Trip A-4 & B-1

CLASSIC LOCALITIES OF THE BLACK RIVER AND TRENTON GROUPS (UPPER ORDOVICIAN) IN THE BLACK RIVER VALLEY: REVISITED THROUGH TRADITIONAL AND SEQUENCE STRATIGRAPHY

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INTRODUCTION

The late Ordovician (Mohawkian Series) Black River and Trenton groups of the northern New York State consist of some 250 m of highly fossiliferous, well-preserved limestones with some intervening shales. These rocks are exposed along a southeast-northwest trending outcrop belt for more than 250 km in central New York and neighboring Ontario, where they closely flank the Precambrian Grenville Province (Figure 1). These units

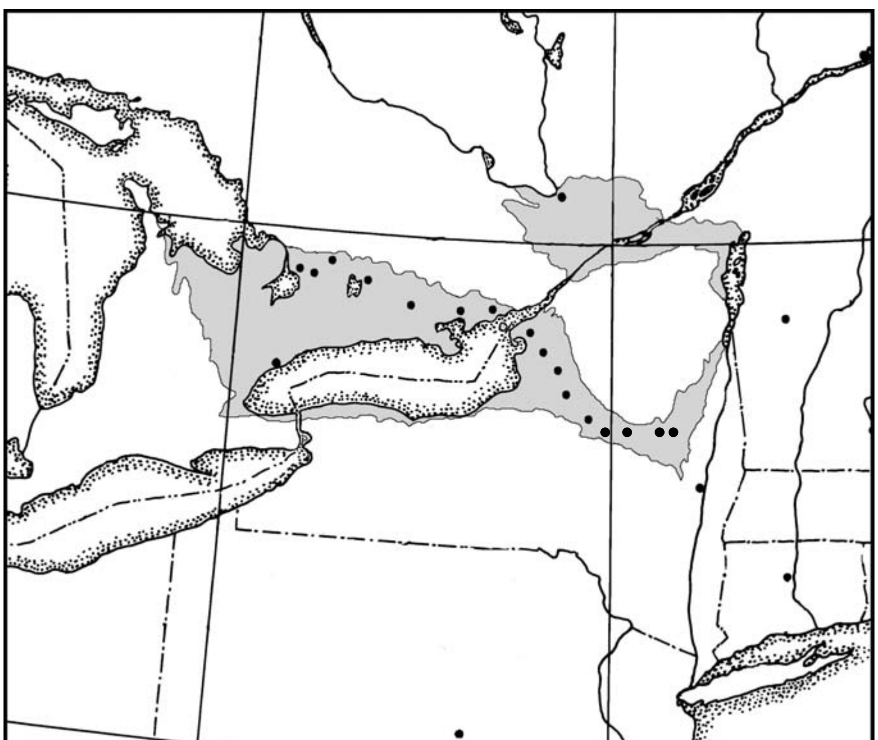

Figure 1 - Ordovician outcrop belt in New York, Ontario, and Quebec are shaded in grey. Key Black River & Trenton Group outcrop localities are indicated within the outcrop belt.

deposited from ~457-450 million years ago, have been studied for nearly two centuries and have become very important units for the study of paleontology, carbonate sedimentology, stratigraphy, paleoclimatology, paleoceanography, paleoecology, structural geology, and more recently, petroleum and natural gas geology. Mostly known from the renowned Mohawk Valley sections including those at Trenton Falls on West Canada Creek, the Black River and Trenton play (and have played) an important role in our understanding of depositional processes, environmental change and even mountain building and plate tectonics. The purpose of this field trip is to revisit the classic stratigraphy of the Black River and Trenton groups, and to introduce some of the modern research ideas that are being applied to answer long standing questions regarding the history of these rocks.

GEOLOGIC BACKGROUND

Absolute and Relative Time Scale:

The Black River and Trenton units, originally defined in central New York State (Vanuxem, 1842), are among the earliest formally designated stratigraphic units in North America (Figure 2). As a consequence, the names of these well-known intervals were applied in a variety of localities not only within the New

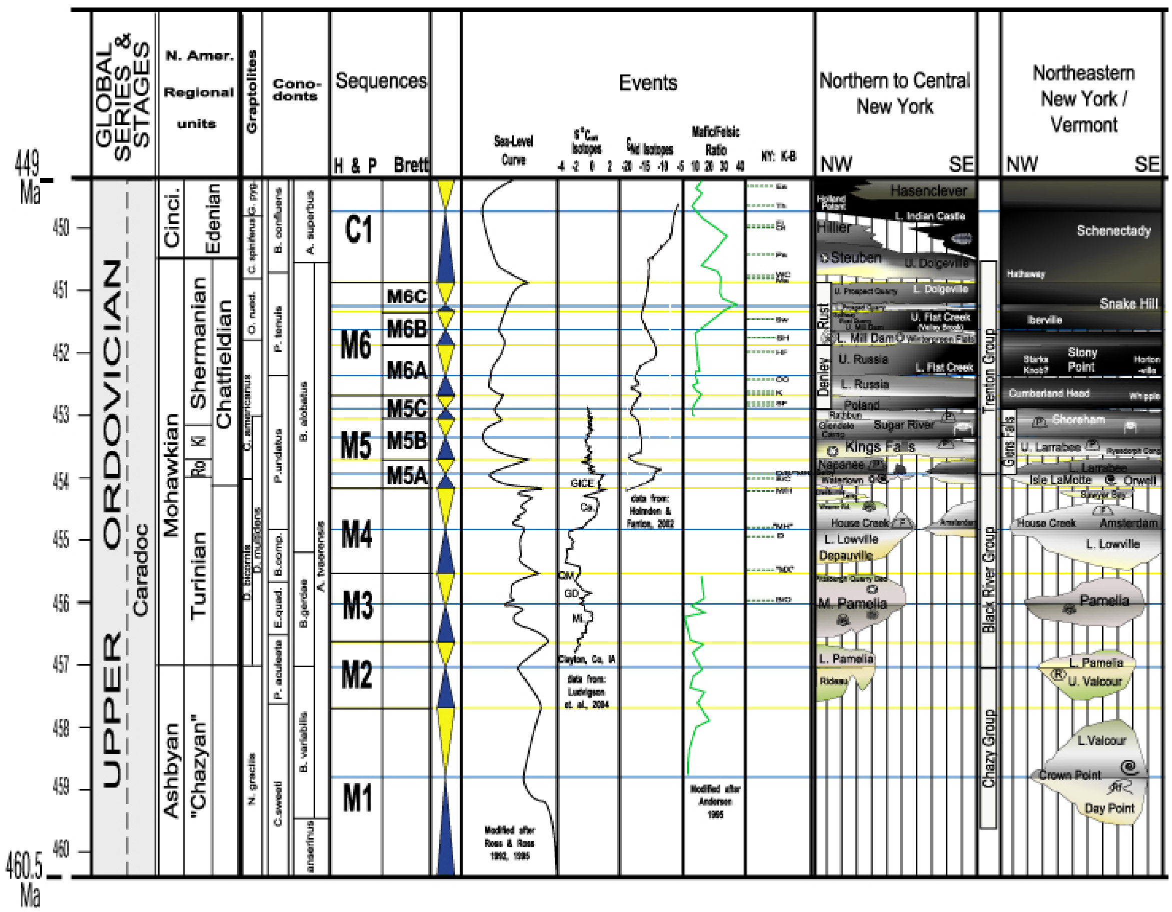

Figure 2 - Upper Ordovician Relative and Absolute Chronostratigraphic Chart. Illustrated are the boundaries of the Mohawkian Series and internal stage boundaries. In addition, positions of key biostratigraphic zones for graptolites and conondonts, as well as 3[rd]-order depositional sequences of Holland & Patzkowsky (1996) and Brett et al., (2004) and important chemo- and event stratigraphic horizons are established. Abbreviations: Ro. = Rocklandian; Ki. = Kirkfieldian.; Cinci = Cincinnatian

York region, but throughout much of eastern North America. Originally these units were described on the basis of gross lithology, however, subsequent investigations looked at these not just as rock-units, but also as a series of distinctive biostratigraphic units which were considered as time-rock units that were sometimes used interchangeably with the original lithologic rock units. The practice of using rock-terminology and time-rock terminology as interchangeable was eventually challenged as it was surmised that rock units themselves did not have a relative time component and indeed in some cases were diachronous through time according to Walther's Law. Not surprisingly, stratigraphers have discouraged the use of lithostratigraphic terms for time-rock terms. As such the older lithology-based rock terminology (i.e. Black River, Trenton) are strictly to be used as descriptors of lithology, while new nomenclatural terms are established to reflect relative chronology. Among these are the stage level classifications of Kay (1937, 1960) which include the Rocklandian, Kirkfieldian, and Shermanian stages for the Trenton Group, and in order to accommodate a return of the older Black Riveran (time-rock) to Black River Group (rock-unit) as was originally intended, Fisher's (1977) term Turinian, has been instituted. More recently, what was called the Trentonian Stage is roughly equivalent to what is now termed the Chatfieldian Stage (Leslie and Bergström, 1995), and collectively the Turinian and Chatfieldian Stages make up the Mohawkian Series as part of the North American time-rock classification. However, the alternative stage classification, using Kay's (1937) more precise subdivisions of the upper Mohawkian Series: the Rocklandian, Kirkfieldian, and Shermanian stages, are still useful in the type region, and are also still in common use in neighboring regions despite some recent opposition.

The interval of time embraced by the Black River and Trenton Groups lies now entirely within the Late Ordovician, and not the Middle Ordovician as previously defined. It should be noted that the IUGS Subcommission on Ordovician Stratigraphy has recommended that the interval previously termed Middle and Upper Ordovician (i.e. the Llandeilo, Caradoc, & Ashgill stages; which include the Chazy, Black River and Trenton interval) all be assigned to Upper Ordovician (Webby, 2004). In the British classification the entire Upper Ordovician interval is assigned to the Caradoc Series (now in emended use as the Caradocian Global Stage) (*see* Figure 2).

Absolute age dating for this interval has become a more realistic endeavor in recent years as multiple K-bentonites have yielded datable phenocrysts both inside and outside of the New York region (Samson *et al*. 1988, Haynes, 1994; Kolata *et al*., 1996, Min et al., 2001; McLaughlin *et al*., 2005; McLaughlin *et al*., in press). Two widely distributed K-bentonite horizons, the Deicke and Millbrig, have been dated by a number of geochronometric systems (*see* Figure 2). The resulting ages using U/Pb dating methodology are established at about 454.5 +/- 0.25 Ma for the Deicke K-bentonite; and to 453.1 +/- 0.65 Ma (for U/Pb dates of zircon) for the Millbrig (Min et al., 2001). Moreover, recent dating of the High Falls K-bentonite (from Trenton Falls) has yielded a highly concordant date from U/Pb zircon date of 451.8 +/- (McLaughlin *et al*., 2005, McLaughlin *et al*. in press). Based on these assessments and by extrapolations from dates on the Ordovician-Silurian boundary, the entire Black River to Trenton Group interval ranges from approximately 457 to 450 million years providing for 6-7 million years of deposition.

Tectonic Setting:

During the late Middle Ordovician, the majority of ancestral North America (Laurentia) was covered by shallow tropical seas commonly referred to as the "Great American Carbonate Bank." At this time, the eastern portion of Laurentia was rotated approximately 60 degrees clockwise relative to its present configuration, and the New York region was located approximately ~30º south of the paleoequator (Scotese *et al*., 1994). Due to the onset of Sloss's (1963) Tippecanoe Megasequence in the earliest Upper Ordovician, sea-levels were, over the long-term, in a transgressive phase such that during the deposition of the Trenton very little land was exposed on the continent. In fact, the only exposed areas were portions of the modern Canadian shield and areas along the Transcontinental Arch that were in general of very low relief (Figure 3). Although we have no epicontinental seas comparable to the size of the Laurentian Great American Carbonate Bank, modern regions such as Florida Bay and the Bahamian Platform are commonly used as analogs for understanding the conditions of the Laurentian craton at that time.

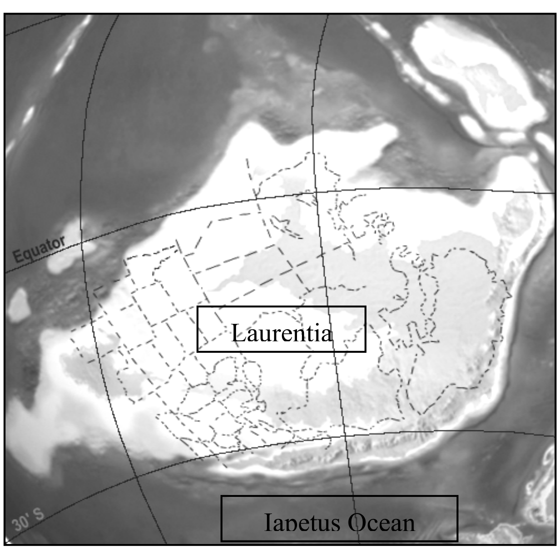

Figure 3 - Paleogeographic reconstruction of Laurentia. Dashed lines indicate the relative position of modern political boundaries for reference (modified from Blakey, 2003).

Moreover, at the time the Black River and Trenton limestones were deposited, the eastern margin of Laurentia had begun to undergo a major paleoceanographic, paleoclimatic, and paleoenvironmental transition associated with the onset of the Taconic Orogeny. The subsidence of portions of the Laurentian craton in Chazy time during the early or Blountian tectophase of the Taconic Orogeny ended a period of over 30 million years (U. Cambrian to M. Ordovician) where virtually no tectonic activity occurred on the craton. However, in the 6-7 million year period that ensued, the Laurentian margin of the present day eastern United States was impacted by the development of two pulses of collision (or tectophases). The first tectophase was located south of New York in the vicinity of Tennessee and impacted sedimentation in the Sevier Basin and neighboring regions throughout the Turinian (Figure 4). The second tectophase, referred to as the Vermontian Tectophase collided in the vicinity of the New York Promontory producing the Martinsburg Basin during the deposition of the Trenton Group in the Upper Mohawkian. This later event ultimately influenced changes across the entire eastern Laurentian Craton as far west as Minnesota.

