeville Member and which consitute the uppermost Russia succession of Kay (1953). Thus, the Brayton Corners beds appear to be relatively condensed and grade to turbiditic ribbon carbonates (upper Dolgeville tongue) downslope and stratigraphically upwards (High Falls Tongue of the Dolgeville Member) (Figures 2, 6).

Above the critical 10 m covered interval is a 20 m-thick succession of lower/middle Utica black shale with widely spaced micritic beds yielding the graptolites *Dicranograptus nicholsonii* and *C. typicallis*. No Rust or Steuben lithology is observed. For a full discussion of the problematic southeastward disappearance of upper Trenton deposits as well as the southeastward appearance of thick Dolgeville and lower Utica divisions, the reader is referred to the text.

31.5	0	Make a right turn out of the meat packing plant onto North Gage Rd.
32.0	0.5	The City Brook bed caps the falls on the north side of the road. The type section for the Rathbun Member of the Sugar River Limestone is exposed in the face of the falls.
32.1	0.1	At the stop sign, turn right (south) onto Old State Road.
33.8	1.7	Turn left (east) at Bridge Road and cross West Canada Creek.
34.0	0.2	Turn right (south) on Rt. 28 in the town of Newport.
36.6	2.6	Turn left (east) on Castle Road.
36.8	0.3	Road forks; stay to the right. (The left fork leads to lower portion of the section--Little Falls Dolostone, Black River Group, and the lower Trenton Group--on Wolf Hollow Creek. However, the landowner for this stream section does not allow people on her property.)
37.0	0.2	Pull off to the right at the parking lot by the utility building, and walk up the left fork to the bridge over the creek.

Stop 4: Wolf Hollow Creek (City Brook), Old City: Condensation of Medial Trenton strata.

We will walk up the creek from the bridge below the Amish farm to examine, in ascending order: the uppermost Sugar River Limestone (Rathbun Member) and the Poland Member, the Wolf Hollow division, and the upper tongue of the Dolgeville Member of the Denley Limestone.

The lowest strata which we will examine are the massive calcarenites of the Rathbun Member of the Sugar River Limestone. Note the large domal bryozoans, *Prasopora*, in the lowest strata of the Rathbun Member. The Rathbun calcarenites are dramatically overlain by the "*Trocholites* Bed" of Kay (1937), which is the base of the Poland Member. The *Trocholites* Bed is herein designated the City Brook bed for the excellent bedding exposures in this interval above the road crossing on this creek. The nautiloid *Trocholites* is not sufficiently common for that name to have much meaning, and an alternative bed name is advanced here. This unit is widespread, marking the base of the Poland Member from the Lowville area (Chenowith, 1952) to the vicinity of Kast Bridge south of Middleville. At Wolf Hollow Creek this bed is 0.7 m-thick, and it is expressed as nodular, intensely bioturbated shaly wackestone-packstone facies which is extremely rich in orthoconic nautiloid and endocerid steinkerns as well as the trilobites *Flexicalymene* and *Isotelus* which are sometimes complete. A thin pelmatozoan packstone layer capping the condensed City Brook bed at this creek appears to be coextensive with a submarine discontinuity which oversteps the City Brook bed between the Kast Bridge area and Little Falls. This discontinuity may further correlate with a corrosion surface flooring the Canajoharie Shale at Canajoharie Creek and at a small stream southeast of Amsterdam.

Poland and Wolf Hollow deposits on this creek are represented by a stratigraphically condensed section which is much thinner than that developed at Rathbun Brook (Figures 2, 6). Again, at this section, the North Gage Road bed is identifiable as a 0.2 m compact, nodular limestone. This condensed interval is disconformably overlain by the sparsely fossiliferous ribbon carbonate facies of the Dolgeville Member of which only the lower 8 m are exposed at this section;

we will see the top of the Dolgeville at Stops 5 and 6. Careful mapping of middle Trenton beds shows that the Poland-through-Wolf Hollow interval of the Trenton Falls section thins negligibly from approximately 32 m in that area to 31 m at Rathbun Brook; however this interval thins dramatically from Rathbun Brook to City Brook, where only 15 m of section is present. Most of this southeastward thinning occurs in the upper (Wolf Hollow division) part of the section (Figures 2, 6); 15 m of nodular, cephalopod-rich wackestone at Rathbun Brook thin to 5.5 m at the present locality. Within the Wolf Hollow division, the two zones of nodular facies at Rathbun Creek thin respectively to form two massive nodular ledges which cap waterfalls on Wolf Hollow Creek and are separated by only 0.8 m of tabular calcilutites (Dolgeville facies). These meter thick benches, rich in nautiloid steinkerns and trilobite fragments, are an Ordovician expression of condensed cephalopodenkalk facies described from Devonian and younger systems (see Jenkyns, 1971; Tucker, 1973; Wendt and Aigner, 1985; Baird and Brett, 1986a, b).

