THE MIDDLE ORDOVICIAN SECTION AT CROWN POINT PENINSULA, NEW YORK

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INTRODUCTION

The Chazy, Black River and Trenton Groups are a well studied sequence of fossiliferous limestones, dolostones and sandstones in the Champlain Valley of New York, Vermont and southern Quebec. These rocks record shallow water cyclic sedimentation in the foreland basin of Laurentia prior to and during the initial stages of the Taconic Orogeny. This field trip reviews the stratigraphy of these units, as well as the evidence for reconstructing depositional environments and cyclic sea level changes.

THE CROWN POINT HISTORICAL SITE

This field trip takes place at the scenic Crown Point Historical Site (Figure 1), a *no-hammer, no-collecting locality*. Approximately 120 meters of section is exposed in a combination of excavations, ridges and shoreline exposures that dip ~8° northwest. The overall stratigraphy (Figure 2) from the Crown Point Formation (Chazy Group) to the Glens Falls Formation (Trenton Group) records the Middle Ordovician transgression seen throughout the Appalachians. Correlation of this stratigraphy exposed at Crown Point to the type Trenton in central New York State is provided by *Prasopora spp.* (Mehrtens and Barnett, 1979). Conodonts collected from strata to the north and east (Harris, pers. comm. and Harris, *et al*., 1995; Roscoe, 1973) provide additional age control. Detailed sedimentologic studies of these units have been published by Bechtel and Mehrtens (1995), Mehrtens and Cuffey (2003) and MacLean (1986) and Selleck (1988).

TECTONIC SETTING

The Middle-Upper Ordovician stratigraphic sequence of westernmost Vermont and northeasternmost New York consists of several rock units (Chazy, Black River and Trenton Groups) which record sedimentation in a progressively deepening foreland basin located to the west of the accretionary prism-volcanic arc terrain of the Taconic Orogeny. To the west of this foreland basin lay the Grenville Province metamorphic basement and overlying Cambrian sandstones of the Adirondack Mountains and Champlain Valley. To the east lay uplifting Taconian lands along the deforming Iapetus margin. To the west of this foreland basin lay the Grenville Province metamorphic basement and overlying Cambrian sandstones of the Adirondack Mountains and Champlain Valley. To the east lay uplifting Taconian lands along the deforming Iapetus margin. As described by Rowley and Kidd (1981) and Stanley and Ratcliff (1985) the eastern margin of Laurentia was an eastward dipping continental margin beneath the Iapetus Ocean and associated island arc terrain. The transgressive sequence recorded by the Middle-Upper Ordovician stratigraphy in Vermont, New York and southern Quebec is interpreted to be the result of a combination of factors related to the Taconic arc-continent collision, including foundering produced by passage of the peripheral bulge through the foreland basin (Jacobi, 1981), thrust loading, or a combination of the two processes (Bradley and Kusky, 1986). The global Ordovician eustatic sea level rise (Mussman and Read, 1986) was also a factor in producing the transgressive sequence along the Iapetus margin.

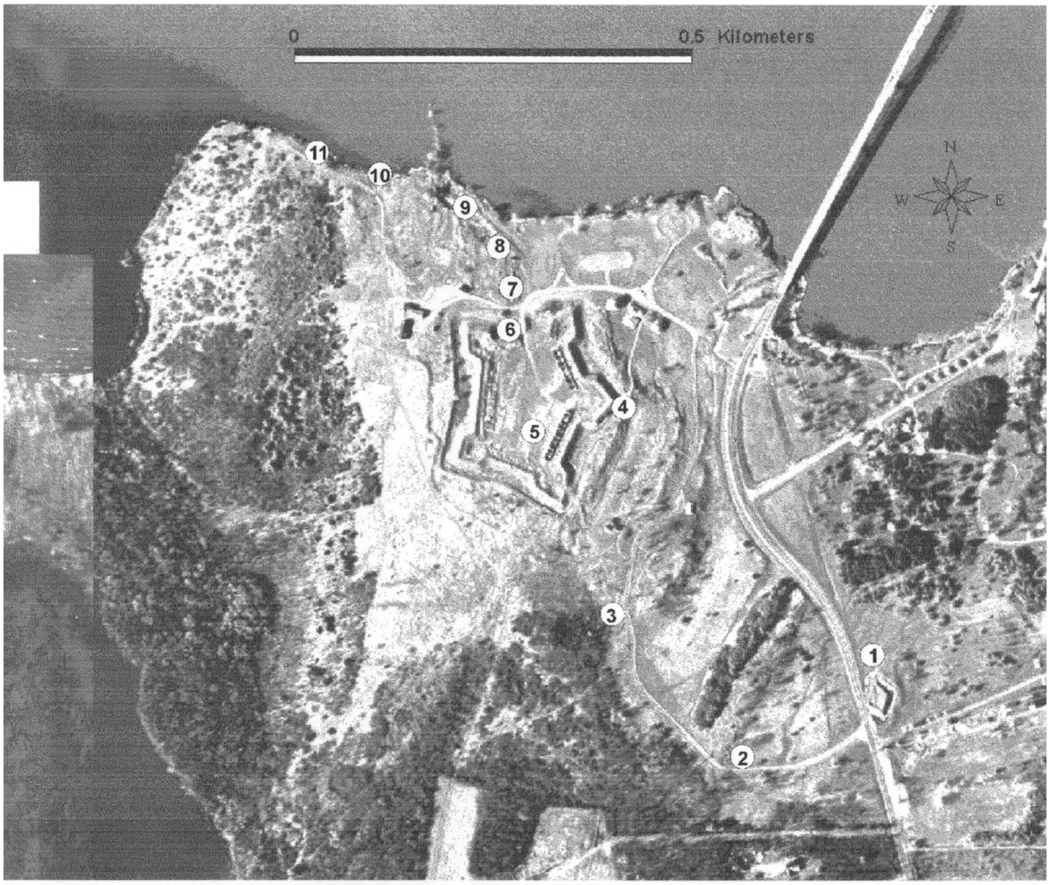

Figure 1. Locality map for the Crown Point Reservations. Numbers refer to field trip stops.

Important to our understanding of the Middle-Upper Ordovician stratigraphy in the Champlain Valley region is the role of syn-depositional block faulting in controlling facies and thickness patterns in the sedimentary sequence. Evidence for active fault movement during deposition of the Middle Ordovician units, a phenomenon described for the Middle Ordovician of central New York by Cisne *et al.* (1982), and southern Quebec (Mehrtens, 1988), includes karstified limestone horizons within the Black River Group (Bechtel and Mehrtens, 1995), clast composition evolution within fault breccias such as the Lacolle Formation (Mehrtens and Gleason, 1988), and condensed stratigraphic sequences, for example, Lower (?)-Middle Ordovician Providence Island Dolostone overlain by the Black River Group, with no intervening Chazy (Bechtel and Mehrtens, 1995). There is also biostratigraphic evidence for an unconformity between the Lower Ordovician part of the Beekmantown Group (Providence Island Dolostone) and basal Chazy (Speyer and Selleck, 1986). Today, the Champlain Valley contains excellent exposures of the Cambro-Ordovician stratigraphic sequence (Welby, 1982) that include autochthonous Middle Ordovician limestones, dolostones sandstones and shales which have been overridden by a series of major thrust faults. The Champlain Thrust, for example, has emplaced siliciclastic and carbonate rocks approximately 80 km westward onto authochthonous black shales (Stanley, 1987).