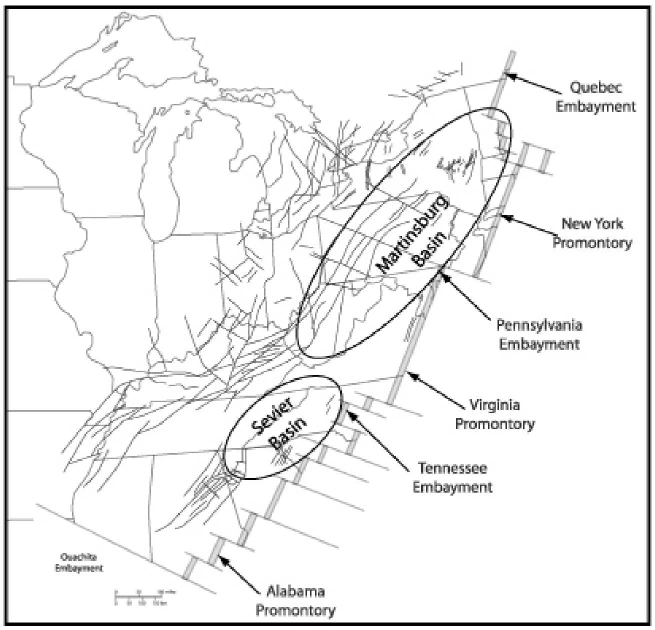

Figure 4 - Extent of the post-Iapetan rift margin of eastern Laurentia upon which the Great American Carbonate Bank Developed. Highlighted are the position of key transform and rift segments that are responsible for the development of an irregular series of promontories and embayments (after Thomas, 1991). In addition, the position of two basins induced by the Taconic Orogeny: the southern or Sevier Basin (Blountian Tectophase) and the northern or Martinsburg Basin (Vermontian Tectophase) is shown. Also indicated are the position of key fault structures that are either Pre-Cambrian rooted or have been demonstrated to have had Taconic-related movement.

Although the exact relationships of these tectophases have been studied (Ettensohn, 1991, 1994) many circumstances of their temporal-spatial relationships are still being worked out. In spite of this, however, it is now fairly certain that the development of orogenic activity on the eastern Laurentian margin resulted from the subduction of the cratonic margin of Laurentia under the closing Iapetan Oceanic plate resulting in the development of a foreland basin (Shanmugam & Lash, 1982; Rowley & Kidd, 1981) or deep-water moat exterior to the cratonic interior termed the Champlain Trough (Kay, 1937) into which siliciclastic sediments derived from the collisional belt were deposited (Figure 5).

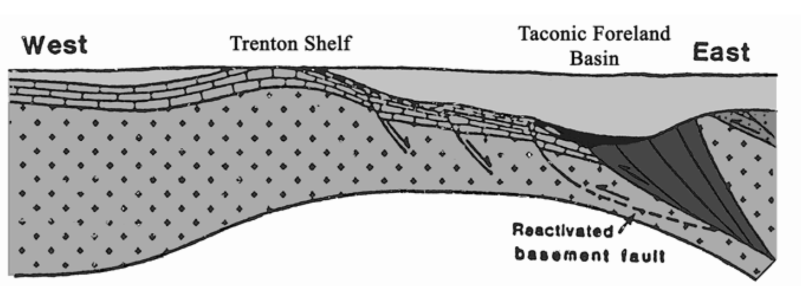

Figure 5 - Schematic Cross-Section of Trenton Shelf and Taconic Foreland Basin during early Kirkfieldian Time. Notice the development of an accretionary prism introducing a deformational load to the eastern margin. Outboard of the accretionary prism, is the location of the volcanic arc which during the Trenton delivered significant quantities of sediment into the foreland basin and up onto the craton (Modified after Shanmugam & Lash, 1982)

These siliciclastic sediments were dominated initially by clays (hence the predominance of shaly limestones in the Trenton) but in later phases of each orogeny clays were replaced upward and laterally by silts (siltstones) sands (sandstones) and even gravels (conglomerates) as tectonic activity subsided and the foreland basin was filled in. Although both tectophases produced similar basin fill packages, provenance studies of these siliciclastic sediments have highlighted a major difference in the source of Blountian and Vermontian sediments (Mack, 1985; Andersen, 1995; Bock et al., 1998). These data from both sandstones and mudrocks, suggest Blountian sediments were derived from accretionary prism sources that were scraped off the cratonic margin during the initial subduction and collision of the Blountian tectophase (Figure 4). On the other hand, sediments derived from the Vermontian tectophase (including those of the Trenton Group) indicate a significant shift to volcanic source rocks indicating a fairly major difference in tectophase processes (*see* Cornell, 2005).

Within the field trip region, these tectonic settings are expressed through a variety of observations: First within both adjacent Ontario and in the central and southern Black River Valley, Precambrian basement rocks are surrounded and onlapped by the carbonate rocks of both Black River and Trenton affinities. This suggests that there were some small islands of low lying granitic basement exposed near the shore of eastern Laurentia (Brookfield, 1988). Although dominantly carbonate, initially, the relatively flat low-lying shield complex allowed the deposition of discontinuous siliciclastic-rich sediments in topographically low areas and at times, especially during lowering sea-levels these quartz-rich siliciclastics were remobilized and carried out across the carbonate platform for some distance. In the ensuing transgressions, these siliciclastics were extremely scarce. As such, the general lack of siliciclastic sediments in the almost pure carbonate succession of the Black River indicates very little transport and introduction of terrigenous craton-derived sediments into the local depositional regime. Therefore, this suggests a fairly arid climate and/or a very low elevation with a broadly peneplained configuration for the Grenville Shield and neighboring islands.

Second, within the foreland basin succession and on the adjacent shelf, early in the depostion of the Black River and continuing throughout the deposition of the units are the occurrences of K-bentonite or altered volcanic ash. The predominance of these K-bentonites supports the theory of a volcanic island arc located offshore. Responsible for the largest volcanic eruptions in earth's history (Kolata *et al*., 1996; Huff *et al*., 1992), this volcanic terrain referred to variably as the Ammonoosuc Arc (Rowley & Kidd, 1981) or Shelburne Falls Arc (Karabinos *et al*., 1998) was beginning to migrate towards the northeastern margin of Laurentia as it was subducted.

Climatic Setting

The Black River and Trenton Group sediments of New York State accumulated in subtropical to sub-temperate latitudes, ranging from about 25° to 30°S of the paleoequator (Scotese, 1990). Although very much dominated by tropical carbonates throughout much of the Ordovician, Mohawkian strata record the critical change from the widespread shallow carbonate platform of the Great American Carbonate Bank into the actively subsiding Taconic foreland basins. In the New York region, the impact of Blountian-aged siliciclastic sedimentation is lacking as is the case within much of the region of the subsequent Taconic Foreland Basin. As such clean, peritidal to shallow subtidal Black River carbonates were widespread in the New York region and contained algae and coral-dominated faunas. Subsequently with the onset of the Vermontian phase of the orogeny, the Black River rocks give way vertically and laterally to mixed carbonate/siliciclastic units with

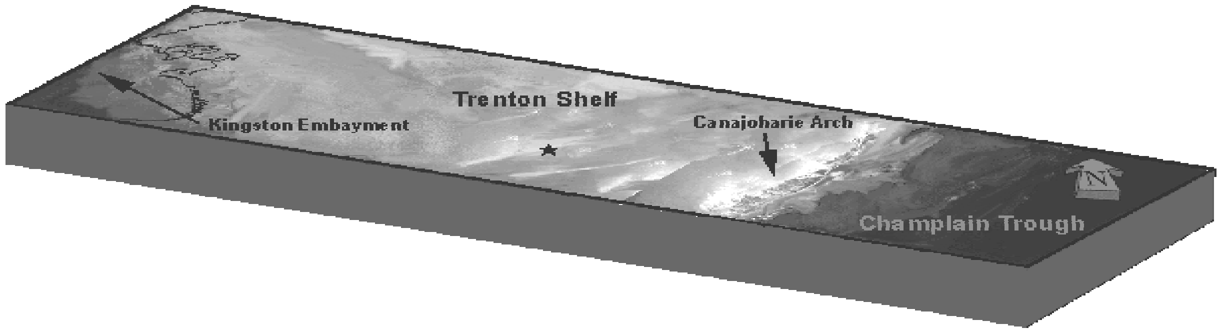

Figure 6 - Paleogeographic reconstruction for the New York (Trenton Shelf Region) during the earliest Trenton (L. Rocklandian and Kirkfieldian) just prior to the major advance of the Martinsburg foreland basin (Champlain Trough) into the eastern New York region. Notice the Canajoharie Arch, a topographically high region during deposition of most of the Black River and lower Trenton. This exposed arch was initially submerged intermittently during periods of high sea-level (i.e. Upper Rocklandian) and exposed and eroding during periods where sea-level was low. Moreover, the Canajoharie Arch acted as a local barrier to open ocean circulation and may have influenced deposition during the latest Turinian through early Shermanian. Thereafter, the Canajoharie Arch became submerged (inverted?) and no longer influenced carbonate sedimentation in that region.

diverse brachiopod-bryozoan-echinoderm biotas and, finally, to black shales. As a result, Laurentia witnessed oceanographic, environmental, and climatic changes which are presumably responsible for concomitant faunal change. In this regard, observations of various outcrop regions suggest an important difference between the Black River and Trenton interval was a difference in climatic regime possibly related to Taconic tectonism. Brookfield (1988) has argued for a cool water (temperate) carbonate depositional regime extending through the entire Black River and Trenton interval in southwestern Ontario (Lake Simcoe), based largely on sedimentologic evidence (e.g., lack of reefs, calcareous algae, and ooids; common occurrence of peloids, and increasing Sr values from Black River into Trenton rocks). Whereas Holland and Patzkowsky (1998) suggested that the Trenton interval was transitional from tropical Black River to temperate post-Trenton intervals. In contrast to Brookfield's observations in southwestern Ontario, and supportive at least in part of Holland and Patzkowsky, many workers in New York and southeastern Ontario have recognized the dominance of many calcareous algae, ooids, and even in some horizons evaporite crystal molds and primary dolomites. These observations suggest that deposition was at least tropical to sub-tropical (at times fairly arid?) and occurred under warm water conditions for at least part of the interval.

STRATIGRAPHY OF THE BLACK RIVER AND TRENTON GROUPS

As mentioned previously the Black River and Trenton Groups have been studied for well over a century and have been, almost since the beginning, a topic of contention and debate for generations of geologists resulting in many revisions and reassessments in stratigraphic nomenclature (Figure 7). Part of this contention and debate stems from: 1) their predominance in early geologic studies of North America such that these units were often used as "guinea pigs" for the education of students, 2) the implementation of new stratigraphic methods (using advanced science) which required the re-evaluation of some of the older long-standing ideas, and to some extent 3) the complex and disconnected outcrop regions which offer minimal continuous exposure and apparent geographic variability. Despite their long-standing history of research, the Black River and Trenton groups are once again the subject of major new discoveries within the immediate region of New York, and within the larger cratonic setting of eastern Laurentia. Moreover, newly recognized chemostratigraphic events (*see* Figure 2) have been studied over fairly broad regions of eastern North America and even in Scandinavia and Estonia (Ludvigsen *et al*., 1996; 2004; Saltzman *et al*., 2001; Bergström *et al*., 2004) and suggest that the transition from the Black River into the Trenton was a fairly major event that was certainly trans-Iapetan in nature and may have even been global.

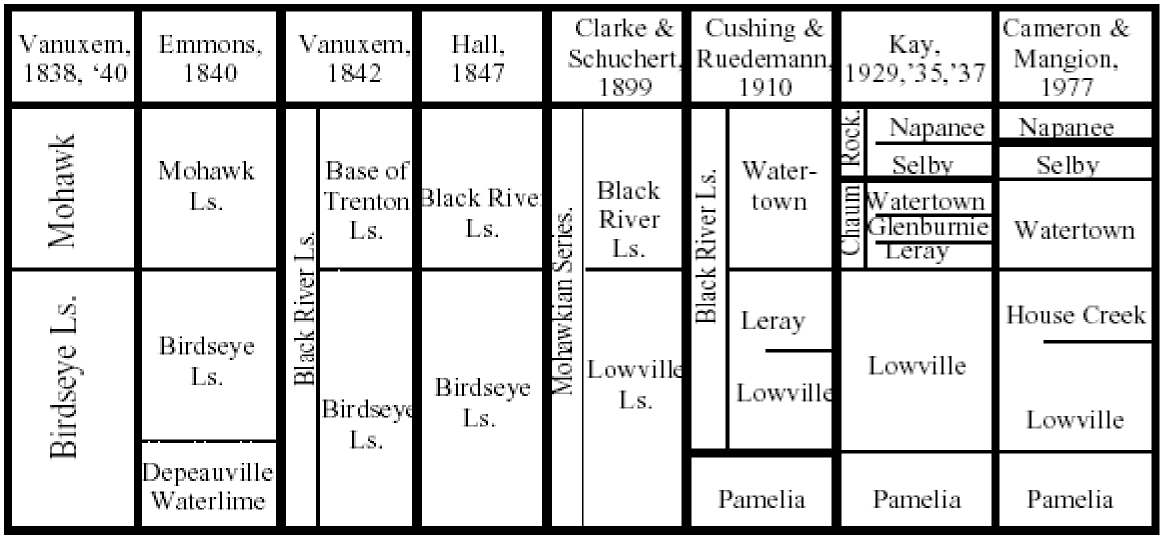

Figure 7 - Historical nomenclature for the type Black River to lower Trenton Group interval for New York State. Note the position of the Black River-Trenton Group Boundary (drawn in bold black line) as drawn by Kay at the base of the Selby, and Cameron & Mangion at the base of the Napanee (from Cornell, 2001).

