SILURIAN-EARLY DEVONIAN SEQUENCE STRATIGRAPHY, EVENTS, AND PALEOENVIRONMENTS OF WESTERN NEW YORK AND ONTARIO, CANADA

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INTRODUCTION

The Silurian rocks of the Appalachian Basin provide an excellent suite of strata for application of sequence, and event stratigraphic approaches. The strata are well exposed and display marked vertical changes in facies, commonly associated with distinctive condensed beds and/or discontinuities. The Niagara Escarpment in western New York and the Niagara Peninsula of Ontario represents a key reference area for the North American Silurian System. Indeed, the term "Niagaran," which has been variably applied to the "middle" or lower and middle portions of the Silurian, is still commonly used in North America. These rocks have been well documented by many researchers, beginning in the mid 1800s (Hall, 1852; Grabau, 1901; Williams 1919; Gillette, 1947; Bolton, 1957; Zenger, 1965, 1971; Sanford, 1969; Martini, 1971; Rickard, 1975; Brett, 1983 a,b; Brett et al., 1995; 1998).

A major theme of this report and field trip is the documentation and interpretation of Silurian facies and sequences along the northwestern rim of the Appalachian Basin. The larger scale ("third order") sequences described herein are unconformity bound stratal packages, ranging from less than a meter (where partially truncated or condensed) to about 50 m in thickness. Most display a generally deepening- shallowing pattern. They are divisible into smaller (fourth-order) sequence-like units that display similar patterns but are not separated by major unconformities; we have termed these units subsequences (see Brett et al., 1990a, b, 1995, 1998, for further details).

With its renewed emphasis on through-going discontinuities and condensed beds, the sequence approach has encouraged a broader, more regional view of stratigraphy and an attempt to understand the genetic significance of particular beds and surfaces. To some degree it vindicates the earlier "layer cake stratigraphy" approach. Sequence stratigraphy, originally developed from remote seismic studies of passive margin sediment wedges (Vail et al., 1977, 1991; Wilgus et al., 1988). is now being applied at an outcrop scale to diverse depositional settings including foreland basins such as the Appalachian (or Taconic) foreland basin of the Ordovician and Silurian (Brett et al., 1990 a,b; Witzke et al., 1996; Brett et al., 1998). Many distinct surfaces in the local stratigraphic record are interpretable as sequence boundaries or flooding surfaces. Moreover, a number of phenomena which occur non-randomly in the geologic record, from phosphatic nodule horizons to reefs fit in predictable ways into depositional sequences.

A secondary theme of this article is the recognition of widespread events, such as storm deposits (tempestites), rapidly buried fossil horizons (obrution deposits), and even seismically deformed beds (seismites). A variety of such catastrophic events are recorded in the Silurian rocks of the Niagara region and will be examined on this trip.

REGIONAL GEOLOGICAL SETTING

Silurian-Devonian strata of the Niagara Peninsula-western New York area were deposited along the northwestern rim of the Appalachian Basin, defined by the intermittently active Algonquin Arch, a presumed peripheral bulge (Figs. 1, 2). The Niagaran paleoenvironments were generally shallow, subtropical epeiric seas, situated 30-35° south of the paleoequator (Witzke, 1990).

Siliciclastic sediments were derived from eastern and, possibly, northeastern source terranes that were uplifted during the Taconic orogeny. Renewed uplift of tectonic terranes may have occurred during the medial- and Late Silurian in the Salinic Disturbance (see Ettensohn and Brett, 1998).

During the Early Silurian Medina Group siliciclastics accumulated in non-marine to shallow marine environments in western New York and extended with little or no break into the region of the Michigan Basin (Fig. 2A). However, by medial Silurian time (middle Llandovery), a broad carbonate platform (Algonquin Arch) appears to have existed in the area around Hamilton, Ontario northwest into the Bruce Peninsula (Fig. 2B). This platform was a region of shallow, epeiric seas, with little or no siliciclastic input, that accunulated a relatively thin succession of dolomitic carbonates. This arch formed a partial to nearly complete barrier between the Appalachian and Michigan Basins during the late Llandovery and Wenlock time (Fig. 2). During the early to medial Silurian (Llandovery-Wenlock Epochs) the axis of the foreland basin remained essentially northeast-southwest in its orientation but migrated laterally, first eastward and then starting in the latest Llandovery back to the west (Goodman and Brett, 1994; Figs. 2C,D, 14). In the Late Silurian Pridoli Epoch the basin again migrated eastward, such that its axis lay near the Hudson Valley by the Early Devonian.