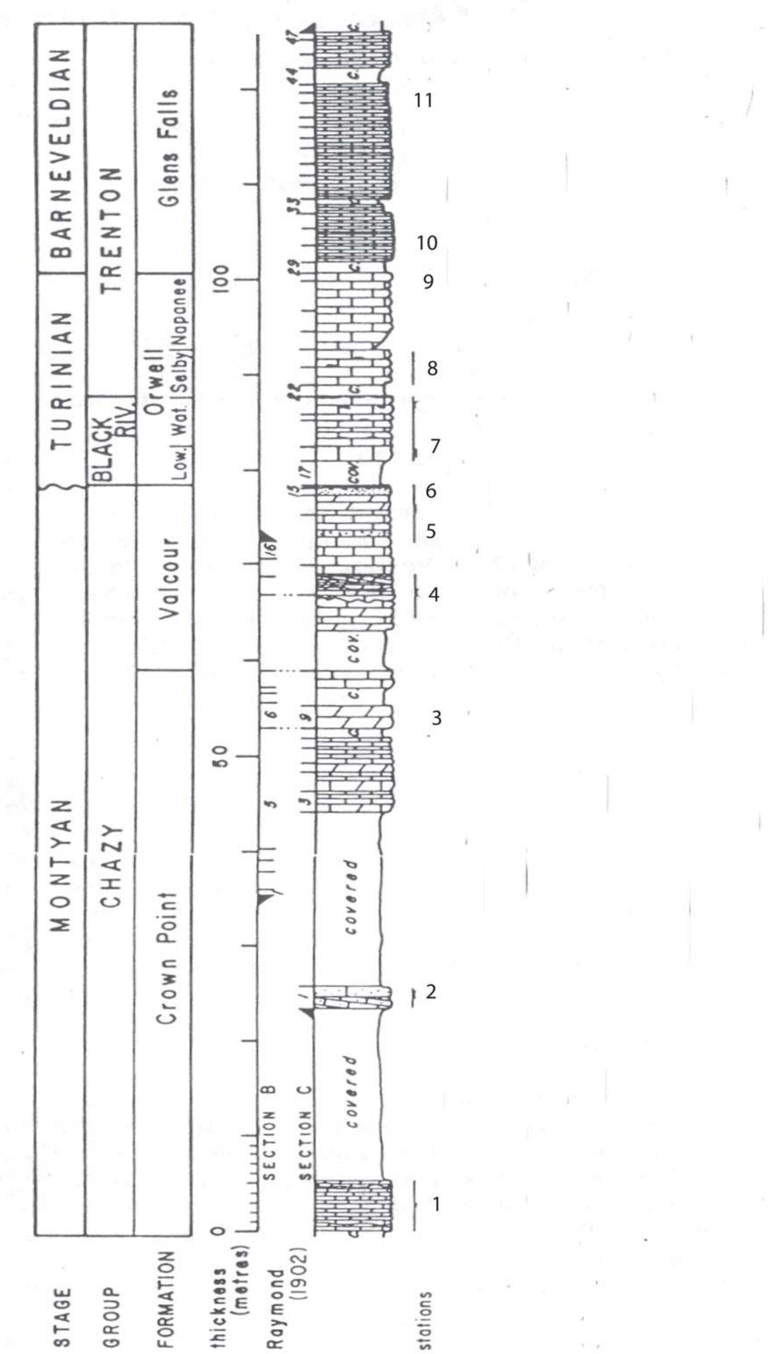

Figure 2. Stratigraphic column for the units visited during this field trip. Numbers refer to field trip stops. Modified from Baldwin and Harding (1993).

CHAZY GROUP

The stratigraphy of the Chazy Group in eastern New York and adjacent Vermont was described by Oxley and Kay (1959) and is summarized in Fisher (1968). Welby (1962) includes a summary of stratigraphic relationships between exposures in New York and Vermont and Hoffman (1963) presents the stratigraphy for the Middle Ordovician units in southern Quebec. Speyer and Selleck (1986), present regional correlations within the Chazy Group in the Champlain Valley.

The Chazy Group is Middle-Upper Ordovician (Whiterockian Series, Chazyan Stage) in age (Figure 2). Based on conodonts (Harris, *et al*., 1995) the Chazy spans the upper half of the *Phragmodus polonicus* through *Ca. sweeti* zones (North Atlantic lower latitude province) or the base of the *Pygodus serra* through *Pygodus ans* Zones (North American cosmopolitan province). In terms of graptolites, the unit extends from the base of the *Diplograptus decoratus* to mid-*Nemagraptus. gracilis* zones.

The Chazy Group varies in thickness within the Champlain Valley from 250 meters in the north (Isle la Motte region) to 90 meters at Crown Point, to less than 15 meters at Ticonderoga and to zero at Whitehall (Oxley and Kay, 1959). In the type area in the northern Champlain Valley, the Chazy can be divided into three formations (Figure 2) as well as several members. Organic buildups (called variously biostromes, mounds, and reefs) occur in all three units, however the composition of the framebuilders varies stratigraphically; Pitcher (1964) summarizes the stratigraphic trends in faunal composition. Organic buildups are absent here at Crown Point, although they can be found across the lake and to the north, in Vermont. The nature of the basal contact of the Chazy Group with the underlying Lower Ordovician Beekmantown Group also varies within the Champlain Valley. In the south, basal Chazy horizons are in unconformable contact with tilted, eroded Beekmantown Group strata. In the northern Champlain Valley, basal Chazy horizons (the Scott Member of the Day Point Fm.) are in apparent conformable contact with the Providence Island dolostone of the Beekmantown Group (Speyer, 1982). The nature of the upper contact of the Chazy Group with the overlying Black River Group is lithologically abrupt, but evidence for significant erosion is generally absent (Bechtel and Mehrtens, 1995). This contact is covered at the Crown Point Historical Site.

The basal Chazy unit, the Day Point Formation, is not exposed at Crown Point and will not be seen on this field trip. Mehrtens and Cuffy (2003) described the depositional environments and reef succession in this unit. They documented the growth of bryo-mounds that typically attained one meter in height and which grew seaward of cross-bedded sand shoals. The mounds frequently exhibit internal zonation; early colonizing *Champlainopora chazyensis* often grows on brachiopod shells and are in turn encrusted by *Batostoma chazyensis*. Cycles of sea level are documented by recurring sand shoals as well as variation in upward and outward growth of the bryo-mounds.

The Crown Point and Valcour Formations will be examined on this field trip; in general both units consist of fossiliferous bioclastic wackestones, packstones and grainstones, with varying degrees of fabric-selective dolomitization. Shaley, nodular limestones are present in the stratigraphy, but are rarely exposed at the surface. Environments of deposition vary from subtidal, storm-dominated shelf settings to more nearshore sand shoals and tidal flats. Intervals of penecontemporaneous cementation and karstic erosion may mark intervals of subaerial exposure.