History of the Black River - Trenton Group Boundary

Given the predominance of previous stratigraphic studies, the stratigraphic details of the Black River-Trenton Group boundary is still problematic in the type section areas and this has led to major correlation controversies outside of the New York State type region. A major dilemma in this issue has been the paucity of outcrop exposures in the specific boundary interval within the Black River Valley thus limiting their interpretation. As such, most stratigraphic studies of the boundary have been completed in the Mohawk Valley region where the Black River Group itself is highly modified and abbreviated by surfaces of non-deposition, extreme facies change, and erosional truncation-karstification. These details are only now being worked out, but historically the position of the Black River/Trenton boundary has been debated (Kay, 1937; Fisher 1962; Titus & Cameron, 1976; Cameron & Mangion, 1977) for nearly a century (*see* Figure 7).

Most recently, the boundary has been synonymous with top Turinian or base Rocklandian in the type area (Fisher, 1962). This placement corresponds to a position at the base of the Selby Formation (of earliest Rocklandian Age) and at the top of the Watertown Formation of uppermost Turinian Age (Figures 2 & 7). This particular boundary interpretation is drawn on a biostratigraphic basis and in the Black River Valley region, this biostratigraphic interpretation is born out through the development of a subtle facies dislocation across a mineralized hardground surface. When traced into the abbreviated and substantially thinned sections of the Mohawk Valley, the equivalent of the sub-Selby facies dislocation is represented by a distinctive lithologic boundary separating off-shore deeper-water facies from underlying shallow water facies at a marked discontinuity (Kay, 1935; 1937). This very shallow-water equivalent of the Watertown and the overlying deeper-water Selby is coincident with the same biostratigraphic transition as in the Black River Valley, but as the lithostratigraphic distinctiveness of this contact is minimized it has not been accepted universally. On this basis, Cameron and Mangion (1977) have established the boundary position not at the biostratigraphic base of the Rocklandian (as in the Mohawk Valley), but at the more pronounced lithologic break at the top of the Selby and base of the Napanee. In both the Mohawk and Black River Valleys this particular surface is quite pronounced by the first appearance of shales and interbedded calcisiltites, and micritic wackestones. However again, this particular delineation is also complicated due to the thin condensed and mineralized nature of the underlying Selby (25-30 cm), as such, it has commonly been overlooked.

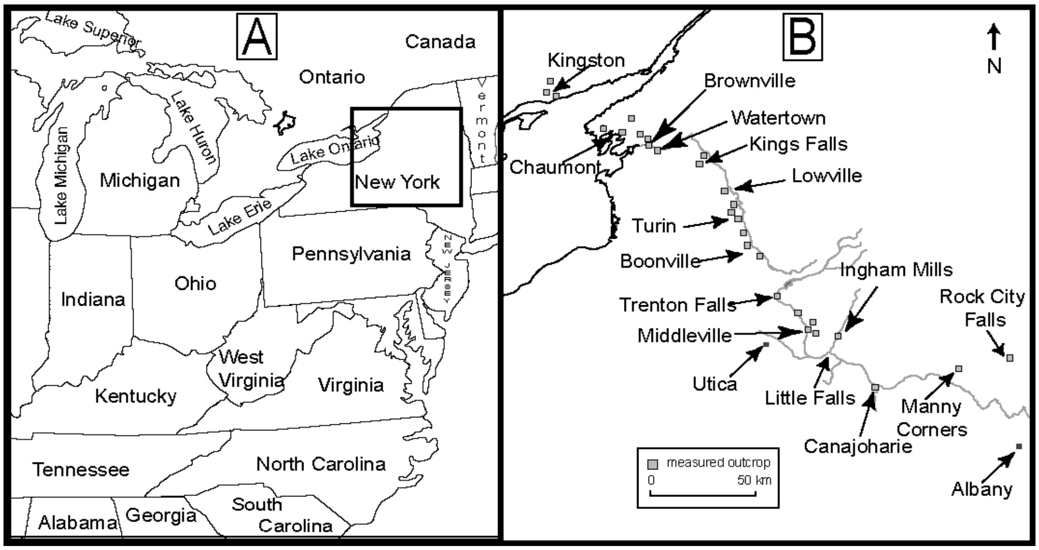

Figure 8 - Important Black River to Trenton Group outcrop localities in New York State. Field trips stops are located in the vicinity of: Chaumont, Brownville, Kings Falls, Lowville, Boonville, and Turin.

Adding to the controversy, another contact (recognized by 19th century geologists) occurs at the top of the "Birdseye Limestone" and base of the overlying Mohawk or Trenton Limestone. For decades this lithologic contact was the important lithologic delineation recognized by geologists. This particular contact was de-emphasized in later studies because the massive-bedded Watertown Limestone, although not equal to the Birdseye, was more similar to it than the overlying thin-bedded and argillaceous limestone of the basal Trenton. In the Mohawk Valley where the Watertown was not previously recognized, the basal Trenton contact approximated this stratigraphic position which suggested that the entire Watertown had been truncated in this region at the base of the Rocklandian – a position held by Kay. However, through detailed correlations Cornell, (2001) was able to identify a lateral (isochronous) transition in the Watertown from off-shore to more onshore intertidal facies in a southeasterly direction. Thus at the base of the shallowest Watertown equivalent facies in the Mohawk Valley, a distinct channelized and karstic surface is documented at Inghams Mills where several meters of underlying Birdseye have been truncated by pronounced erosion (*see* below). The same contact in the Black River Valley is also documented by truncation of underlying units, although the amount of truncation becomes less and the contact is more subtle where the basal Watertown grainstone is not readily apparent. Thus although the boundary at the top of the Birdseye has since previously been abandoned, there is the possibility (and precedence) for establishing the lithostratigraphic and biostratigraphic boundary at the base of the Watertown and not at its summit (*see* below).

Outside of the New York type region, the complexity of this argument has promulgated an unenthusiastic view of New York nomenclature and there have been attempts to apply, rework, or otherwise abandon the type region classifications for lithostratigraphic and time-rock or stage nomenclature (which means the abandonment of Kay's time-rock terms: Rocklandian, Kirkfieldian, and Shermanian) in lieu of a newer stage called the Chatfieldian (Leslie & Bergström, 1995; *see* Figure 2). The establishment of this particular stage also has furthered an additional complexity to the argument: in that the base of the Chatfieldian Stage is drawn at the position of the Millbrig K-Bentonite. This particular volcanic ash is not yet firmly established in New York State (*see* Mitchell *et al*., 2004; and Brett *et al*., 2004 for this particular controversy). Yet regardless of its placement, if the type New York stage classifications can be highlighted and identified on a more regional scale in relationship to the Millbrig using other chronostratigraphic methods such as sequence stratigraphy these stage classifications have precedence over the Chatfieldian.

General Stratigraphy

The Black River Group, as originally defined in the lower Black River Valley near Watertown, northwestern New York State (*see* Figure 8), is about 60 m thick and has been subdivided on the basis of

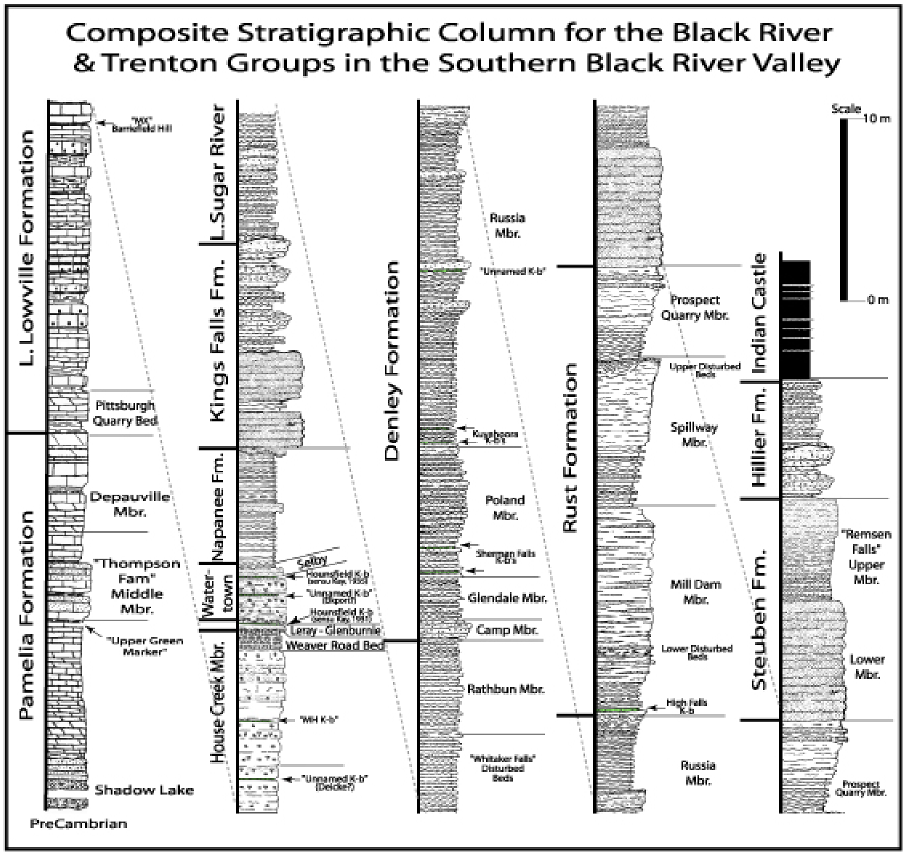

Figure 9 - Standard composite stratigraphic section for the Black River and Trenton Groups in Northwestern New York State. Important stratigraphic units and distinctive markers including K-bentonites, and other unique correlation horizons are identified in the sections (compiled from: Ross, 1968; Brett & Baird, 2002; Brett, et al., 2004, Cornell et al., 2004).

lithostratigraphy into three formations: the Pamelia (40 m), Lowville (17 m) and the Watertown limestone or upper Chaumont (3 m) formations (Fisher, 1977) (Figure 9). Additional units were subsequently named based primarily on biostratigraphic criteria and came to take on a chronostratigraphic connotation. Hence the term Chaumont, originally used for medium to thick bedded carbonates with distinct faunas typified by a wide variety of brachiopods, echinoderms, and cephalopods, was replaced in part by the lithostratigraphic term Watertown, and was modified to be used as the Chaumontian Stage (Kay, 1937). This term is not used at present, but it is included in the uppermost portion of the Turinian below the transition to the Rocklandian. As is illustrated here, many of the early workers including Kay (1937), and Young (1943) considered many of the Black River Groups (and overlying Trenton) to be both biostratigraphically and lithostratigraphically controlled thus often equated time-rock terms and rock-terms and used them interchangeably. Although this practice was discouraged these authors considered many of these units to be fairly isochronous and layer-cake in style (*see* Figure 10: model A) over fairly broad distances and therefore using either a lithostratigraphic or biostratigraphic classification was often sufficient for correlation.

Unfortunately without the specific "total package" understanding of these early workers, combined with loosely-constrained lithostratigraphic boundaries between these major Black River sub-units, many subsequent authors focused on gross lithology (and not fossil content) to establish spatial and temporal relationships of each of these stratigraphic units. Moreover without a major effort to trace out these units from their type sections using substantive internal marker horizons, only minor progress was made in correlating larger facies packages (Johnsen, 1971; Walker, 1973; Textoris, 1977). Thus without fairly well-correlated sections that were constrained using some geochronologic system, the facies distribution of Black River strata came to be viewed as a mosaic of large-scale diachronous facies, with little to no continuity of individual facies over long distances (Figure 10: model B, C). Thus, these strata were once viewed as time transgressive facies, with component facies grading laterally to each other in a large-scale,

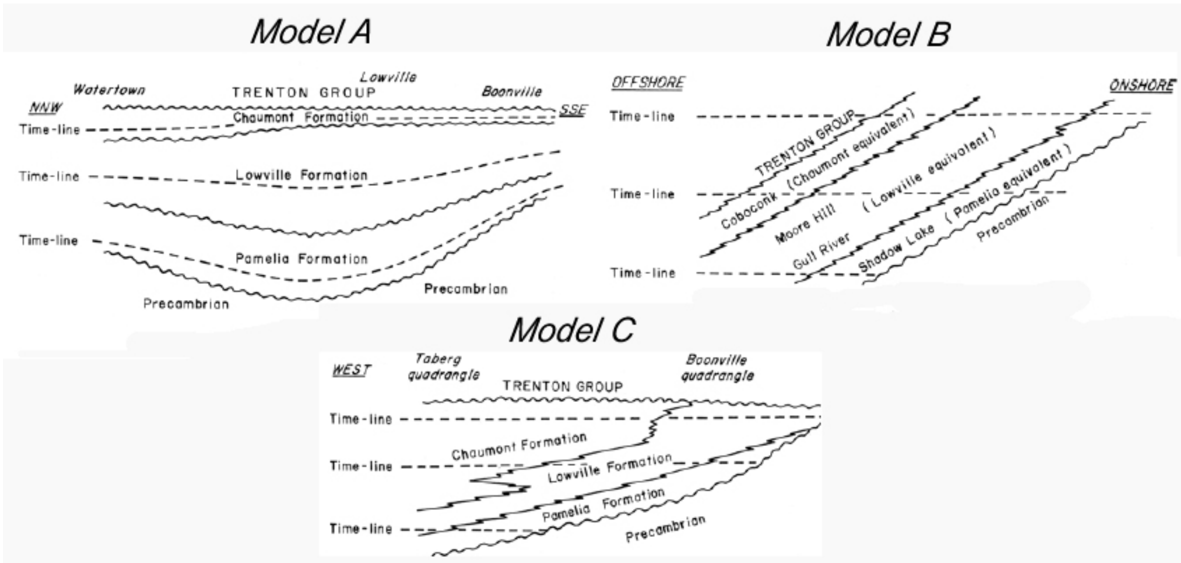

Figure 10 - Depositional models used to explain the relationship of individual Black River and Lower Trenton units. Model A: Time parallel facies model (after Kay, 1937; Young, 1943), Models B & C: Diachronous progradational facies models (B: after Winder, 1960 and C: after Fisher, 1962 and Walker, 1973)

time-transgressive Waltherian manner (*see* Figure 10). These models have been tested in recent studies (Cornell, 2001a, and b) on the basis of sequence stratigraphy, K-bentonite and other marker horizon correlations. Although facies patterns do show evidence for lateral time-equivalent variation, it is possible to differentiate individual units lithologically and biostratigraphically based on the re-evaluation of "type-section units." These studies suggest that isochronous horizons run parallel to formational contacts without crossing them (Figure 10, model A) and in some cases formational and intraformational contacts are even isochronous surfaces. Clearly, however there is also evidence for diachronous facies patterns (i.e. progradation/retrogradation) within formations and ultimately help in the recognition of shallowing and deepening between successive packages.