Kay (1953) first reported the mineralized corrosion (discontinuity) surface which separates the upper nodular carbonate (Wolf Hollow division) from the overlying upper Dolgeville tongue. This conspicuous break, seen to best advantage upstream from our turnaround point, records a period of submarine erosion (and probably also carbonate dissolution) on the seafloor prior to deposition of Dolgeville sediment. The association of this break with condensed underlying facies is no surprise; extremely slow rates of sediment accumulation are often exceeded by rates of sediment removal by winnowing and dissolution. We saw this discontinuity in a more subtle development above the nodular interval at Rathbun Brook (Stop 3) where sediment-removal was apparently less severe. Still further west, at Trenton Falls, the top of the nodular interval is conformable with overlying beds. Preliminary study of sections between City Brook and Little Falls suggests that the condensed nodular beds are overstepped by this erosion surface towards the southeast such that some of the Wolf Hollow interval is missing in the latter area (Figures 2, 6, 7).

Kay (1953) correlated his Poland-Russia boundary at Rathbun Brook (near our North Gage Road bed position on that creek) with the corrosion surface level on City Brook. This resulted in the "abrupt facies change" of nodular Russia to Dolgeville between the two sections. Our recognition of the North Gage Road bed on Wolf Hollow Creek as well as successful matching of the nodular condensed limestone intervals (Figures 2, 6) provides a more palatable stratigraphic match between these sections, and it eliminates the disjunctive facies change. On Wolf Hollow Creek, the Poland interval, herein redefined, encompasses a 9.5 m-thick interval, dominated by tabular-to-wavy bedded micrite beds between the base of the City Brook bed and the base of the North Gage Road bed which caps a low waterfall on this creek. The Wolf Hollow division includes the remaining 5.5 m of Trenton section up to the discontinuity surface.

The overlying Dolgeville Member is composed of tabular bedded ribbon carbonate which alternates with very dark gray to essentially black shales. The Dolgeville strata yield a sparse fauna including graptolites and the small trilobites *Flexicalymene* and *Triarthrus*. We agree with other workers that this is a basin slope facies characterized by carbonate turbidites and an impoverished dysoxic fauna. Some beds show distinctive current markings (sole marks, ripple marks, and aligned fossils). Soft-sediment failure is represented by ball-and-pillow deformation at several levels.

The age of this Dolgeville sequence and its relationship to the Trenton Limestone is, in part, problematic (see text). The basal 1.5 m contains beds rich in nodular, sand-sized, phosphatic debris. This interval appears to be the downslope expression of the Brayton Corners division which we saw at Rathbun Brook and which also crops out at Trenton Falls (Figures 2, 6). However, higher, non-phosphatic Dolgeville deposits at Wolf Hollow Creek and near Middleville may correlate to the High Falls tongue of the Dolgeville at Trenton Falls and/or possibly to the Rust Member (see discussion in text).

37.0 0.0 Retrace route back to Route 28.

37.5 0.5 Turn left on Route 28.

38.0 0.5 Vuggy carbonates of the Little Falls Dolostone crop out on the left side of the road.

Many of these vugs contain doubly-terminated quartz crystal--the famed Herkimer Diamonds.

39.1	1.1	In the town of Middleville, turn right to continue following Rt. 28 south. Cross West Canada Creek.
39.3	0.2	Turn left to continue following Rt. 28 south.
39.6	0.3	Note the "Ace of Diamonds" Herkimer Diamond quarry and campground. We will pass another Herkimer Diamond quarry (Herkimer Development Corp.) over the next mile.
44.1	4.5	Turn left on West End Road.
44.3	0.2	Cross West Canada Creek on Kast Bridge.
44.8	0.5	Cross North Creek.
45.0	0.2	Turn right on North Creek Road.
45.3	0.3	Kay's Poland Mbr. of the Denley Limestone crops out along North Creek to the right.
47.5	2.2	Turn right (south) on Rt. 169.
47.7	0.2	Turn left onto Meyers Road.
48.2	0.5	Park by the farm on the left and walk down the hill to the stream.