Cements within the Chazy Group at Crown Point typically consist of an early equant to prismatic low-Mg calcite followed by later coarse calcite spar. Dissolution and chert replacement of aragonite bioclasts is common. Dolomitization in the Crown Point limestones is widespread, and is highly fabric selective in some facies. Variations in primary mineralogy (low-Mg calcite vs. aragonite) appears to have controlled the dolomitization of some bioclastic materials; grain size, sorting, porosity, intensity of borrowing and distribution of early cements (and thus permeability of materials during burial diagenesis) seem to best explain the highly variable patterns of dolomitization (Selleck, 1988).

BLACK RIVER GROUP

The Black River Group in the Champlain Valley is a relatively thin unit (25-30 meters) that consists of massively-bedded wackestones to packstones which represent deposition in lagoonal to shallow subtidal environments. The gradual deepening that characterizes this unit (and which continues into the overlying Trenton Group) is punctuated by cyclic sea level changes that occur on the macroscopic (meter) as well as microscopic (centimeter) scales, the latter visible only in thin section. The lithologic variation within this unit over its outcrop area of New York, Ontario, Quebec and Vermont has contributed to the proliferation of stratigraphic names, however the Pamelia, Lowville (House Creek and Sawyer Bay Members) and Chaumont Formations can be recognized in the Champlain Valley. Bechtel (1993) summarizes the evolution of nomenclature applied to this unit. Based on conodonts (Harris, *et al.*, 1995), the Black River Group is Middle-Upper Ordovician (Mohawkian Series, Blackriverian Stage).

The lower contact of the Black River with the underlying Valcour Formation of the Chazy Group is covered at Crown Point, however the basal beds of coarse-grained subarkose sandstones are exposed and will be visited on this field trip. The upper contact of the Black River with the overlying Trenton is likewise covered.

Cement Stratigraphy of the Black River Group

There are multiple types of cements present within the Black River limestones which record a complex diagenetic history. The general cement stratigraphy pattern records early nonluminescent cement associated with precipitation in oxidizing waters of the shallow meteoric phreatic zone. With increasing reducing conditions, bright and dull luminescent cements represent precipitation under shallow burial conditions. Ferroan calcite with dull to nonluminescence represents precipitation in a late burial situation from high temperature burial fluids. Early marine Black River Group micritic cement is ferroan and very dull luminescence, representing deposition in a reducing, lagoonal environment. Subsequent cementation took place in the shallow meteoric phreatic zone, with nonluminscent cements with bright rims representing oxidizing conditions becoming slightly more reducing with burial. These observations are consistent with those of Mussman, *et al*. (1988) who interpreted such patterns to be related to a cratonward-dipping meteoric water lens beneath tidal flats. Tectonic uplift would lead to stagnation of the aquifer and increasingly reducing conditions. Within this general pattern, however, there are many variations in the Black River limestones which record frequent base level changes associated with sea level fluctuations and block fault movements in the Taconic foreland basin. These base level changes have produced numerous firmgrounds (at all Black River localities in the Champlain Valley) as well as beachrock (at Arnold Bay, VT) and paleo-karst (at Arnold Bay, Chippen Point and Sawyer Bay, VT localities).

Fractures are common throughout the Black River and their cements also record evolving burial conditions. The cement stratigraphy of the fractures indicates that their formation occurred throughout the diagenetic history of the Black River Group, from early syndepositional events associated with karst and beachrock formation, through to deep burial under reducing conditions. Figures 3 and 4 illustrate some of the observed patterns. In the first thin section (Figure 3, following page) two cement events are visible in the fracture. The first consists of nonferroan scalenohedral crystals extending outward from the fracture wall. These are interpreted to have been precipitated in the meteoric phreatic zone. The later, large ferroan equant blocky crystals in the center of the fracture represent a late burial cement precipitated under reducing conditions.

In Figure 4 (following page), a photograph taken under cathodoluminescence, the zoning of rhombohedral crystals infilling a fracture can be seen. The very symmetrical zoned patterns starts (from the interior outward) with a nonluminescent nonferroan core, a dull rim, a bright orange rim, another dull rim, to another bright rim, and fading to nonluminescent outer rims. The nonferroan to ferroan zonation is indicative of increasing reducing conditions during cementation. The cement stratigraphy of the fractures indicates that their formation occurred throughout the diagenetic history of the Black River Group, from early syndepositional events associated with karst and beachrock formation, through to deep burial.

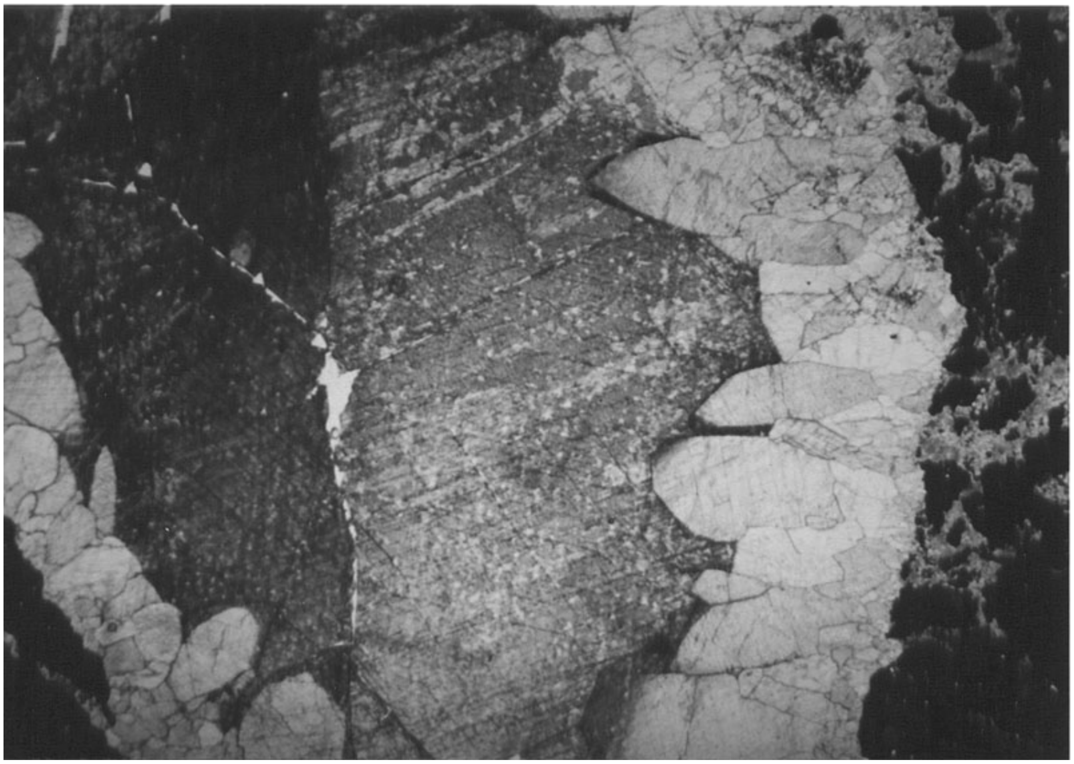

Figure 3. Two generations of fracture cement; field of view is 1.8cm

Figure 4. Cathodoluminescent photograph of fracture cements (field of view 0.5mm)