Pamelia Formation. In northwestern New York, the Pamelia Formation is the lowest unit exposed in the Upper Ordovician. The Pamelia itself is early Mohawkian in age and rests either on Precambrian Grenville basement rocks or on Cambrian-Lower Ordovician sandstones and carbonates. In either case, the contact at the base of the Pamelia represents a significant unconformity ranging in age from nearly 600 million years to less than 10 million years. Described from exposures in the Town of Pamelia in Jefferson County, the Pamelia Formation itself is a fairly significant unit and can be divided into several internal units. These are generally referred to as the lower, middle, and upper members. In total the Pamelia in the type region reaches ~45 m in more northwestern New York and Ontario and thin substantially to the southeast into the southern Black River Valley where the thickness varies but is generally less than 20 m and thins to extinction in some regions south of Boonville, only to reappear in a few locations in the western Mohawk Valley.

In terms of composition, the Pamelia is a heterolithic unit containing a wide range of siliciclastic influenced carbonates. Where clearly exposed the lower member is generally in contact with either the Theresa Formation or the Precambrian, nonetheless in either case, the base is consistently dominated by quartz-rich sands with fragments of underlying beds imbedded in its matrix. In the upper part of the lower Pamelia, massive planar & crinkly laminated dove-gray micritic limestones appear and are often interbedded with dolomitic caps and green shaly micrites that show an overall shallowing upward pattern to dolostone-dominated beds and mud-cracked argillaceous micrites near the top. The middle member of the

Pamelia formation, informally referred to as the "Thompson Farm Member" for the exposures in the Thompson Farm Quarry at Lafargeville, Jefferson County, New York, is distinctive from the lower or upper Pamelia in that although it contains some quartz-rich beds at its base, it does transition upward into fairly coarse-grained micrite-dominated carbonates exhibiting wackestone to packstone textures in some beds. This unit is clearly a deeper water facies and is recognized through the appearance of bryozoans, large-cephalopods, brachiopods, a variety of bivalves, and some crinoid ossicles and occasionally an entire crinoid itself. Moreover, in places this unit may contain *Tetradium* coral colony thickets and an occasional stromatoporoid and in the southern Black River Valley also contains intervals of ooid grainstones. As near the summit of the lower Pamelia, the upper portion of the "Thompson Farm" contains a distinctive argillaceous green dolomitic limestone containing small well-rounded, poly-crystalline quartz grains and sometimes a fairly red or magenta shale sitting on top of a subjacent dolomitic limestone. This bed has been referred to as the "Upper Green Marker" in southeastern Ontario or the Pittsburgh Quarry bed informally by Conkin & Conkin (1991). The uppermost contact of this bed often contains some evidence for truncation at the base of the overlying upper or "Depauville Member." The uppermost member of the Pamelia, referred to again as the "Depauville Member" after the Depauville Waterlime of previous geologists. Historically, the Depauville was described as gradational out of the middle member and developed from the first massive earthy weathering dolomitic limestone up through the uppermost dolomitic limestone. Although this expanded Depauville does contain all of the main dolomitic beds, there are significant patterns (shallowing-upward followed by deepening-upward) within the expanded Depauville. Moreover it also contains several key contacts and correlatable marker horizons internally. Thus herein the Depauville is restricted to the most substantial massive-bedded dolostone with extensive vug development sitting on the Pittsburgh Quarry Bed. The vugs are typically filled with celestite (strontium sulfate) nodules and / or other evaporitic pseudomorphs. In some case, although no mineral remains, it is not uncommon in some bedding cross-sections to see evidence for moldic preservation of cubic or bladed evaporite textures similar to halite or gypsum impressions.

Lowville Formation. Previously, the Lowville was subdivided into a lower member, about 13 m of sparsely fossiliferous, fenestral dove gray micrites and minor shales and an upper House Creek member (which in its upper part is intermittently called the Leray Limestone) comprising about 4-5 m of medium gray burrow mottled, locally cherty wackestone to packstone. The Lower Lowville, is the classic "Birdseye" Limestone of 19th century geologists and exhibits numerous fenestral spar filled voids, laminated micrites, often containing the vertical burrow *Phytopsis tubulosum* which is the characteristic trace fossil in this particular unit. Other faunal components are minimal but generally the unit contains small gastropods, ostracods, fragmented bryozoan colonies, and a few *Bathyurus* sp. trilobites all of which suggest a fairly restricted and slightly saline environment of deposition. The latter Lowville or House Creek Member is clearly a more off-shore yet still of a shallow depositional environment. The unit commonly contains abundant *Tetradium*, large tabulate corals, stromatoporoids, and associations of gastropods, bivalves, and a few brachiopods. Overall, the biofacies and the lithologic character of the House Creek indicate an overall shallowing upward from the base. A particularly important marker horizon in the uppermost House Creek Member contains a thin interval of mud-cracked gray-yellow weathering shales, platy micrites and domal stromatolites, designated informally as the "Weaver Road." In most of the Black River Valley successions this unit is present although it may lose the characteristic domal stromatolites in lieu of less prominent LLH style or laterally linked types in the southern Black River Valley. It does however become truncated below the overlying unit southward.

Chaumont Formation. A 0.5-l m bed of crinoid gastropod grainstone and welded coral brachiopod richpackstone separates the Weaver Road bed shales from a higher 0.5 to 1 m shaly nodular limestone interval with a distinctive fauna. This couplet of beds occurs in the position of Kay's (1929; 1931) Leray Limestone which formed the basal portion of the Chaumont Formation. Thus as a member, the Leray would sit beneath the Glenburnie member and overly unconformably the underlying House Creek. Although not well developed in most localities south east of Brownville, New York, the shaly-nodular facies of the Glenburnie does show up in the Martinsburg region and exhibits some of the faunal similarities to the underlying Leray although it contains many more bryozoans. This shaly interval is preserved in southeastern Ontario, and in a few portions of New York, but is generally thin to absent south of Watertown but reappears in the vicinity of Martinsburg. This particular member was also described (sensu Kay, 1931) to contain the Hounsfield K-bentonite, which subsequently in Kay (1935) was relocated to a higher stratigraphic position, although indeed a K-bentonite does occur in this position. The upper contact of the Glenburnie Member with the overlying Watertown is demarcated by a fairly sharp, yet in weathered outcrops, subtle transition into much more massive beds of the Watertown which may contain at its base a series of intraclastic conglomeratic beds indicating that there may be erosional truncation of underlying units. In the type area, a 2 to 3.5 m horizon of massive, ledge-forming condensed packstone to micritic grainstone interval occurs above the Glenburnie/Leray interval. With a distinctive coral, algae, brachiopod, and cephalopod fauna, this unit was termed the Watertown Limestone by Cushing et al., (1910) and reserves this designation today. The Watertown has generally been assigned to the Black River Group as it appears lithologically more similar (more carbonate, less shale) to the underlying strata than the overlying Trenton. Conkin and Conkin (1991), however, have argued that this unit should be assigned to the Trenton Group based on faunal and lithologic evidence and this corroborates other long-standing evidence discussed previously. When traced into the southern Black River and Mohawk River Valleys, the Watertown becomes substantially thinner, more fine-grained, and even becomes intertidal as at Ingham Mills and a few other western Mohawk Valley localities. Lithologically, these Watertown–equivalent limestones appear very similar in appearance to the lower Lowville and have been referred to as such in many localities, yet by tracing out individual packages and marker horizons it is possible to differentiate Watertown equivalent shallow water facies. This lateral facies change is identifiable and follows the diachronous concepts of Fisher (1962) and Walker (1973) but only within high-order cycles, and not on the formation-scale as previously proposed.

Selby Formation. In the Watertown, New York to Kingston, Ontario area the massive and often coarse grained Watertown limestone is overlain by about 0.5 to 3 m of nodular bedded, bituminous dark gray packstone, termed the Selby. Although a complete outcrop section of the Selby is lacking in Ontario, this interval becomes substantially reduced and thins to a single condensed packstone to wackestone observed in localities south of Martinsburg, New York. This particular unit exhibits typical faunas found in the Watertown, but becomes dominated and relatively enriched in both planispiral and orthoconic cephalopods, numerous brachiopod species, and occasional crinoids. A prominent K-bentonite horizon is located at the contact with the underlying Watertown, and in 1935, Kay reassessed the position of his Hounsfield K-bentonite to this horizon in an attempt to establish more regional correlations with sections in the Mohawk Valley. The uppermost contact of the Selby is again a fairly sharp lithologic break with the sudden change to thin shaly interbedded wackestones and calcisiltites of the overlying Napanee Formation. This surface shows evidence for substantial deepening across the contact and will be discussed as a flooding surface later.

Napanee Formation. As in most sections, especially to the northwest and southeast of Middleville, this interval is overlain by deep-water thin bedded, platy calcisiltites, and interbedded wackestones and shales assigned to the Napanee Formation. Collectively, the Selby and Napanee by definition have been assigned to the Rocklandian Stage, based on lithologic and biostratigraphic evidence, and form the base of the Trenton Group. Despite its rather distinctive lithologic appearance, the Napanee was first defined on the basis of its faunal composition. Originally, Kay (1937) designated this unit (the upper member of the Rockland) on the presence of the brachiopod *Triplesia cuspidata* (Hall). These *Triplesia*-bearing strata were superjacent to the Selby Limestone and subjacent to the Hull (or Kings Falls Limestones). In addition, the Napanee tends to be heavily dominated by the small orthid brachiopod *Paucicrura (Dalmanella) rogata* (Sardeson).

However, lithologically, the Napanee Formation can be recognized independently of faunal evidence based on its stratigraphic position above the underlying Selby and beneath the overlying crinoidal grainstones of the Kings Falls Formation. Unfortunately, due to the softer weathering shaly interbeds the Napanee-Selby contact is poorly exposed in most regions where the Napanee is weathered back along terrace plains and covered by colluvial debris as in Roaring Brook. Some key sections can be observed including those at Sugar River near Boonville.

Kings Falls Formation. Above the Napanee Formation, limestones once again become coarse-grained and dominated by brachiopod-crinoid grainstones and skeletal packstones. The contact between the Napanee and the overlying Kings Falls Formation (Kirkfieldian Stage) is very sharp and often dramatic in weathered outcrop sections. The Kings Falls weathers in stark contrast to the underlying Napanee and in some places channels and erosional features indicate that the Napanee is truncated at the base of the Kings Falls. This is evident at several localities including those at Ingham Mills, and Middleville in the Mohawk Valley and at Boonville on the Sugar River where there is evidence for the truncation of underlying beds. As a unit, the Kings Falls Formation is dominated by medium to thick bedded crinoidal grainstones especially in the base. These basal beds transition upward into mega-rippled grainstones and packstones that become substantially interbedded by additional thicknesses of shale and slightly deeper water taxa. As such, the Kings Falls is composed of several shallowing-upward cycles of thick ledges of calcarenite or crinoidal grainstones and brachiopod coquinas. Interbedded with these very coarse-grained lithologies are a series of thin dark gray to black shales. Most often the grainstone beds show excellently preserved hummocky cross-stratification, and large-scale pararipples on the top surfaces of many beds. As mentioned the distinctive component of this particular interval is the dominance of echinoderm skeletal remains. In the Ontario region, this unit is equivalent to the Kirkfield Formation (uppermost Bobcaygeon) and is demonstrated to contain many classes of primitive and not-so primitive echinoderms including asteroids, ophioroids, cystoids, edrioasteroids, carpoids, crinoids, etc. While most of these have not been recorded from entire specimens in New York, there are numerous plates found that are thought to be derived from many of these taxa.