Stop 5: Unnamed branch of North Creek, Eatonville: Upper Dolgeville - lower / middle Utica Shale contact

We will proceed to the falls above the lower end of the creek section and examine the top 4 to 5 m of the Dolgeville Member, the Dolgeville-lower/middle Utica contact (Thruway discontinuity) and metabentonite (volcanic ash) layers in the lower/middle Utica.

Turbiditic, ribbon limestones of the Dolgeville are visible at the base of the falls and in the downstream bank. In the downstream bank, these beds are of a nearly uniform thickness and spacing, which is typical for large portions of the upper Dolgeville. A low diversity, dysaerobic fauna of graptolites, orthoconic nautiloids, and the trilobite *Triarthrus* is characteristic of these strata, though diminutive *Onniella*, *Rafinesquina*, and *Flexicalymene* can be found in winnowed hash layers in some parts of the Dolgeville. Just below the discontinuity, and extending up to it, is a zone of folded and contorted Dolgeville beds. (Use caution as you ascend the falls; these beds can be slick!) This disturbed zone is seen to better advantage on the New York State Thruway and it is discussed under Stop 6.

The Dolgeville-Utica discontinuity is slightly undulatory here due to effects of differential compaction over beveled limestone beds, and/or, secondary diagenesis along the contact. A lag zone of phosphatic hash overlies this break with subsidiary phosphatic debris layers recurring through the next 10 m of section. Phosphatic debris includes orbiculoid fragments , phosphatic rod-like structures possibly belonging to *Sphenothallus*, diminutive *Onniella*, corroded pelmatozoan grains, and comminuted graptolites. On the Thruway and in sections near Middleville and Norway, a spectacular lag of imbricated,corroded ribbon limestone fragments is present on this contact. These clasts display pitted exteriors characteristic of dissolution; partly exhumed *in situ* limestone beds at the section northeast of Norway display interior crack systems which have been extended and widened by this same process, allowing lag debris to work its way into the cracks.

The lower/middle Utica Shale consists of very hard, laminated shale with thin ribbon limestones and metabentonite layers. Graptolites are common and are spectacularly current-aligned on several bedding planes. Two excellent metabentonites can be examined in the falls; these beds appear as pasty, pale gray layers. New "fingerprinting" techniques, which allow identification of specific ash beds (specific eruption events) as geochemically unique, are presently being applied to these layers in still another approach to working out Trenton-Utica stratigraphy.

The Utica Shale at this section is distinctly older than that observed at Stop 2; the upper beds of this lower/middle Utica strata yield the graptolites *Climacograptus typicalis* and *Dicranograptus nicholsonii* whereas the upper Utica Shale at South Trenton contains *C. pygmaeus*, a distinctly younger graptolite (Kay, 1953; Riva, 1969). This change reflects, in part, the northwestward overlap (termination) of progressively younger Utica beds against the discontinuity surface in that direction. It also reflects the additive merging of the Thruway discontinuity with the younger Honey Hill discontinuity due to erosional overstep (see text: Figures 2, 6, 7).

As indicated earlier, the age of the upper Dolgeville, seen at this section, and at Stops 4, 6, and 7, is problematical with respect to the Trenton Limestone. The lower part of Dolgeville (perhaps 10 to 13 m) and lower Canajoharie strata can be matched with the Poland Member using graptolites (Kay, 1953). However, the >22 m-thick upper Dolgeville tongue of the Norway - Kast Bridge area clearly overlies the top- Wolf Hollow corrosion surface, hence it cannot be linked with anything older than the Brayton Corners division at Trenton Falls. The great thickness of upper Dolgeville (and upper Canajoharie) strata relative to the upper Russia interval at Trenton Falls and at Gravesville opens the possibility that the upper Dolgeville may be time-equivalent with the Rust Member. This hypothesis remains to be tested.