TRENTON GROUP

The contact between the Glens Falls Limestone (Trenton Group) and the Black River Group is covered at most localities in the Champlain Valley, including here at the Crown Point Historical Site. At Arnold Bay, to the northeast of the Crown Point site, the contact is exposed and is interpreted to be a disconformity; the dark gray colored, massively bedded Black River is in sharp contact with the nodular-bedded, laterally discontinuous beds of the Trenton. MacLean (1987) measured the Trenton Group around the Champlain Valley and found that here at Crown Point only 9 meters are exposed (but more may be covered by lakeshore muds) whereas a few miles to the north, at Button Bay it is more than 15 meters thick. The Button Bay exposure is significant because it is the only place where both the lower upper and contacts, with the Black River and Cumberland Head Argillite, respectively, are seen. Bechtel (1993) summarizes the variable nature of the Black River/Trenton contact around the Champlain Valley, New York and Ontario, and he notes that the regional variation in the nature of this contact, as well as the thickness variation along strike, would be expected in a foreland basin actively undergoing syndepositional block faulting.

MacLean (1986) identified seven lithofacies in the Glens Falls Formation, recognized by variations in lithology, bedding style, sedimentary structures and biota. The shallowest bathymetry is represented by a lithofacies consisting of grainstones composed of peloids and oncoids exhibiting pinch and swell bedding, graded bedding and cross laminations, which suggest wave reworking within fair-weather wave base (Figure 5, following page; arrow points to hummocky cross laminae in the grainstone). At the other bathymetric extreme are bioturbated (*Teichinchnus* and *Chondrites*) mudstones interbedded with shale and distal tempestites/turbidites composed of wackstone/packstone to mudstone couplets (Figure 6, following page). MacLean also recognized a bryozoan-rich wackstone/packstone lithofacies (his Facies F) that is characterized by abundant *Stictopora* and *Eridotrypa* that form dense thickets or lens-shaped patches on the muddy sea floor. In addition to these ramose bryozoa, this lithofaces contains trilobite, gastropod and brachiopod remains; algae are notable absent. These bryozoan thickets are interpreted to have accumulated on the shelf near fair-weather wave base. Although the absence of algae suggests bathymetry below the photic zone, the abundance of interbedded shale suggests that turbidity may have reduced sunlight infiltration.

Using occurrences of *Cryptolithus* and *Prasopora* for correlation, MacLean documented that the Glens Falls stratigraphy in the northern Champlain Valley differed from that in the south; the transition from shallow water (inner ramp) to deep water (outer ramp) is abrupt in the Champlain Islands whereas in the south (including Crown Point) bathymetric change is hard to discern and more cyclic.

The Glens Falls stratigraphy visible at Crown Point is very representative of the bulk of this unit in the southern Champlain Valley, dominated by grainstone to wackestone/mudstone couplets in laterally discontinuous beds (MacLean’s Facies C). Grainstone beds are commonly laminated and exhibit fine-tail grading (Figure 7). Thin shale seams separate beds. *Chondrites* and *Helminthropsis* are the dominant ichnofauna. Rare bedding planes exhibit a bedding plane fauna of bryozoa (*Prasopora*, *Stictopora*) and trilobite fragments. Moving up section at Crown Point the hummocky bedding style of the base of the section is replaced by more laterally continuous grainstone beds with sharp, planar bases that grade upwards into bioturbated wackestones/mudstones (MacLean’s Facies E). These horizons are interpreted to be bioclastic turbidites.

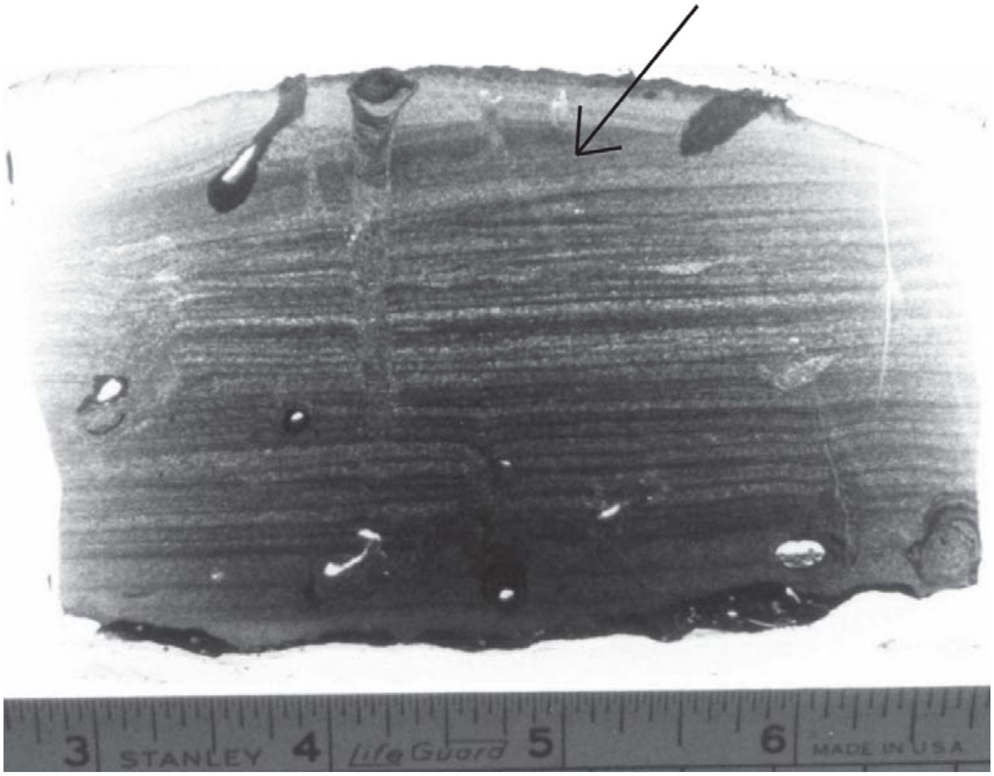

Figure 5. Large thin section (tape for scale) of cross lamination in a Glens Falls Fm. grainstone.