<u>Sugar River Formation.</u> In the Black River Valley region and in the nearby West Canada Creek Valley, the upper Kings Falls transitions rapidly into thinly interbedded shales, and fine-grainstones, with thin nodular wackestones and calcisiltite stringers common. This lithology is more similar to the Napanee Formation subjacent to the underlying Kings Falls, than it is to the distinctively coarse-grained Kings Falls Formation. Although the Sugar River is dominantly interbedded shales and fine grainstones, it becomes distinctively more nodular and finer-grained. Near the top of the succession, the Sugar River becomes more medium-bedded, calcilutite facies with fewer fossiliferous horizons. This upper unit has been recognized as a separate unit and named the Rathbun Member of the Sugar River Formation. To the southeast into West Canada Creek and Mohawk Valley regions, the Rathbun Member is traceable into a coarser-grained, crinoidal packstone lithology with minor grainstone stringers, as is exposed south of Middleville, New York. This upper member shows evidence of thinning, and shallowing into the Middleville region and then transitions into the shale dominated facies of the lower Flat Creek Shales east of Little Falls. The Sugar River carries a distinctive fauna that enables its easy field recognition wherever it is exposed. Generally speaking this interval is established by the occurrence of two major faunal elements in the New York sections. First, the blind lace-collared trilobite *Cryptolithus tesselatus* (Green) is present in large numbers at several horizons but most predominantly in the medial Sugar River. Second, the largest occurrence of the gumdrop-shaped bryozoan, *Prasopora* is within the lower portion of the Sugar River. Both of these faunal elements are abundant and often compose very dense accumulations on some bedding planes.

<u>Denley Formation.</u> Although it has been recognized as a very distinctive stratigraphic interval, it has undergone a substantial transition in stratigraphic nomenclature. Initially, Kay applied the term Denmark Formation to the fossiliferous interval of dominantly fine-grained carbonates and interbedded shales, overlying the Sugar River Formation in the central Black River Valley in and around the town of Denmark. In 1968, Kay relegated the term Denmark for more biostratigraphic purposes and applied the term Denley Formation to denote rock terms. In common usage, the Denley Formation is recognized lithologically and on the occurrence of two distinctive marker horizons at the lower and upper contacts of the formation. These two marker horizons include the basal "*Trocholites* beds", or Camp Member, and the High Falls K-bentonite from Trenton Falls. Thus delineated, the Denley Formation now encompasses only a portion of the original Denmark Formation, and now contains two members: the lower or Poland Member and the upper or Russia Member. Collectively grouped the Denley is generally considered to be composed dominantly of fossiliferous nodular fine-grained limestones which show evidence for shallowing-upward cycle development and numerous internal and distinctive marker horizons. Generally speaking the Poland Member is defined between the basal City Brook or Camp Member and the lowermost Kuyahoora K-bentonite. As bracketed, this interval is a relatively condensed, nodular calcilutite interval containing abundant *Trocholites* and transitions to more tabular-bedded barren calcilutites which are interbedded with buff weathering shales and thin coquinal beds of the Glendale or upper Poland. This unit is moderately fossiliferous with species of trilobites especially common. The planar middle to upper Poland interval grades upward into coarser-grained, rippled calcarenites that often contain intraclastic conglomerates showing significant evidence for early cementation and development of storm clasts. This interval is

relatively resistant to weathering, and makes up the ledge forming the cap of many waterfalls in the region including Sherman Fall at Trenton Falls.

The upper member of the Denley Formation was originally named by Kay in (1943) for the upper calcilutite-dominated facies above the Poland and below the coarse-grained carbonates of the overlying Cobourg (now called Rust Formation). This particular member of the Denley is very distinct in that it shows several well-developed cycles with shallowing upward motifs. Moreover, as the lower series of cycles show slight facies differences between the lower, middle, and uppermost beds, three sub-members have been designated. Although these will not be considered here, the uppermost submember of the Russia is represents a very distinctive change in lithofacies with the basal 2 m composed of very tabular and even-bedded calcilutites that grade upward into more standard nodular wackestones and packstones showing well-developed bioturbation. The cap of this interval is rather distinctive in that the uppermost beds show evidence of soft-sediment deformation. This unit is sometimes mistakenly referred to as the "Lower Disturbed Zone" which occurs in the base of the overlying Rust Formation. This bed is immediately overlain by a condensed, quartz-rich, crinoidal grainstone that truncates portions of the underlying interval.

Rust Formation. As originally described, Kay (1943) introduced the term Rust for the lower member of the Cobourg Formation. Recognizing two divisions within the Cobourg in West Canada Creek Valley, he named the lower unit Rust, after exposures of the well-known quarries on the William Rust Farm just east of Trenton Falls. Up to that point, the interval near the top of the Trenton was not differentiated, but because of its rather distinctive facies, it was separated from the overlying Steuben or upper Cobourg. Recent review by Brett & Baird, (2002) has redefined the nature of the Rust such that, in contrast to the finer-grained Russia below, this unit is generally considered to be composed of nodular to wavy-bedded coarse-grained packstones to grainstones which can internally be divided into three lithologic divisions. These divisions although very similar in overall composition, again can be distinguished as shallowing-upward packages with similar motifs to the underlying Russia. However because of its distinctive internal stratigraphic intervals, as well as its coarser lithology, the Rust is very easily recognized in the West Canada Creek Valley. Further to the east, however, correlations show that this interval becomes substantially modified to the east and transitions into a condensed turbidite-shale succession and then finally into basinal black shale facies. Internally, there are many interesting horizons useful in correlation and include K-bentonites, and deformed or "disturbed" horizons.

In addition to lithologic characteristics, the Rust Formation is one of the best-known stratigraphic intervals in the Trenton Group because of the well-known collection of trilobites, echinoderms, and other fossil specimens collected from this interval, by William Rust and Charles Doolittle Walcott. With respect to biostratigraphic zonation, the base of the Rust Formation is now clearly established as containing the boundary between the *Corynoides americanus* and *Orthograptus ruedemanni* graptolite zones.

Steuben Formation. The Steuben Formation represents the uppermost unit exposed in the Trenton of the Mohawk Valley and was used for the upper portion of the Cobourg of Kay (1943). This unit is exceptionally coarse-grained and has been recognized since the very first geological surveys of New York. The Steuben Formation is represented by massively bedded, very coarse-grained skeletal grainstones that commonly show evidence for cross-bedding and sediment reworking. In the Trenton Falls region the Steuben is represented by two main coarse-grained intervals interrupted by a thin interval of shaly, wavy-bedded wackestones and packstones. Thus delineated, the Steuben is separated into two main units separated by the middle shaly interval. Due to its association with the underlying Prospect Quarry Member of the Rust Formation, the Lower Member of the Steuben appears as the upper half of a shallowing or coarsening-upward succession. The Upper Member, referred to here as the Remsen Falls Member displays a similar upward-coarsening pattern from the base of the middle shaly interval.

Modern Stratigraphy: Correlation Tools

Historically, correlations have been hampered by the low resolution of conodont biostratigraphy, a lack of readily identifiable index taxa, and the practice of broad-scale lithologic grouping. Although useful for mapping stratigraphic units, the practice of lumping units by lithology, without regard to internal marker units, has been demonstrated to be an extremely simplifying practice that has sometimes overlooked major surfaces and unconformities. Modern stratigraphers spend much time looking for and identifying these particular intervals so as to establish a more precise-level of correlation that provides for higher spatial-temporal resolution of rock units.

Within the Black River and Trenton groups, the presence of a number of K-bentonites and other event beds distributed throughout the succession provide the basis for establishing more regional correlations within previously recognized "lithostratigraphic or rock-units". K-bentonites are generally deposited instantaneously, with respect to geologic time, over a very large region and are profoundly useful in establishing chronostratigraphic correlations (thereby when they are correlated) which help to delineate time-rock units independent of biostratigraphy and lithology. Other types of unique marker beds used to establish regional high-resolution correlations include a variety of event beds such as sharp facies disjunctions, erosional contacts, mineralized surfaces and hardgrounds, unique taphonomic beds, stromatolite beds, epiboles, unique lithologic units, and distinctive patterns of bedding. Given the development of the practice of stratigraphic packaging using predictive patterns of deepening and shallowing of facies (i.e. sequence stratigraphy), it is now possible in association with the variety of correlation tools mentioned, to provide the discriminating stratigrapher a variety of tools from which detailed high-resolution correlations can be based (*see* Figure 2).

SEQUENCE STRATIGRAPHY

Recent studies of graptolite and conodont biostratigraphy, and K-bentonite and isotope geochemistry have resulted in a refined chronostratigraphic framework for the Black River and Trenton groups in central New York State (Goldman et al, 1994; Mitchell et al, 1994; Baird et al, 1992; Brett & Baird, 2002; Baird & Brett, 2002), and southern Ontario (Armstrong, 1997; Melchin et al, 1994; Brookfield & Brett, 1988; Cornell, 2001). Progress has also been made toward developing a high-resolution sequence stratigraphy within the framework of chemo- and biostratigraphy (*see* Figure 2). Nonetheless, while the Black River/Trenton-equivalent interval has recently become the focus of study from the standpoint of sequence stratigraphy and cyclicity in other parts of North America; similar studies have only recently been undertaken in the type area. Holland and Patzkowsky (1996, 1998) have identified and correlated six Mohawkian depositional sequences (M1-M6) throughout the southern Appalachians and eastern Midcontinent area (*see* Figure 2). Until recently, these sequences and their components have not been recognized or studied in the classic New York-Ontario sections (Cornell, 2001; Brett *et al*. 2004; Figure 11).

Within this context, the following sequence stratigraphic interpretations have been delineated for the Black River to Trenton interval (Figure 11). As is illustrated, the Black River Group forms three entire depositional sequences and portions of a fourth. These correspond to the M2, through M4 sequences of Holland & Patzkowsky on the basis of lithostratigraphic, biostratigraphic, and chemostratigraphic correlations. Moreover, although K-bentonite correlations are controversial, these also can be demonstrated to show at least local correlations. Emphasis here will be placed on the uppermost complete 3rd-order depositional sequence in the Black River. This sequence, referred to as the M4 sequence begins with the lower Lowville deepening up to a maximum flooding surface at the base of the House Creek Member. Subsequently, the offshore bioturbated wackestones of the House Creek shallow upward through the stromatolitic and mudcracked Weaver Road Beds before being capped by the thin grainstone-wackestone couplet – nodular carbonate of the Leray/Glenburnie. Although very thin in nature, and similar to some individual parasequences, this interval is interpreted as a mini condensed sequence that may have developed and been truncated prior to the development of the larger transgressive phase of the overlying M5 (*see* Figure 2).

The overlying Watertown, Selby, and Napanee form yet another sequence commencing with the deepening and condensing-upward Watertown and Selby formations. These formations are much more fossiliferous than the underlying Lowville, yet are transitional between the House Creek and the Napanee above. The traditional Black River/Trenton lithostratigraphic boundary, at the top of the Selby, is interpreted as a flooding surface separating the TST below from the HST above. In fact, this flooding surface is very distinctive and represents an important correlation surface across the outcrop belt and in other outcrop regions as well. In some cases in the Mohawk Valley, this sequence boundary becomes composite where the sequence boundary at the base of the Kings Falls comes down to merge with this one through truncation of the Napanee Formation. Based on the position of the M4 sequence, this boundary interval sequence forms a portion of the M5 sequence (of Holland & Patzkowsky, 1996), as it is recognized that there are several sequences represented within the entire M5 of these authors. This sequence is herein referred to as the M5A sequence.

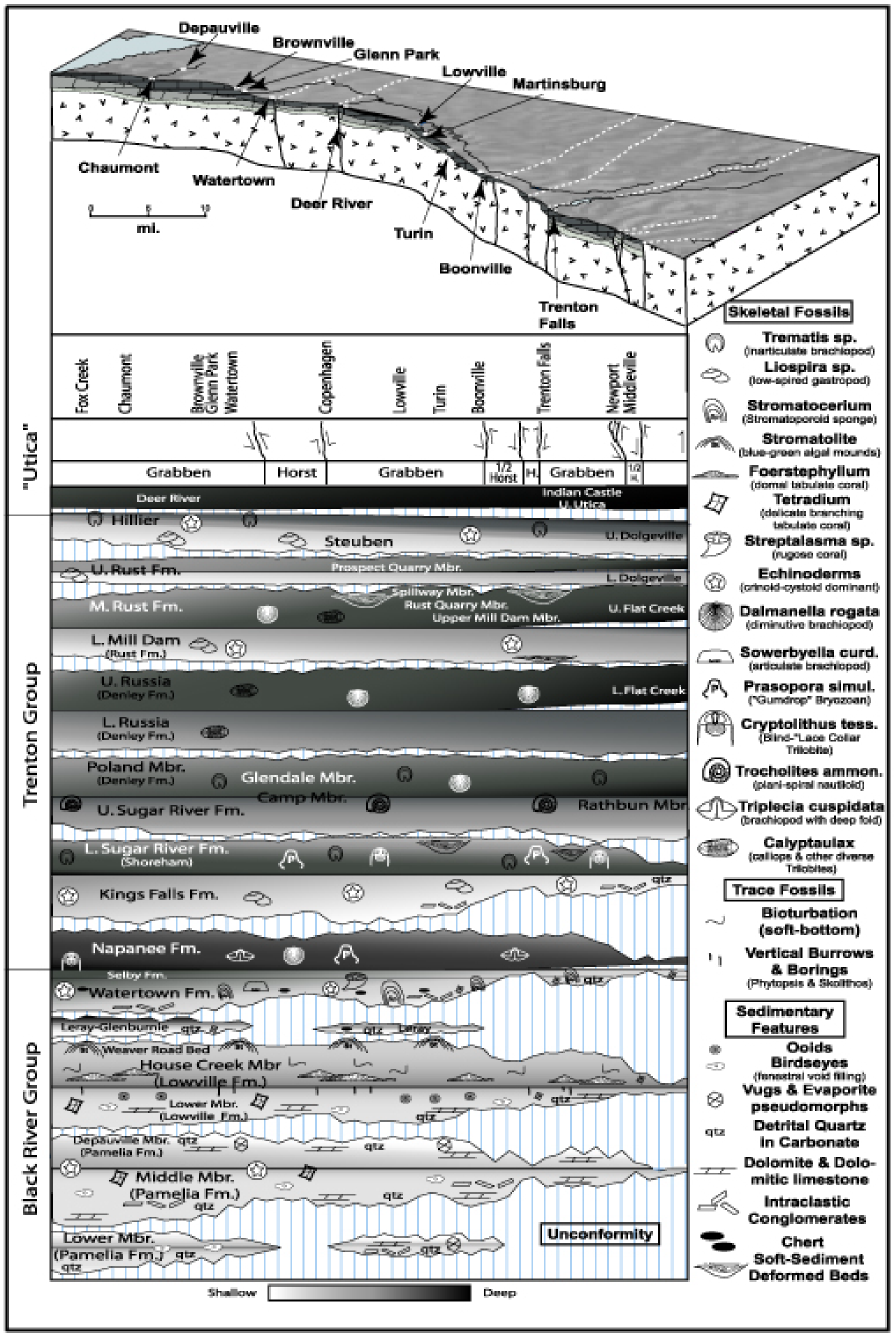

Figure 11- Sequence Stratigraphic Interpretations for the West Canada Creek to Black River Valley Region of New York State. Illustrated are the position of key stratigraphic units, lithologic marker horizons, and characteristic body and trace fossils. Vertical lineation represents unconformity, which in most cases represents the development of sequence boundaries, although in some cases maximum flooding surfaces demonstrate minor truncation and fairly sharp discontinuities. Sequence delineation follows Brett et al., (2004), and Cornell, (2005).