48.2	0.0	Retrace route to Rt. 28.
52.3	4.1	Turn left (south) onto Rt. 28.
54.0	1.7	Enter the village of Herkimer.
55.2	1.2	Turn right to continue following Rt. 28 south.
55.7	0.5	McDonald's (a possible rest stop) is on the right.
55.9	0.2	Turn left to continue following Rt. 28 south.
56.1	0.2	Bear right on Rt. 28 towards the thruway entrance.
56.4	0.3	Turn left to the thruway entrance ramp. Bear right after going through the toll gates.
56.8	0.4	Merge with US Interstate 90 (east)
57.0	0.2	Cross the mighty Mohawk River.
60.0	3.0	Thick bedded Dolgeville carbonates crop out on the right (south) side of the highway.
61.4	1.4	Low outcrops showing Dolgeville and lower/middle Utica strata are on the right (south) side of the highway.
63.3	1.9	Pull over to the shoulder of the thruway.

Optional Stop 6A: New York Thruway: The Thruway discontinuity

This (along with optional Stops 6B and 6C) will be a relatively brief stop owing to hazardous traffic. We will stay in vehicles and observe outcrop features from van windows.

This outcrop exposes essentially the same section as at Stop 5. However, this roadcut is cleaner, more extensive, and much more dramatic. Only the upper succession of Dolgeville strata is visible at this locality. Note that the upper Dolgeville contains densely packed beds of calcilutite and calcisiltite. In this region, top Dolgeville strata are underlain by a middle, shale-rich Dolgeville interval which contains relatively few ribbon carbonate beds. This middle Dolgeville interval, in turn is underlain by a calcilutite-rich lower Dolgeville succession which correlates with the Poland Member and the lower part of the Wolf Hollow division; the base of the Dolgeville however, is quite shaley. This "double paired" pattern of shaley strata giving way to more calcareous strata continues east to the Canajoharie region. On Flat Creek for example, the uppermost Canajoharie Shale is actually a Dolgeville lithology and contains closely spaced ribbon carbonate beds.

Most notable in this roadcut are the numerous folds which are best developed in the top 1.5 m of the Dolgeville. This zone of deformed strata can now be traced for at least 20 km from a small creek northeast of Norway to Nowadaga Creek (north of Newville). Lower Dolgeville beds are also locally deformed, as can be seen on the Thruway approximately 2 km west of Stop 6, but the highest deformed zone is the most conspicuous and persistent.

The cause and timing of this folding is controversial, and it is central to hypotheses concerning the inferred sequence of events associated with the Taconic Orogeny. Fisher (1979) noted that axial planes of these slump folds typically dipped to the east, indicating a down-to-the-west paleoslope, and postulated that the paleoslope reversal was the result of compressional upbuckling of the Adirondack Arch. Work by Bradley and Kidd (1991) outlining the dynamics of this sort of "flexural extension" largely supports this interpretation. Clearly, a number of features indicate that this deformation is the result of post-depositional slumping. Firstly, although most deformation is ductile, fracturing and brecciation does occur in the deformed zone. Furthermore, even ductiley deformed strata contain wedge-shaped fractures suggesting that this sediment was partly lithified. Secondly, most folds incorporate numerous beds.

At West Crum Creek, 5 km to the east of Little Falls, slump features indicate a more complex scenario. At that locality, most slump features indicate a northeastern dipping paleoslope; however, some folds indicate slumping towards the southwest. Perhaps these slump features represent a number of episodes of fault block adjustment. Similarly, directions of fold axes tend to be polydirectional at Nowadaga Creek, suggesting the possibility of muliple deformation events.

Above the folded beds is a sharp horizontal contact marking the change to lower Utica deposits. As we saw at Stop 5 and will see at Stop 7, this is an erosional discontinuity marked by reworked phosphatic lag debris, disseminated pyroclastic material, and localized concentrations of variably corroded, reworked Dolgeville limestone intraclasts. Furthermore, the uppermost micritic ribbons of the Dolgeville are coated by a pyritic crust. Because the contact between the Dolgeville and the lower/middle Utica is so well exposed at this locality, we refer to this contact as the "Thruway discontinuity."

The Thruway discontinuity appears to breach many of the underlying folds such that many of the anticlines are "bald headed" structures. This indicates that post-Dolgeville, pre-Utica submarine erosion would have occurred after the folding event. Since we envision the episode of erosion as having taken place during a period of relative sealevel rise and consequent sediment-starvation to the region, it is interesting to speculate that the folding event may have been a seismic harbinger of tectonic deepening of the basin. Again, we must note that the relationship of the fold horizon to the upper Trenton Limestone of the Poland-Prospect region is problematic; these folds may link to one the deformed zones in the Rust Member or to Brayton Corners strata (see text, Stop 1).