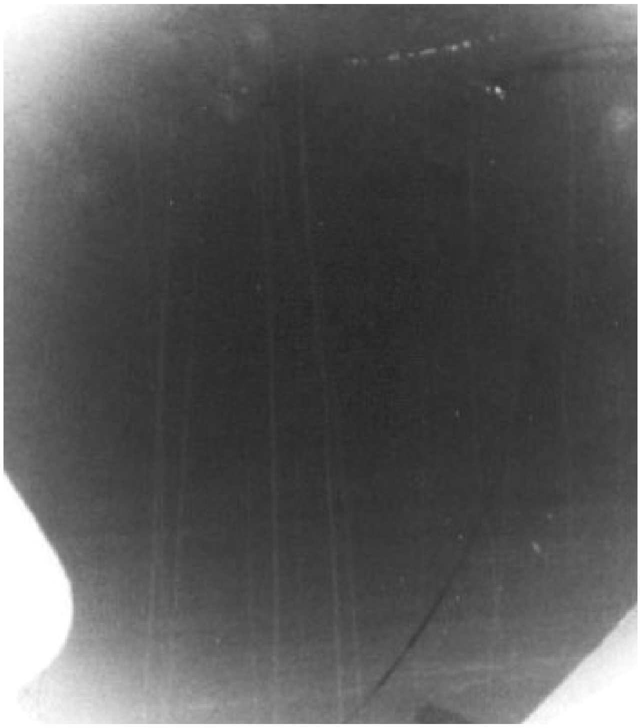

Figure 6. Large thin section (12 cm long) of the outer ramp lithofacies of the Glens Falls Fm.

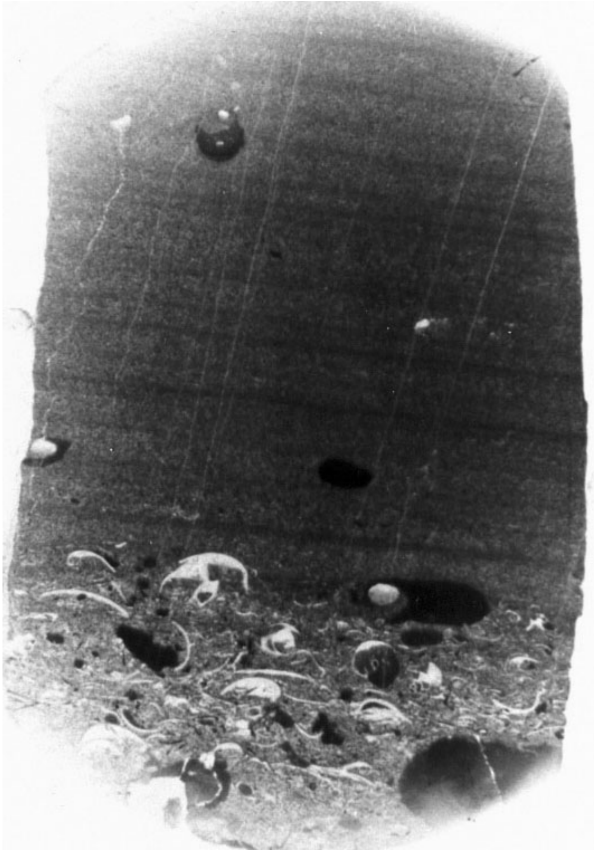

Figure 7. Large thin section (18 cm in length) of graded bed in the Glens Falls Fm.

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FIELD TRIP LOG

All the stops for this field trip are within the Crown Point Reservation Historical Site. From the west, take NY Route 22 north from Ticonderoga, continuing north through the village of Crown Point. Turn east approximately five miles north of the village, following signs to the “Bridge to Vermont.” The Crown Point site is immediately before the bridge crossing. From the east, take VT Route 22A north from Fairhaven, or south from Burlington, and follow signs to “Bridge to New York.” The Crown Point site is immediately over the bridge crossing. Stop locations are keyed to Figures 1 and 2. The Crown Point Reservation Historical Site is a no hammer, no collecting outcrop.

Stop 1 – the Redoubt

Approximately 6 meters of burrowed, slightly dolomitic, thin to medium bedded bioclastic packstone and grainstone is exposed at this stop. Some beds are relatively well-sorted grainstones with sharp bases which are interpreted as tempestites. The same interpretation is made for the grainstone intraclast-rich bed visible in the low ledge at the southeast corner of the ditch. Approximately 3 meters above the base of the section abundant *Girvanella* algal oncolites are common allochems. Nuclei of fossil fragments are visible within some oncolites. In other beds fossils are relative abundant, and are best seen on slightly weathered bedding surfaces. Trilobite fragments, brachiopods, bryozoans, pelmatozoan fragments, nautiloids and large *Maclurites magnus* are present (exterior shells and opercula). Dolomite occurs in along shaley seams and in burrow fill.

The relatively high faunal diversity, general bioturbation, and storm-related sedimentation all point to a low energy shallow subtidal environment at depths slightly below fair-weather wave base. The abundant algal oncolites and discrete calcareous algal fossils (e.g., *Hedstromia spp*.) suggest depths well within the photic zone. A possible modern analogue is found in the mixed mud and sand shelf to the west of the emergent tidal flats of Andros Island, Bahamas, as described by Purdy (1963).

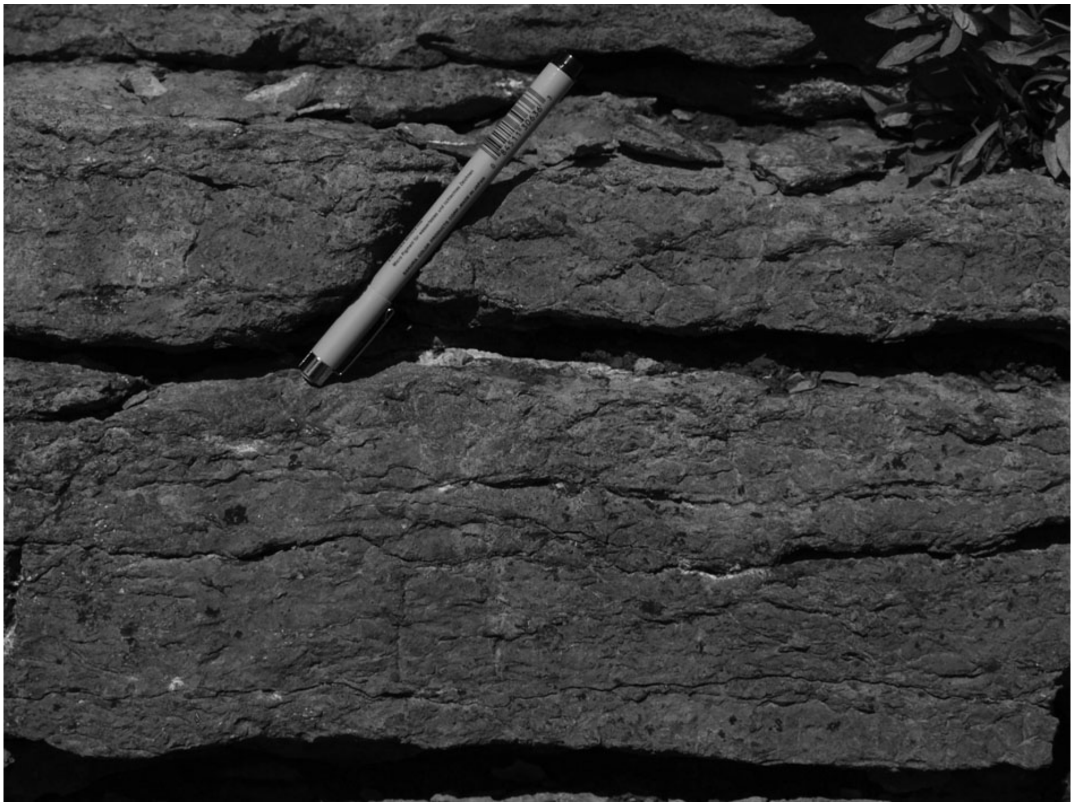

Figure 8. Nodular limestone in shaley dolostone matrix, Crown Point Fm. Pen is 13 cm long for scale