The base of the Kings Falls terminates the M5A sequence with fairly substantial erosion in some localities. Coupled with the lower Sugar River Formation, the Kings Falls forms an entire sequence (M5B) before it transitions upward into the Rathbun Member of the Sugar River Formation. Thus constructed this M5B sequence begins in the top of the Kings Falls which has historically been referred to the Kirkfieldian Stage and terminates in the Shermanian at the summit of the lower Sugar River Formation. The extremely coarse grainstones of the Kings Falls fine and deepen upward to more shaly interbedded nodular limestones rich in *Prasopora* bryozoans and the trilobite *Cryptolithus*. Thus it is interpreted that the deeper water nature of the Sugar River indicates that the contact is a maximum flooding type contact. Subsequently, the Sugar River itself begins to shallow upward to its summit where it transitions into the Rathbun Member at the base of the next overlying sequence.

The last sequence of the M5 succession of Holland & Patzkowsky (1996) is entirely within the basal Shermanian Stage. Composed of the Rathbun and basal Denley, Poland Member, this sequence is much less distinctive than either of the underlying sequences. However changes in sedimentary and biofacies character enable the recognition of important patterns that help delineate this sequence. Important observations in this sequence include the widespread occurrence of channel-filled slump-folded strata just below the upper Sugar River which shallows upward to a subtle discontinuity surface with slightly shallower water facies juxtaposed on the top. This is interpreted as a sequence boundary although it was probably not a type I or exposed sequence boundary. The maximum flooding interval is recorded by the condensed Camp or "*Trocholites*" beds. These beds are sharply overlain by much deeper and finer grained lutites of the Upper Poland.

The uppermost sequence of the Trenton Group, using the Holland & Patzkowsky model, is the M6 sequence. On the broad-scale, this sequence is divisible into 3 subordinate sequences (M6A, B, and C) with each entirely within the middle to upper Shermanian Stage. The M6A, sequence is entirely developed within the Upper Denley or Russia Member and represents fairly deep water mixed siliciclastic carbonate assemblages. Due to the widespread and correlatable nature of many of the Russia cycles, it is possible to pick out more subtle progradational and retrogradational patterns in lithology that enable development of the sequence interpretation. The M6B sequence represents a fairly substantial change in the overall M6 sequence. The development of the fairly coarse-grained Rust Formation, indicates a fairly substantial shallowing over the Russia and given the nature of the contact, there is evidence for truncation at the base of the Rust. Thus a sequence boundary is established at this position. The distinct occurrence of deformed or "disturbed" horizons within this sequence is indicative of widespread tectonic activity (earthquakes) which impacted the sediments deposited on the sea-floor. Within the Rust, cycles in the Mill Dam member show an upward deepening pattern to a substantial flooding surface in the upper Mill Dam and lower Rust Quarry interval. This particular drowning event is responsible for some of the most spectacular preservation in the trilobites and echinoderms collected by Walcott and Rust. The final sequence of the M6 is the M6C. This particular interval is substantially thin on the shelf, but in the nearby basin thickens. This sequence is entirely constructed in the Prospect Quarry Member of the Rust and documents a fairly substantial amount of deformed and brecciated channel-fill fabrics. Like then condensed mini-sequence at the base of the M5A sequence, the M6C sequence also demonstrates some remarkable condensation, again on the shelf while expanding out in the foreland.

The shaly nodular wackestones and packstones of the Prospect Quarry are sharply overlain by a much more substantial body of coarse-grained crinoid-brachiopod grainstone of the Steuben Formation. Due to its biostratigraphic assessment and the comparable sequence stratigraphic position, the Steuben is classified as equivalent to the basal portion of the C1 sequence, although it is not yet Cincinnatian in age. Nonetheless, even more pronounced than the shallowing in the Mill Dam member of the Rust, the Steuben Formation records a very sharp change to extremely shallow-shoal type conditions from the West Canada Creek Valley northwestward through the Black River Valley. As this unit is traced further northwest into Canada it does become less massive and becomes interbedded with minor shales. Regardless, upward from the base, the Steuben shows several large-scale and many small-scale cycles illustrating a deepening upward pattern to a maximum flooding interval. The overlying Cincinnatian aged black shales of the Indian Castle sit atop a fairly major unconformity interpreted by most authors as a drowning-type unconformity.

REGIONAL SYNTHESIS

As mentioned above, the transition from Black River to Trenton is coincident with the onset of the Vermontian Phase of the Taconic Orogeny. During this time, the cratonic margin was again influenced by plate tectonic processes to establish yet another renewed phase of tectonism. Within the successions of the Black River Valley through the Mohawk Valley, these strata exhibit an abrupt transition from the fairly passive continental margin to the tectonically active, rapidly subsiding foreland basin. Although this transition has historically been considered to be straight forward and coincident with major deepening in the "Trenton transgression," our recent work in the upper Black River to lower Trenton groups demonstrate a more complex pattern of activation. Using the spatially and temporally constrained framework of sequences first delineated by Brett and colleagues (2004), it has been possible to establish patterns of uplift and subsidence within the Trenton Shelf region. When patterns of deposition are investigated in relationship to structural features of the region, it appears that activation of the Vermontian phase was manifest on the shelf through the reactivation of ancestral faults resulting in a series of uplifted blocks and associated down-dropped regions (*see* Figure 12).

Using onlap/offlap patterns, the amount of incision/truncation across sequence boundaries, and within sequence facies change, it is possible to establish a chronology of events leading up to the main phase of subsidence in the New York region associated with the cratonward migration of the northern extension of the Martinsburg foredeep basin (Champlain Trough). The Black River platform in New York has been studied in detail by Young (1943) and it had been determined to have extended from southern Ontario into south-central New York State. Through this region, the platform was characterized by a region of major subsidence in the Kingston-New York region. Although never formally named the "Rideau Trough" was a region of subsidence showing onlap patterns in the lower Black River both: to the north and west (onto the Frontenac Arch and Canadian Shield), and to the south and east onto the Adirondack Arch of Kay (1937). This pattern of onlap is clearly documented in Figure 11 where the M2, M3 and M4 sequences clearly show the progressive shift of sedimentary facies to the southeast so that by the M4 highstand (U. Lowville, House Creek), most of the Adirondack Arch had become submerged and deposition occurred in a fairly shallow lagoonal system from Ontario through eastern New York. Paleocurrent analysis of aligned orthoconic nautiloids yield a northeast-southwest trend indicating that a minor barrier may have been present in the eastern Mohawk Valley (Canajoharie Arch) and may have acted as a protective barrier but it was of minimal extent during the M4 highstand.

Near the end of the M4 highstand and during the M5A sequence boundary, there is evidence that the majority of the region became exposed during sea-level lowering, however, in the southern Black River Valley to Mohawk Valley region, this lowstand was accentuated by the uplift of horst structures allowing for the truncation and karstification of the M4-M5 sequence boundary. In some regions in the southern Black River Valley and in the Mohawk Valley, especially at Inghams Mills, New York it is possible to identify several meters of truncation at the base of the M4-M5 sequence boundary.

ROAD LOG FOR CLASSIC LOCALITIES OF THE BLACK RIVER AND TRENTON GROUPS (UPPER ORDOVICIAN) IN THE BLACK RIVER VALLEY: REVISITED THROUGH TRADITIONAL AND SEQUENCE STRATIGRAPHY (Part I)

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	SUNY Oswego campus entrance and intersection with US104. Head East on US104.
20.8	20.8	Maple View. Continue East on US104, past the overpass for I81.
22.3	1.5	Turn left (N) onto I81.
51.7	29.4	Exit 42 (Adams Center). Turn right (E) on Rte 177.
52.4	0.7	Intersection with US11. Continue East on Rte 177.
77.3	24.9	Junction with NY12. Turn right (S) on NY12.

80.1	2.8	Lowville. Turn right (S) on NY12&26.
80.4	0.3	Turn left (E) on River St.
81.0	0.6	Turn right (N) on State St. and take and immediate left into parking area for Joan's School of Gymnastics. Walk down to exposures in stream bed.

STOP 1: LOWVILLE, NY, MILL CREEK GORGE
[UTM 18T 0461517 4847863]

This locality represents the type locality for the Lowville Formation and although the original quarry section is flooded (it is just across the road from the gorge) the gorge offers excellent exposures and weathered outcrops for the review of sedimentary structures and fossiliferous strata. The section starts in the Pamelia Formation and intermittently in the banks at the lower end of the gorge. It is possible to observe the uppermost Pamelia Formation. Exposures of the "Depauville" Member and overlying Pittsburgh Quarry Bed of Conkin and Conkin (1991) can be identified.

Up in the narrows of the gorge, exposures of the lower Lowville Member or "Birdseye" of early workers can be seen in a series of well-developed meter-scale cycles, each with a flooding surface at their base and a shallowing upward motif. The Upper Lowville, or House Creek Member (of Walker, 1973), is fairly well exposed in the southern wall of the gorge and although it can be difficult to access, this member of the Lowville is distinctively less argillaceous and more massively bedded. It is composed almost exclusively of bioturbated wackestones with minor stringers of intraclastic packstones, and a few ribbon-bedded horizons showing some ooid development. Overall the House Creek represents protected, but marine conditions typical of shallow water lagoon areas. Although it is much more subtle and is occasionally recognized as one more cycle of the Lowville, the uppermost beds of the House Creek, or the "Weaver Road Beds" show the distinctive development of domal stromatolites in fairly argillaceous platy micrites. Overlying the Lowville Formation is a series of more massive-bedded limestones previously referred to the Watertown Limestone. Although much of this particular interval is extremely cherty, the basal few feet are less so and are fairly coarse-grained. In stark contrast to the underlying lithologies, the basal few feet of the upper massive unit are characterized by large colonies of *Tetradium*, crinoids, brachiopods, a variety of high-spired gastropods and numerous other taxa. Given the faunal and lithologic composition of this bed and through correlations with sections to the northwest in the Watertown area, it is believed that this thin interval of beds represents what is left of the Leray-Glenburnie interval. Without the occurrence of the Hounsfield K-bentonite (*sensu* Kay, 1931), in this succession it is surmised that the Glenburnie and the K-bentonite have been eroded by the overlying sequence boundary and were removed prior to the deposition of the Watertown. The Watertown is the last well-displayed unit is this portion of Mill Creek. Just below the Rt. 12-26 bridge over Mill Creek, the south wall of the gorge displays the massively bedded and chert-rich equivalent of the Watertown Limestone. Approximately 4 m of Watertown are exposed and are typically well bioturbated wackestone to packstone facies. Like the House Creek, the Watertown contains many coral taxa, sponges and stromatoporoids, and more diverse brachiopod and crinoid assemblages. Based both on lithologic and faunal patterns, the Watertown itself demonstrates a significant and even more substantial upward deepening pattern. Although many of the internal cycles have become amalgamated, they can often be identified through the recognition of firmground and hardground surfaces. These surfaces become especially prominent near the top of the succession where they show evidence for phosphate, pyrite, glauconitic staining, and may even contain K-bentonites sitting on them. Moreover, these surfaces often are accentuated by hard-substrate borings and in some instances have been found to contain crinoid & bryozoan holdfasts indicating that these surfaces were well cemented on the sea-floor prior to their final burial. Collectively then, the Watertown itself is clearly an upward deepening unit and although it does not represent the deepest portion of the sequence, it is the deepest facies within the entire Black River to this point.