64.1 0.8 Pull over to the shoulder of the thruway.

Optional Stop 6B: New York Thruway: Lower/middle Utica strata.

Along this portion of the roadcut, the lower/middle Utica Shale, which overlies the Dolgeville, is well exposed. As noted at Stop 6A, the contact between the Utica Shale and underlying Dolgeville strata is unconformable. Note, the metabentonite which forms a prominent rusty recession in the outcrop approximately 1.75 m above the base of the Utica. This particular metabentonite was seen at Stop 5 and will be seen at Stop 7. Other thin metabentonites can be seen in this roadcut and also in the "Black Canyon" (Stop 6C). Qualitatively, we have noticed that metabentonites typically are present in condensed intervals.

Also note that the lower/middle Utica strata in this outcrop contains thin, rusty (pyritic?), calcilutites. Locally, the lower/middle Utica succession between the Thruway discontinuity and the Honey Hill discontinuity is crudely divisible into three lithostratigraphic successions: 1) a lower calcilutite-rich interval, 2) a middle calcilutite-poor, black shale interval, and 3) an upper calcilutite-rich interval.

Finally, note that this outcrop contains numerous small faults. These faults which displace both Dolgeville and overlying Utica strata belong to the Little Falls fault zone. The major fault of this fault zone, the Little Falls fault (> 1 km to the southeast), has a vertical displacement of 155 m (Bradley and Kidd, 1991).

65.2 1.1 Take the Little Falls exit to leave the thruway.

65.4 0.2 Pull over to the shoulder of the exit lane.

Optional Stop 6C: Little Falls exit, New York Thruway: Utica strata of the "Black Canyon"

As we drive through the "Black Canyon," note the apparently monotonous nature of the Utica black shales. A number of thin metabentonites (which form rusty recessions in the outcrop) are present at this locality. The metabentonites along with graptolite zonation offer key--yet sometimes controversial--stratigraphic information for regional correlation of Utica strata (see Cisne and Rabe, 1978; Mitchell and Goldman, 1991).

65.9 0.5 Toll booth. Go through toll gate (after paying toll) and follow Rt. 169 north.

66.4 0.5 Junction of Rts. 5S and 169. Continue north on Rt. 169.

67.9 1.5 Take bridge across the Mohawk River.

68.3 0.4 Turn right on Rt. 5W. Drive through the graffiti-enhanced canyon of Precambrain Grenville basement.

68.6 0.3 Turn left (north) on Rt. 167.

71.0 2.4 Turn left to continue following Rt. 167.

74.3 3.3 Enter the village of Dolgeville.

74.9 0.6 Turn right on Faville Avenue. Follow Faville Avenue to Niagara-Mohawk power station.

75.6 0.6 Park outside of the power station gates.

Stop 7: East Canada Creek, Dolgeville: Drag-folded Dolgeville and Utica strata.

Along East Canada Creek, below the Dolgeville Dam, the upper 15 m of Dolgeville strata and a large thickness of the overlying shales of the lower/middle Utica are spectacularly exposed in a drag fold along the east side of the creek. This drag fold is associated with the Dolgeville Fault, another of the syntectonic normal faults of the Mohawk Valley region.

Many of the features discussed and seen at Stops 5 and 6 are also readily examined at this outcrop:

1) The upper Dolgeville strata are slump-folded, but, due to the drag folding process, slump folding is not as evident as at Stop 6.

2) The Dolgeville strata are overlain by a 5 cm-thick phosphatic lag which we will sample if the stream level is low.

3) A metabentonite forms a prominent recession in the outcrop approximately 1.5 m above the Dolgeville-Utica contact.

4) The lower/middle Utica contains rusty-weathering calcilutites. However, calcilutite beds are less numerous than in lowermost Utica strata at Stop 5. This may be due to distance from a carbonate source, proximity to a siliciclastic source, and accommodation space (subsidence). Alternatively, we may be seeing a slightly lower stratigraphic interval at Dolgeville which is not represented at Stop 5 or is represented by condensed facies in that area.

Well developed fine-grained turbidites (T_{bcd}) are present in the Utica. Winnowed shell lags containing trilobite hash, small brachiopods, and current-aligned graptolites within black shales, however, indicate that not all downslope-directed currents resulted in deposition.

75.6 0.0 Retrace route to the thruway (US Interstate 90).

85.3 9.7 Take the thruway west.