We interpret the wavy, irregular dolomite laminae as the result of dolomitization of lime mud, followed by compaction and pressure solution of calcite that produced irregular clay and dolomite-rich stylocumulate seams. Preferential dolomitization of burrows is due to contrasts in permeability of burrow-fill versus burrow-matrix sediment. The burrow-fill material retained permeability longer during diagenesis and allowed more pervasive dolomitization. In similar facies exposed on Bullwagga Bay (the west shore of the Crown Point Peninsula), modular limestone with shaley dolostone seams and stringers are present. The limestone nodules appear to have been cemented prior to significant burial compaction, whereas the shaley dolostone material was compacted around the cemented limestone. The early-cement limestones were resistant to dolomitization. This sort of fabric selective dolomitization is common in the Chazy and Black River Groups throughout the Champlain Valley.

Stop 2 – Ridge of outcrop running NE from entrance gate
WARNING: poison ivy is common along this ledge

Cross-stratified coarse bioclastic grainstones are well-exposed near the main gate along the entrance road and adjacent ridge. Nearly three meters of section form a prominent belt parallel to strike, extending from the entrance road to the main highway. Foreset cross-strata show bipolar dip directions. Angular quartz and felspar grains are concentrated in some laminae. The carbonate particles are dominantly sub-rounded abraded pelmatozoan plates with gastropod and brachiopod fragments. Large *Maclurites* fragments and grainstone intraclasts are present on the upper bedding surfaces of these ledges.

We propose that the environment of deposition of this facies was a shallow subtidal wave and current reworked bioclastic sand shoal. Active transport of abraded grains may have been accomplished by tidal currents (as suggested by the bi-directional cross-strata) or by storm-generated currents that produced complex, anastomosing patterns of cross-strata and intervening reactivation surfaces. The lack of burrowing and well-preserved whole-shell body fossils may be due to the inhospitable shifting sand substrate. A modern analogue for this environment would be the unstable sand shoals of the Bahamas Platform (Ball, 1967), as the scale and style of cross stratification are similar. Oxley and Kay (1959) report that similar strata in the northern Lake Champlain Valley are oolitic.

Stop 3 – low ledges adjacent to the entrance road (Picnic Pavilion ridge), approximately 50 meters north of Stop 2

Brown-weathering, slightly shaley dolostone exposed here contains lenses and stringers of fossiliferous lime packstone and wackestone. The fauna is similar to that at Stop 1, with trilobites, small brachiopods and *Maclurites* common. The environment of deposition is assumed to be similar to that of Stop 1, however lacking evidence of storm activity. Note that some of the fossils are almost entirely encased in dolomite, which is assumed to be of replacement origin here.

Stop 4 – SE moat of Fort Crown Point

Approximately 3 meters of thickly laminated limestone and dolostone of the Valcour Formation are exposed in the southeast moat of the British Fort. The dominant facies here is alternating 0.5-2.0 cm thick laminae of limestone and dolostone, we term “ribbon rock.” The limestone ribbons are very fine-grained peloid grainstones or “calcisiltites” and appear blue-grey color on slightly weathered surfaces, and as indentations on more deeply weathered surfaces. The dolostone ribbons weather tan-brown in color, and consist of an interlocking mosaic of 20-300 micron dolomite crystals of replacement origin. Quartz silt grains are present in the dolostone ribbons, versus medium to fine-grained quartz sand in the limestone ribbons, suggesting the limestone horizons were slightly coarser-grained than the dolostone when deposited.

An erosional surface with 10 to 20 cm of relief is exposed near the base of the south wall of the moat (Figure 9). Similar erosional surfaces occur within this facies in other Chazy exposures in the Champlain Valley. We interpret these to represent micro-karstic solution surfaces on a tidal rock platform that developed during subaerial exposure of cemented limestone. Typically, the rock below the surface is mostly calcite limestone, suggesting that cementation and diagenetic stabilization of the limestone occurred prior to development of the erosional surfaces. Overlying rock horizons contain more dolomite. *Maclurites* shell hash can be found in pockets on the erosional surface. Dolomitized burrows cut across the limestone ribbons in some parts of the outcrop. Trough cross-strata filling low scour surfaces are also visible.

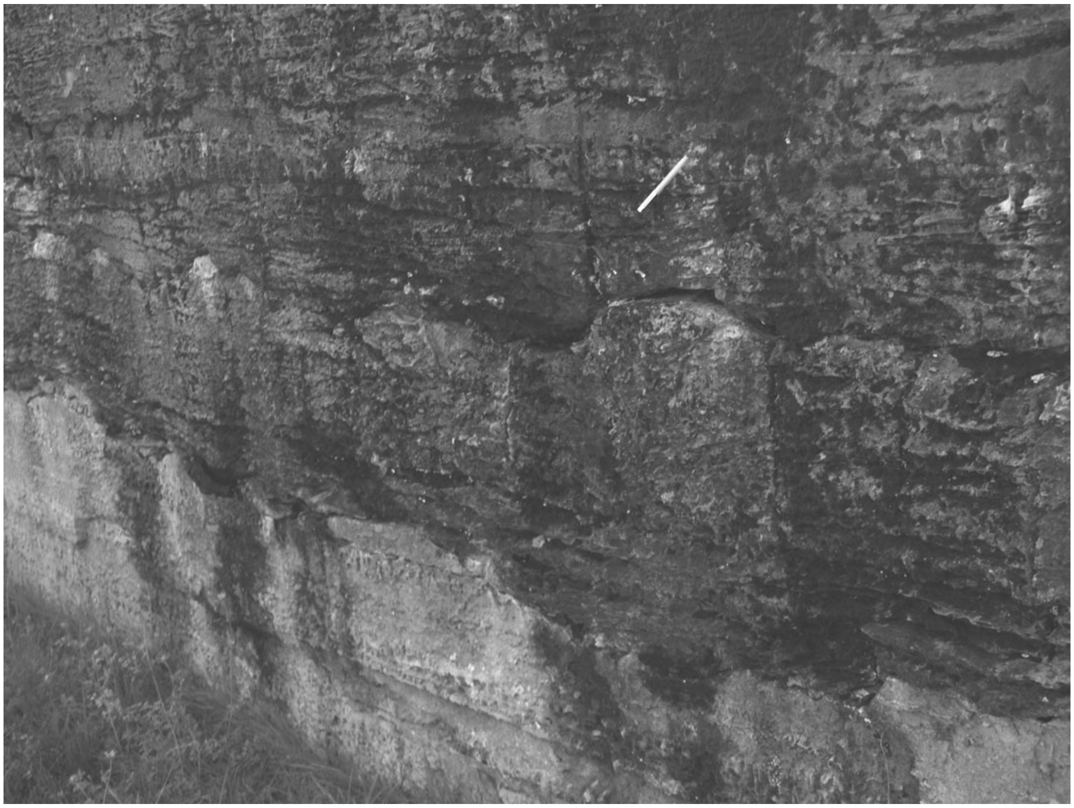

Figure 9. South wall of moat, with erosional surface near the base overlain by differentially weathering "ribbon rock." Pen is 13 cm long for scale.