Near the top of the gorge section below the bridge, a small poorly-exposed succession of rubbly weathering wackestone-packstone lithology stands in stark contrast to the underlying massive bioturbated beds of the Watertown. This particular interval becomes very condensed in places and shows evidence for sediment starvation through the accumulation of numerous current aligned cephalopods (with a variety of taphonomic signatures), and a range of diminutive orthid, and strophomenid brachiopods (*Dalmanella*,

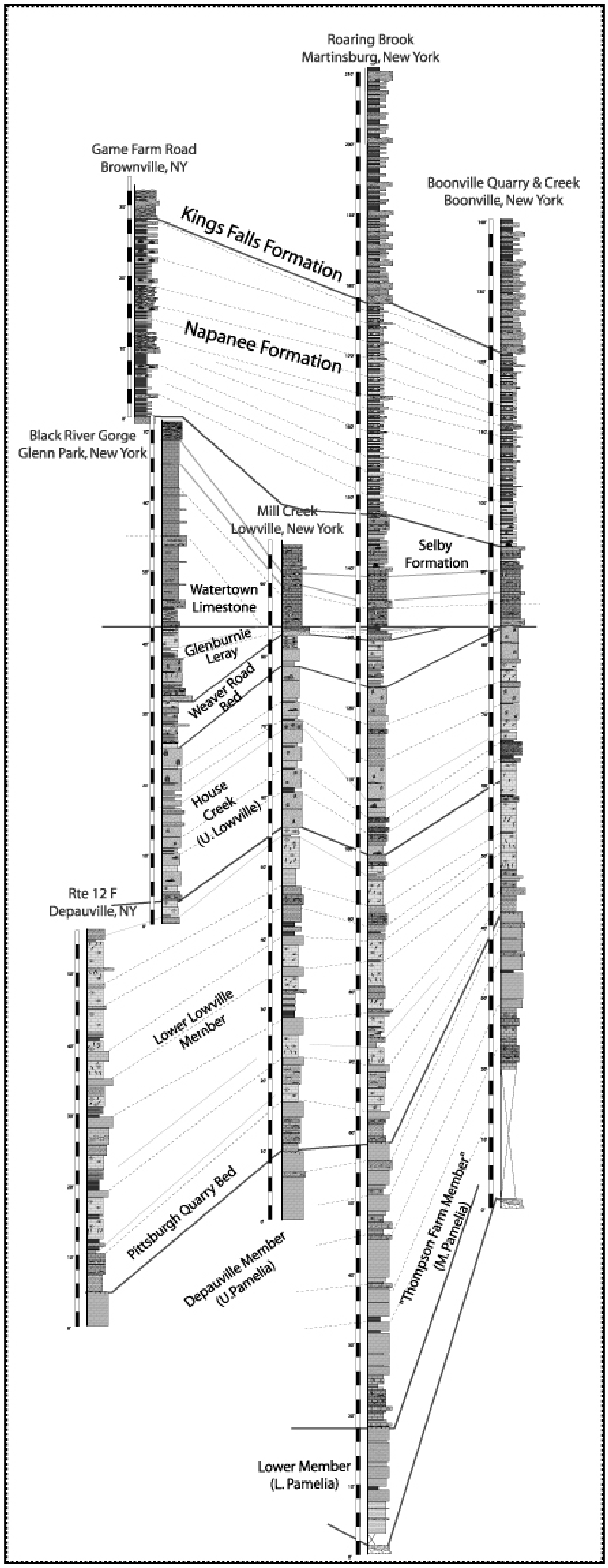

Figure 12 - Correlation of stratigraphic sections for Upper Ordovician field trips (Parts I and II).

Sowerbyella respectively). This unit is referred to as the Selby, and is included in the Rocklandian Stage. Lithologically and faunally, the Selby is transitional out of the Watertown into the overlying Napanee Formation. Unfortunately, poor exposures above the bridge do not permit the observation of the upper Selby to Napanee interval.

81.1	0.1	Turn right back onto State St. At STOP sign turn left onto River Rd.
81.8	0.7	Turn right on Markowski Rd.
82.7	0.9	Turn left (S) on NY12. Note Precambrian outliers on West side of highway.
85.3	2.6	Turn right into Linda's Roaring Brook Restaurant. Park. Proceed to Roaring Brook and walk downstream to Precambrian contact.

STOP 2a: EAST MARTINSBURG, NY, ROARING BROOK, LOWER SECTION
[UTM 18T 0465811 4843142]

Just east of Route 12 on the lower section of Roaring Brook is the unconformable contact of the Pamelia Formation with the underlying Precambrian Grenville Gneiss. Although exposure here is covered for some distance above the contact, a few feet of the Pamelia are exposed and document the transition from a siliciclastic sandy (dominated by quartz and feldspar fragments) carbonate upward into more medium-bedded argillaceous limestones. Although very few fossils are found in this unit, occasionally a few gastropods, ostracods, and small fragments of bryozoans are represented. These are commonly of poor preservational style and many are coated with greenish glauconitic material. Although the depositional history of this lowermost Pamelia is not well constrained, it is very similar to strata exposed in southeastern Ontario where this particular interval is located on the top of the Shadow Lake and is time equivalent with the basal Gull River Formation. Here in New York, the basal Pamelia sandy limestones are thought to represent the deepest phase of the Shadow Lake or Rideau sequence and overall remain fairly shallow but mudcracks a few feet off the basal sands suggest that this may be a shallowing succession off the basal transgressive surface. That is the red and green shaly carbonates of the Shadow Lake (which are not developed here in the central Black River Valley) were probably deposited during the transgressive phase, while the overlying lower Pamelia was deposited during the maximum inundation of that particular sea-level rise event.

85.3	0.0	Walk upstream to additional exposures of the Pamelia and of the Lowville and Watertown.

STOP 2b: EAST MARTINSBURG, NY, ROARING BROOK, MIDDLE SECTION

Up section, the remainder of the Black River Group is exposed through the top of the Watertown Limestone. The middle-upper division of the Pamelia is well represented and overall represents one transgressive-regressive sequence. Although not formally named, the middle or "Thompson Farm" member is a distinctive facies of the Pamelia and is well developed through the transition from laminated argillaceous micrites and dolomicrites to more medium-bedded (and distinctively less argillaceous) wackestones containing a fairly restricted fauna but occasionally contains a few echinoderm fossils (crinoids), a few large strophomenid brachiopods, very large endoceratid cephalopods, and several trilobite taxa. In contrast to the more restricted ostracod-bivavle-gastropod assemblages of both the lower and upper Pamelia, the middle member is characteristically more normal marine in faunal composition. Although it is still considered a fairly shallow peritidal deposit, the presence of these faunal elements indicates that the middle Pamelia was deposited in deeper water. A fairly rapid and substantial transition upward into the upper Pamelia or "Depauville Waterlime" of early workers is documented by the transition back into dolomitic limestones and sandy dolomites characteristic of this interval. In addition, distinctive sedimentary features suggest that this particular interval shows evidence of hypersaline conditions. In some beds evaporite crystal pseudomorphs are distinguished as are the development of large vugs containing celestite and/or gypsum. Although it is clear that many of these have been recrystallized during later diagenesis, the moldic preservation of some of these crystal faces indicates that these environs may have been highly saline at the time of deposition.

Above the Pamelia, both the lower and upper Lowville members are well exposed and with some investigation are readily compared to sections visited at Mill Creek in Lowville. Unfortunately, due to extreme solution along joints in the stream bed, many of the sedimentary and faunal details of the Lowville are obscured but many are still readily observable. In this region, the Lowville is approximately 25 m thick. Near the top of the succession, an argillaceous, mudcracked interval at the base of the Watertown is recognized. Although there are no large domal stromatolites (as in the northern Black River Valley), there is evidence for low, broad stromatolitic mounds (LLH style) in this interval. These stromatolites border on thrombolitic textures where they are burrowed and are evidently grazed.

Continuing upstream are exposures of the Watertown Limestone. Again as below, some local small-scale structures are developed in these exposures. Although most appear to be related to differential compaction over shallow Precambrian basement features, it is also evident in this section that there are minor faults that offset strata locally. It is not clear at this time if these are related to more recent uplift associated with Neogene to recent Adirondack tilting or if these are representative of local faulting at or near the time of deposition in the Upper Ordovician. Nonetheless, the Watertown and overlying Selby Formation represent a continuous deepening showing the upward transition from typical bioturbated cherty wackestones and packstones of the upper Watertown into more nodular, rubbly weathering Selby. The Watertown itself is substantially thinner than the Watertown in the type region and it is believed that only the upper portion of the Watertown is here by overlap. At the top of the section, as is the case in most of the region, the top Selby forms a broad terrace where the overlying shaly bedded Napanee Formation is eroded back almost a half mile. Although we will not trek overland to the next exposure, the basal beds of the Napanee are intermittently exposed just upstream.

	0.0	Return to vehicles
89.3	4.0	From parking lot, turn right (W) onto Tiffany Rd.
90.5	1.2	Turn right (NW) on Glendale Rd.
95.7	5.2	Turn right into Whittaker Park.
96.1	0.4	Drive into park to designated parking area. Excellent view of the Adirondacks to the East. LUNCH. Proceed down trail to exposures in stream. We will examine the lower exposures first, then walk upstream and exit at the bridge on Glendale Rd. Vans will ferry participants back to vehicles.

STOP 3: WHITAKER FALLS PARK, MARTINSBURG, NY, ROARING BROOK UPPER SECTION [UTM 0463947 4842616]

Upstream from the previous stop, we start just above the lower waterfall in Whitaker Falls. Although we could travel downstream, for the sake of time, we will focus on the interval from the lower falls upward through the upper Trenton. This portion of Roaring Brook exposes the entirety of the Shermanian from the Sugar River at the base through the Denley, Rust, and finally the Steuben formations. We will not see the Kings Falls or Napanee up close at this locality although they are exposed downstream (we will see them at the STOP 4 in Boonville, NY). Exposed in Whitaker Falls Park are three closely spaced waterfalls in this portion of the gorge. Just below the lip of the first waterfall, and exposed in the south wall of the gorge are the uppermost beds of the Kings Falls (forming the floor below the falls) and the Lower Sugar River formation. The shaly nature of the Lower Sugar River allows for it to be slightly less resistant and allows for the notch under the waterfall. Also exposed in the wall of the gorge at this point are at least two recessive weathering notches and a deformed channel. The channel and the layer above the waterfall show evidence for brecciated fabrics suggesting syn-sedimentary movement of materials on the sea-floor after some period of lithification. Although it is not yet clear as to the regional relationship of this feature, both of these features are found in many local sections throughout the region and are prominent horizons useful for correlation.

The lowermost waterfall is capped by the Rathbun Member of the Sugar River Formation and near the top of the middle waterfall is the transition to the upper Poland. Just above the lip of the middle falls and below the bench leading to the upper waterfall is the transition to the Upper Denley (Russia Member). Within the face of the third falls are the well developed cycles of the Russia and the basal Mill Dam Member of the Rust Formation. The fairly coarse cycle caps of the Mill Dam help to hold up the face of the falls and are exposed for some distance upstream where excellent large-scale ripples are well developed on them. Like the coarse-grained Kings Falls some distance downstream, the Mill Dam in this region was substantially shallower than the underlying Denley Formation, although it too shows an upward deepening pattern.

Continuing upstream some distance exposures in the wall of the gorge afford views of the Rust Formation and its members. In the walls of the gorge before the Glendale Road Bridge, exposures of the Mill Dam and Spillway members show characteristic coarser-grained facies with well preserved faunas, extremely large brachiopods and some crinoids. Another deformed interval is located here and is tentatively correlated with the uppermost Spillway member slump structure at Trenton Falls. Just above the bridge, exposures of the Prospect Quarry member give way to the basal coarse-grained Steuben Formation. Although an additional 25-30 meters of section are exposed upstream near the Martinsburg town garage (as is the contact with the overlying black shales), owing to time constraints we will defer their investigation at this time.

96.5	0.4	Return to Park entrance and turn left on Glendale Rd.
99.4	2.9	Turn right (S) on NY12. Again, note Precambrian outliers and roadcuts on East and West sides of highway.
105.6	6.2	Hell’s Kitchen Rd. to right. Do not turn. Notice canal locks for the Black River section of the Erie Canal.
110.2	4.6	Four canal locks on left (E).
111.1	0.9	Pull into Barrett Quarry on left. HARD HATS! Time permitting, we will also examine the exposures along NY12, both N and S of the quarry and in the Sugar River.

STOP 4: BOONVILLE NY, BARRETT MATERIALS AND PAVING QUARRY AND SUGAR RIVER SECTIONS
[UTM 18T 0473787 4819422]

Just north of the village of Boonville, NY on the north shore of Sugar River sections are exposed in the Barrett Materials and Paving Quarry and in the adjacent stream section to the south of the quarry and along route 12. Entrance is by permission only and hard hats and steel-toed shoes must be worn at all times. Although exposures in this section extend down to the base of the Pamelia, we will focus on the uppermost Black River Group exposed in the quarry. In the older northwest corner of the pit and along the west wall of the pit, exposures start in the lower Lowville and extend upward through an abbreviated House Creek section where the Watertown Limestone, or “7’ tier” of quarry operators, immediately overlies the middle House Creek with possible unconformity. Although the 7’ tier is dominantly a single massive bed composed of fairly coarse micritic wackestone, in the face of the unit to the southwestern corner of the pit, the upper massive bed displays a prominent recessive notch containing a prominent clay horizon. Although it still remains to be chemically fingerprinted it sits in the same position as a K-bentonite approximately 1.5 meters below the top of the Watertown at Brownville gorge. In the older portions of the quarry, the K-bentonite has been squeezed out and it is difficult to make out, as is the case in most of the weathered stream sections.

Although no higher exposures are afforded in the quarry–the cap of the quarry wall is the Watertown–additional exposures in the stream bed allow for the continuation of the stratigraphic section. Just to the south of the quarry in the stream bed and southern bank of the Sugar River, the upper contact of the

Watertown with the Selby is observed. The massive Watertown is easily recognized in the bed of the stream and along the southern bank a several decimeters of thin-bedded rubbly weathering limestone is exposed below the typical shaly-interbedded Napanee Formation. At this particular location, only the basal 2-3m of the Napanee is exposed in the outer bend of the stream. Upstream, above the NY 12 bridge, additional sections are exposed from the Napanee up through the King Falls Formation. W will not walk upstream to see them in weathered section, but we will look at the same interval in the road cuts on both the north and southwest side of the highway. Here in the road cuts are the uppermost ~5 meters of Napanee followed by ~3 meters of Kings Falls. Although not in the best position for weathering, the outcrop shows the sharp contact of the Kings Falls on the underlying Napanee. In fact, the contact shows evidence for channeling into the underlying Napanee at the M5A-M5B sequence boundary. Additional exposures are visible upstream, including the type succession of the Sugar River Formation, and additional units up through the upper Trenton.

		Return to vehicles, turn left (S) on NY12 and proceed to Boonville.
114.1	3.0	Turn right (W) on E. Schulyer St.
114.3	0.2	Proceed to traffic light (follow signs to Rte 46/294).
114.4	0.1	Turn right (W) on Rte. 294 and follow to West Leyden.
121.2	6.8	Turn left (S) on NY26.
131.6	10.4	Stokes Center. Turn left (W) onto Lee Center Rd.
139.2	7.6	Intersection with NY69, just SW of Taberg. Turn right (NW).
147.3	8.1	Intersection with NY13. Turn left at light.
147.4	0.1	Turn right at light. Continue on NY69.
174.6	27.2	Mexico. Turn left (W) at intersection with US104.
191.1	16.5	Campus entrance. End of field trip.

ROAD LOG FOR CLASSIC LOCALITIES OF THE BLACK RIVER AND TRENTON GROUPS (UPPER ORDOVICIAN) IN THE BLACK RIVER VALLEY: REVISITED THROUGH TRADITIONAL AND SEQUENCE STRATIGRAPHY (Part II)

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	SUNY Oswego campus entrance and intersection with US104. Head East on US104.
20.8	20.8	Maple View, NY. Continue East on U104, past the overpass for I81.
22.3	1.5	Turn left (N) onto I81.
62.2	39.9	Turn off on Exit 41. Take US12 (N) to Depauville, NY.
70.4	8.2	Cross Rte 180, Gunn's Corners.
75.0	4.6	Depauville, NY
75.4	0.4	Continue to roadcuts just N or village. Park (with care!).

STOP 1: DEPAUVILLE, NY, ROADCUT ON NY12
[UTM 18T 0414505 4888355]

The village of Depauville contains an excellent succession of the Black River Group and the contact of the basal Pamelia with the underlying Theresa Formation (Upper Cambrian). The Pamelia is mostly exposed in the waterfall succession of the Chaumont River (and just to the west along Buttermilk Creek) where nearly 9m of Pamelia are exposed below the county route 170 (Depauville Road) bridge. We will not look at this succession and instead we will focus on the relatively new outcrop on the northern limits of the village along NY 12. Just above the Depauville VillageMarket, and below the town garage, a fairly long stratigraphic succession of nearly 20m is visible along both sides of the roadcut. We will use this section to discuss the long-standing debate concerning the description of the Pamelia-Lowville contact. In previous classifications the contact was drawn either at the highest dolomitic limestone or at the lowest occurrence of relatively pure "birdseye." In this locality a prominent succession of cyclically-bedded limestones shows an upward deepening pattern and is based at a very distinctive quartz-rich sandy bed. This bed, referred to as the Pittsburgh Quarry Bed by Conkin and Conkin (1991), is a prominent marker from southern Black River region through southwestern Ontario and even in the Ottawa region. Given the prominence of this marker and the very distinctive pattern of cyclically-bedded carbonates above, an argument can be made for placing the upper contact at this stratigraphic position, thus including it in the base of the Lowville Formation. Although some dolomitic limestones do occur above this position, they are few and dominated by the relatively pure micrites of the Lowville. The remainder of the succession through the cap of the outcrop is referred to the lower member of the Lowville Formation and shows the overall transgressive pattern of the M4 sequence. Near the top of the succession a noticeable reentrant occurs and contains a K-bentonite which correlates with a prominent K-bentonite in Ontario referred to as the MH K-bentonite. The recognition of this reentrant is aided by its position just below the sharp flooding surface to the overlying House Creek Member. The terrace at the top of the outcrop is developed in the basal House Creek with the remainder of the House Creek exposed in the bluffs to the north, west, and south of the village.

75.7	0.3	Continue N on NY 12 to Old Town Spring Rd.
80.6	4.9	Turn around at Old Town Spring Rd. at crest of hill. Return through village of Depauville on NY 12 and continue (SE) to Gunn's Corners (Rte 180). Turn left.
83.5	2.9	Proceed to roadcut on W side of highway. Park.

STOP 2: LIMERICK, NY, ROADCUT ON RTE 180, JUST EAST OF GUFFINS CREEK
[UTM 18T 0418165 4878863]

This stop is intended for quick look at facies of the upper Lowville House Creek that have not been observed up to this point. In the small outcrop on the northwest side of the road, a succession of ~4-5 meters of strata are exposed. The base of the succession is dominated by bioturbated wackestones containing various algae, corals, and a variety of brachiopods, the House Creek is clearly more normal marine than any of the underlying units in the Black River. Nearer the top of the section, relatively coarse-grained facies are developed and in places show evidence of cross-bedding and ooids. Intermixed with *Stromatocerium* stromatoporoids, the ooids reflect an important shift in the deposition of the House Creek suggesting a shallowing which is terminated in the Weaver Road beds (observed at STOP 3).

84.4	0.9	Turn around. Proceed N on Rte 180 to Depauville Rd (Rte 54). Turn right (S).
87.9	3.5	Continue S on Rte 54 to parking area on right side of highway at top of hill crest near Brownville Fish Game Club. Roadcut is just before entrance to the Club.

STOP 3: BROWNVILLE, NY, ROADCUT ON RTE 54 NEAR BROWNVILLE FISH-GAME CLUB
[UTM 18T 0420019 4876663]

It is unfortunate that the type section of Kay's Hounsfield K-bentonites (*sensu* 1931 and 1935; *see* STOP 4) is overgrown and poorly exposed. To alleviate this difficulty this newly widened outcrop section located on the northeast side of Rte 54 just NW of the intersection with Mullin Road, is used as a new reference section for the uppermost Lowville through basal Trenton succession. This outcrop displays the Weaver Road beds at the base of the outcrop, the overlying Leray and Glenburnie interval and the overlying Watertown Formation. In this particular succession, K-bentonites are located at several horizons, including near the base of the Glenburnie (Hounsfield *sensu* Kay, 1931) and in the overlying Watertown near the base of the Selby (*sensu* Kay, 1935). The stratigraphic succession shows evidence for mudcracked argillaceous ribbon micrites sharply overlain by the somewhat sandy and coarse-grained basal Leray. The Leray in this succession is relatively thin (~1.5m) and is overlain by the rubbly weathering Glenburnie. This particular facies is very subtle in relationship to the Watertown and is most often included within it. However, as this unit is traced into southern Ontario, the Glenburnie interval becomes distinctively more shale rich and equates to a 1.5m thick shale in the Kingston region located below the much coarser grained and cross-bedded Watertown in that region. In New York, the Watertown is less of a grainstone, but is dominated by extremely bioturbated wackestone-packstone facies. The remainder of the succession displays the cherty facies of the Watertown that generally is developed along bedding planes and within burrows. The Watertown becomes distinctively more nodular towards its top and at the position of a prominent reentrant the facies changes to a much more condensed and darker grey, rubbly weathering unit referred to as the Selby. Only a minor portion of the Selby is exposed, as it and the overlying Napanee Formation were relatively nonresistant to glacial processes that were active in this region.

88.0	0.1	Return to Rte 54, turn right (W) on Mullin Rd.
89.8	1.8	Proceed to STOP sign at 'T' intersection with Cemetery Rd. (Mullin Rd. becomes Game Farm Rd.). Continue S on Game Farm Rd.
90.4	0.6	Park in entrance to Browville Transfer Station (only on Sundays) to your right near the top of the hill.

STOP 4: BROWNVILLE, NY, FARR'S QUARRY AND ROADCUT ON WEST SIDE OF GAME FARM ROAD
[UTM 18T 0419612 4873577]

As mentioned at STOP 3, the original type-section for Kay's Hounsfield K-bentonites is poorly exposed, and despite a covered interval in the quarry and adjacent lower ditch, the stratigraphic succession continues up the hill through the Napanee and into the lowermost Kings Falls Formation which forms the cap of the hill below the junk yard. This stratigraphic section is visited to continue and to illustrate the relatively close stratigraphic proximity of the new Fish-Game Club locality just northwest of here (STOP 3). Although the contact of the Selby and Napanee is poorly exposed during late winter and early spring it is possible to get near the base of the Napanee to measure and describe ~8-9m of section. In this region, the Napanee is fairly fossiliferous and contains several identifiable taxa including many key brachiopods, some crinoids, and several trilobites. Overall, the Napanee is defined as interbedded shales, calcisiltites, and thin-bedded wackestones. Nearer the top of the ditch the Napanee begins to shallow upward showing more thin-bedded coquinal packstones and grainstones. The base of the overlying Kings Falls is represented by the very sharp contact to the medium-bedded and rippled grainstones of the Kings Falls.

91.3	0.9	Continue S on Game Farm Rd. to Rte 54 (Brownville).
91.7	0.4	Turn right (S) on Brown Blvd. Proceed to intersection with Main St. Turn left (E) on Main St.
93.4	1.7	Turn right in Glen Park HydroPower Fishing Access site. [LUNCH]. CAUTION: river levels can rise 5' in 5 minutes; seek higher ground if you hear SIREN.

STOP 5: GLEN PARK, NY, GLEN PARK HYDROPOWER FISHING ACCESS SITE, BLACK RIVER GORGE
[UTM 18T 0423760 4872110]

In the recent past, the Black River Gorge has become synonymous with rafting/kayaking and hydropower. In the narrow part of the gorge, from just below Brownville village through the parking area just above the hydroplant diversion channel, the Black River Gorge descends through about 25m of section ranging from the Lower Lowville at the western end of the gorge through the Selby at the eastern end. On the opposite or south side of the river, exposures of the overlying Napanee are exposed intermittently in the bluff. Although we saw the same succession at STOP 3, the exposures here in the gorge afford an excellent opportunity to look at well-weathered blocks and enigmatic structural features that indicate there may be some offset between the two sides of the river. Below the fish ladder (accessed via the gravel road that runs along the edge of the water diversion channel) it is possible to observe the beautifully exposed Weaver Road Beds. If water level is low enough, we will walk on them and study their complex structures. The field trip will "officially' end here; however, interested people may wish to continue on to outcrops at King's Falls. Road log is continued below.

93.4	0.0	Leave parking area. Turn right on Main St.
95.0	1.6	Turn left on NY 12F (Bridge St.).
95.1	0.1	Turn left (E) on NY 12F. Proceed to Watertown, NY
97.1	2.0	Cross over I81. Continue E on NY 12F.
100.4	3.3	Jcin with NY12/US11, turn right (S). Get in left lane.
100.5	0.1	Turn left (S) on NY 12.
102.7	2.2	Turn right. Stay on NY 12S.
115.3	12.6	Copenhagen, NY. Intersection with Mechanic St.
115.4	0.1	Turn left (NE) on Cataract St. (becomes Deer River Rd.).
118.6	3.2	Turn right on Old State Rd. (gravel surface).
118.8	0.2	Proceed to parking area. Enter Deer River and walk upstream.

STOP 6: COPENHAGEN, NY, KING'S FALLS ON DEER RIVER
[UTM 18T 0448106 486287]

Like many localities in this region, the Deer River is characterized by several well-developed waterfall successions. Among them are the beautiful sections at Kings Falls just north of the Village of Deer River on NY 26. Accessed via Old State Road, this succession begins in the upper portion of the Napanee and continues upstream to the summit of Kings Falls which exposes the upper Sugar River and basal Denley (Denmark of Kay for the region just south of this locality). Several fascinating structures are found at this locality. In contrast to the block-faulted regions of the Mohawk Valley, the Tug Hill Plateau is often considered as a tectonically quiescent carbonate platform during deposition of the Trenton. This stop, in addition to the section along Roaring Brook with the S-fold below the lower falls, and the brecciated horizons, as well as the structures at the Glen Park section, shows that this region may not have been so stable. Much interest has recently been generated in Trenton/Black River structures due to recent natural gas exploration in the Finger Lakes Region of New York State. The producing horizons are in dolomitized grabens where hydrothermal fluids have migrated along the bounding faults. While, the fault kinematics and mineralization is different here at King's Falls, it does appear that they have acted as fluid conduits. Beneath the Old State Road bridge are excellent exposures of basal King's Falls with thick-bedded calcarenites and grainstones, some showing large symmetric ripples. Downstream the lower contact with the Napanee Formation is exposed. Where the river turns to the west the beds on the north side are dipping towards the northeast, while the beds on the south side have experienced minor faulting. A small thrust fault ramps up towards the east with drag folding of the footwall. Just downstream of this thrust is a small (offset ~0.2m) NNE-trending normal fault with rollover folding on the hanging wall. While these structures are minor, there is significant mineralization in the outcrop including thick calcite veins, an iron-rich or possibly sulphide residue on joint surfaces, and significant dissolution of brachiopods in certain beds. This evidence indicates that these faults have acted as fluid conduits. Farther upstream at the base of King's Falls is another fault. This fault strikes roughly east-west, dipping 40ºS with the beds of the hanging wall drag-folded into the fault trace. The hanging wall is composed entirely of the King's Falls Formation. There is also significant mineralization near this fault in the form of thick veins and rare vugs. The King's Falls-Sugar River contact is exposed about halfway up the falls.

TRIP END.

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