On the less weathered prominence on the SE corner of the moat, shallow scours containing brachiopod and gastropod debris can be seen. Intraclasts or pseudoclasts of limestone in dolostone are also present. Some "clasts" appear to be cored by dolomitized burrows.

We interpret the stratigraphy seen at this stop as representing a tidal flat to shallow subtidal facies. The alternating limestone/dolostone ribbon rock represents rhythms of slightly coarser-grained (limestone) and finer-grained (dolostone) sediment deposited on the lower reaches of a tidal flat, similar to the rhythmic bedding described by Reineck and Singh (1980) from the mud/sand tidal flats of the North Sea. These coarse-fine alternations might also reflect storm-related, ebb-surge deposition (Nelson, 1980). Early cementation of the slightly coarser-grained limestone ribbons made this lithology less susceptible to dolomitization, which affected the finer-grained muddy ribbons that became dolomitized. Variations in the intensity of burrowing is interpreted to reflect subtle differences in duration of subaerial exposure of the tidal flat and/or the extent of reworking by tidal currents. Limited *in situ* faunal diversity is to be expected in the tidal flat setting, where organisms are stressed by salinity fluctuations. The absence of mudcracks or evidence of evaporite minerals may indicate that only the lower portion of a humid climate tidal flat system is preserved here.

Stop 5- Parade Grounds near barracks:

As we enter the parade ground from the southwest corner of the moat, note the array of carbonate rocks used in construction of the barracks walls. Chazy, Black River and (rarely) Trenton lithologies can be identified. Restoration of the barracks began in 1916 and in 1976 the New York State Division for Historic Preservation undertook protection and stabilization of the ruins.

The low rock pavement just north of the barracks is within the upper part of the "ribbon rock" unit seen at Stop 4. Immediately up-section, cross-stratified grainstone beds are exposed. Coarse-grained quartz and feldspar sand is easily seen on weathered surfaces. Trough cross-strata and herringbone co-sets of planar-tabular cross-strata are visible on the vertical surfaces. Large, angular clasts of slightly dolomitic grainstone and *Maclurites* are present on bedding surfaces. We interpret this facies as representing a current-dominated sand shoal environment, similar to that seen at Stop 2.

Stop 6- West Parade Grounds

Bechtel and Mehrtens (1993) suggested that the sandstone unit in the westernmost parade ground is the basal sandstone of the Black River Group, an interpretation which differs from that of Speyer and Selleck (1988), who suggested that this unit was part of the underlying Chazy Group. In thin section this sandstone is a quartz arenite, very poorly sorted, and containing fewer lithic fragments and phosphatic fragments than stratigraphically lower Chazy sandstones. Visible at the very easternmost portion of this ridge is a buff-colored dolostone bed containing pockets of quartz sand (burrow infills?). These basal sandstone and dolostone lithologies are very similar to those described by Walker (1972) in his description of the Pamelia Formation at its type locality in north-central New York. Alternatively, placement of the sandstone unit within the Chazy Group is consistent with the common presence of coarse-grained quartz and feldspar sand within the Chazy at the Crown Point Preserve, whereas the siliciclastic material in the Black River Group at Crown Point is mainly silt and clay. Whatever the stratigraphic placement of the sandstones and dolostones here, it marks an interval when sands were transported from a nearby source area to this possible peri-tidal setting. This interval was followed by marine reworking of the sand and deposition of fine-grained limestone of the basal Black River Group.

Stop 7 – Northeastern moat

WARNING: poison ivy is common along the base of this exposure

There is approximately one meter of covered interval between Stop 6 in the parade grounds and Stop 7 in the northeastern moat. Along this wall are exposed several meters of the lower Black River Group (Lowville Formation, House Creek Member) which in Vermont is termed the Orwell Limestone. At the base of this exposure a series of stylolitized gastropod-bearing (*Liospira*) wackestone beds are overlain by thicker beds of *Phytopsis*-burrowed aphanitic mudstones. This sequence can be interpreted as a shallowing-up cycle (SUC) consisting of subtidal overlain by peritidal lagoonal muds. Examine the sharp contact of the aphanitic mudstone with the overlying wackestones, a contact which in thin section appears to be a firmground (Bechtel, 1993). These SUCs also comprise the base of the Black River Group at other localities in the Champlain Valley. There are three motifs of repetitious bedding that occur in the Black River Group and the cycles seen here at the base are the the thickest, occurring at a macroscopic scale, interpreted to represent 4th order (10,000 to 100,000 years) or smaller cycles. Examination of *Phytopsis* burrows in thin section (Figure 10) reveals that many are filled with graded (fining-up) geopedal silt, evidence of cementation in the meteoric vadose zone.

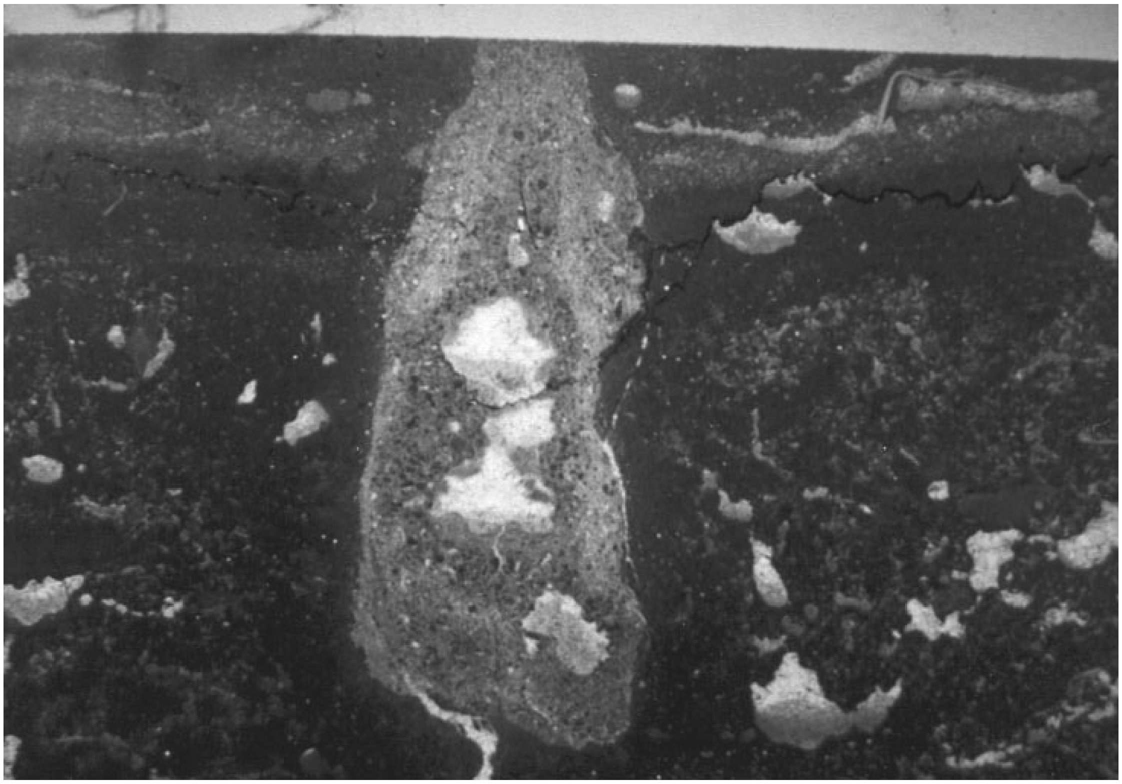

Figure 10. Thin section photomicrograph of burrow fill. Field of view 2.4cm

Continuing up section, several thick packstone beds are exposed. More detailed examination of these beds reveals that they consist of alternating one to six centimeter thick intraclast and oncolite-rich packstone horizons interpreted as tempestites, interbedded with fossiliferous wackestone/packstone horizons. The tempestites consist of graded and crudely imbricated intraclasts and skeletal fragments. Note the nature of the upper and lower contacts of these horizons. The second common bedding motif in the Black River Group are these tempestite horizons interbedded with *in situ* fossiliferous muds.

The uppermost third of the outcrop appears to be a massive bed of limestone, however closer examination also reveals small scale cycles of alternating wackestone/packstone and grainstone, the third motif of bedding in the Black River strata. These cycles are characterized by a base of thinly laminated or cross laminated grainstone horizons 0.5 to 1 cm thick, overlain by fossiliferous wackestones and packstones. In thin section the bases of the grainstones can be identified as firmgrounds, recognizable by the truncations of allochems and cements present in the underlying mud (Figure 11).

Figure 11. Thin section photomicrograph of a firmground; field of view is 1.5cm

The very top of this exposure (best seen at the next stop) exhibits a burrow mottled fabric with selected dolomitization of many burrows. *Tetradium* occurs in life position in these horizons.

Stop 8 – east-west ridge across the service road

A black chert layer near the top of Stop 7 provides the correlation to Stop 8, the outcrop across the service road. The limestone beds on this ridge commonly consist of alternating wackestone/packstone and planar to cross laminated grainstone beds, as seen at Stop 7, however bedding plane exposures permit identification of many fossils in these, the most faunally diverse beds in the Black River Group. Specimens of gastropods (*Liospira*, *Lophospira*, *Hormotoma*), *Lambeophyllum*, *Tetradium*, stromatoporoids, the bivalve *Cyrtodonta,* the brachiopod *Stromphomena sp*. and cephalopods are recognizable. This ridge exposure is most notable for its bedding plane exposures of *Tetradium* and *Lambeophyllum.* It is interpreted as representing a wave baffle margin lithofacies similar to that described by Walker (1972) at the Black River type section.

The third cycle motif we recognize, laminated grainstone overlain by bioturbated wackestone, so common in this portion of the stratigraphy, are interpreted to represent smaller scale 4th order cycles, which could be the result of facies mosaicing and/or small scale base level changes.

There are at lest two distinct types of chert occurrences in the Black River Group. One, the infilling of horizontal burrows, is fabric selective. Chert also occurs less frequently as broad bedding plane parallel sheets. The uppermost chert horizon on this ridge, traceable down to the shoreline, is of this latter variety. Clearly, there was a significant source of silica available for chert formation, perhaps a combination of silica derived from sponges (*Tetradium*?) and bentonite alteration (the Ordovician sequence in the Champlain Valley is notorious for the paucity of bentonites compared to equivalent strata in central New York and southern Quebec, although Ryan, *et al*., 2007 have recently been successful in identifying altered bentonites in the Beekmantown Group in the Champlain Valley). In thin section the chert cross cuts all previous cements, including late fracture-filling calcite, and it is therefore the youngest form of diagenesis present in these rocks.

Stop 9 – Quarry to the north

WARNING: be extremely careful around the quarry as the thick algal scum in the quarry water obscures where the grass ends and the quarry wall drops off.

The older weathered south walls of the quarry show, by color differentiation, two cycles. There are 3 to 4 cm thick beds of planar laminated skeletal and peloidal hash overlain by burrowed wackestones overlain by intraclast-rich horizons. These cycles represent our third motif of Black River bedding. Interbedded with these cycles are tempestite couplets of mudstone/wackestone and fossil hash layers in which brachiopod-rich layers are abundant. The abundant quarried blocks lying about provide the opportunity to look for cycles, and from these, topping directions.

Stop 10 – shoreline of eastern Bulwaga Bay

The uppermost horizons in the quarry can be traced down to the shoreline to the north where the uppermost Black River strata can be seen (Chaumont Formation). Shoreline bedding planes exhibit horizontal traces of *Chondrites* and opercula of *Maclurites.* There is a thin covered interval of approximately one meter to the basal beds of the Glens Falls Limestone of the Trenton Group. The Glens Falls is characterized by thin beds of nodular to wavy bedded wackestones, mudstones and rare grainstones. Bedding planes along the shoreline contain mostly *Chondrites* and *Helmenthopsis* burrows, however as one moves up section, recognizable fragments of *Cryptolithus, Isotelus*, orthid brachiopods, *Stictopora,* and *Prasopora simulatrix* can be found; the latter is important because it permits the correlation of the lower Glens Falls here in the Champlain Valley to the lower Denley Limestone at the Trenton type section in central New York (Mehrtens and Barnett, 1979).

MacLean (1986) interpreted the lithofacies of the basal Glens Falls visible here to represent sedimentation in a shallow subtidal environment periodically influenced by storm activity. In thin section the nodular and wavy bedded wackestones appear thoroughly bioturbated, a process which would influence and enhance subsequent differential compaction. Grainstone beds exhibit more planar bases with basal skeletal fragment lags or finely crushed debris of brachiopod, trilobite and crinoidal material and capped by carbonate mud. MacLean interpreted these as tempestite deposits. Moving further up section (in horizons not seen at Crown Point) the Glens Falls records progressively deepening conditions from the subtidal, storm influenced conditions seen here to bioclastic turbidites separated by authochthonous shale horizons. For those familiar with the lower Trenton Group localities in central New York State (ex., Rathbun Brook, City Brook, Inghams Mills), the paucity of fossiliferous bedding planes here at Crown Point is noteworthy. The overall fine grain size and ichnofauna suggest that bathymetry increased significantly and rapidly from the Black River into the Glens Falls, a transition that might reflect not only rising sea level but base level changes as well. The sedimentologic and faunal transitions from the Glens Falls to the overlying Cumberland Head Argillite and the Stony Point Shale are much more gradational than that of the Black River/Glens Falls contact.