The Algonquin Arch was probably emergent at times during the late Llandovery and late Wenlock when relative base level drops produced major unconformities within the carbonate succession. During Ludlow time, however, the Arch, appears to have subsided such that the area between Hamilton, Ontario and the northern Bruce Peninsula was the locus of deeper water environments than areas to the southeast or northwest. During this time reefy carbonates were widespread in the Appalachian Basin.

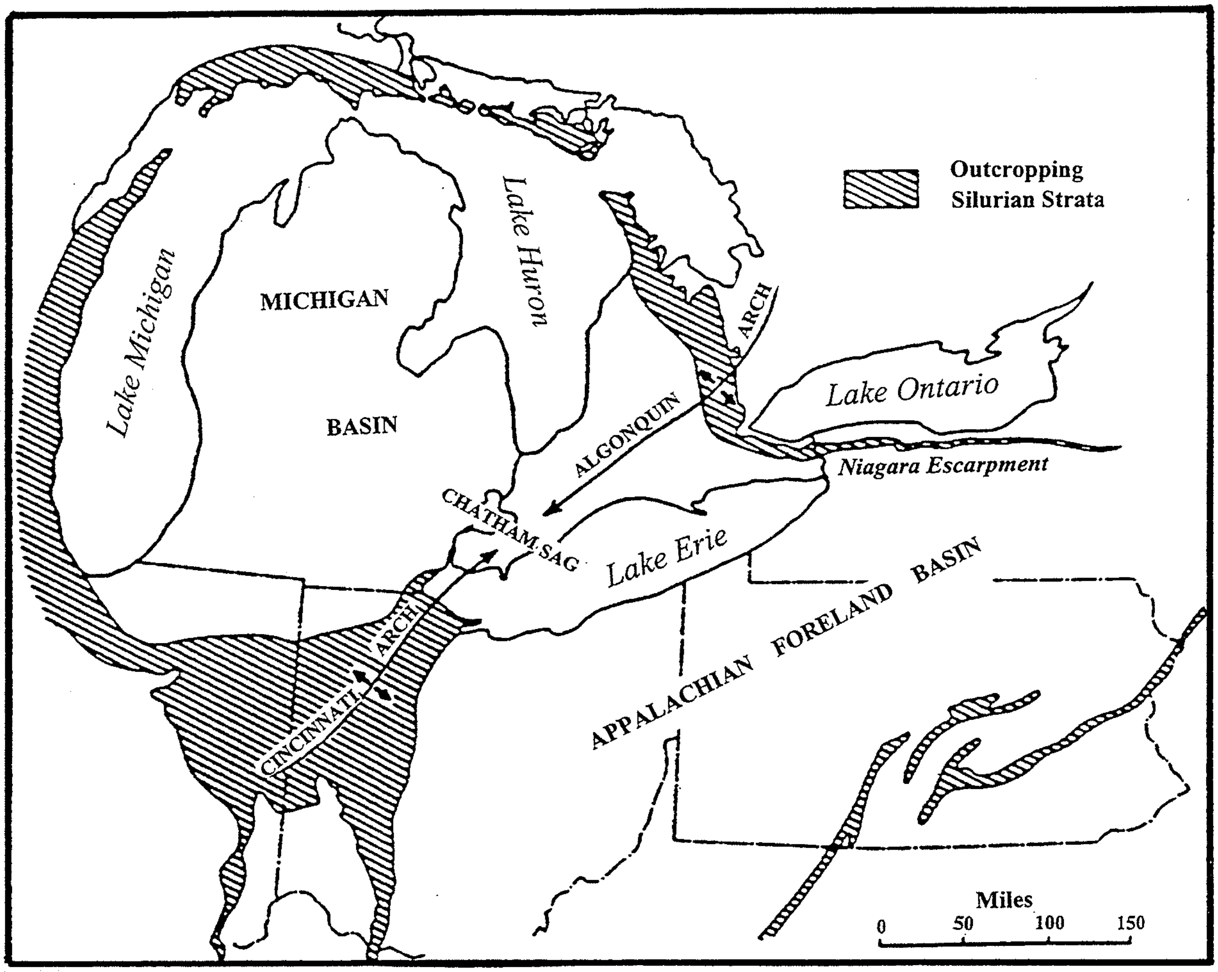

Figure 1. Geological setting of middle Silurian rocks in New York, Ontario, Michigan, and adjacent areas, showing position of the Algonquin-Cincinnati Arch system that separates Appalachian and Michigan basins; position of modern outcrop belt of mid Silurian rocks is shown in diagonal ruling. Modified from Telford (1978).

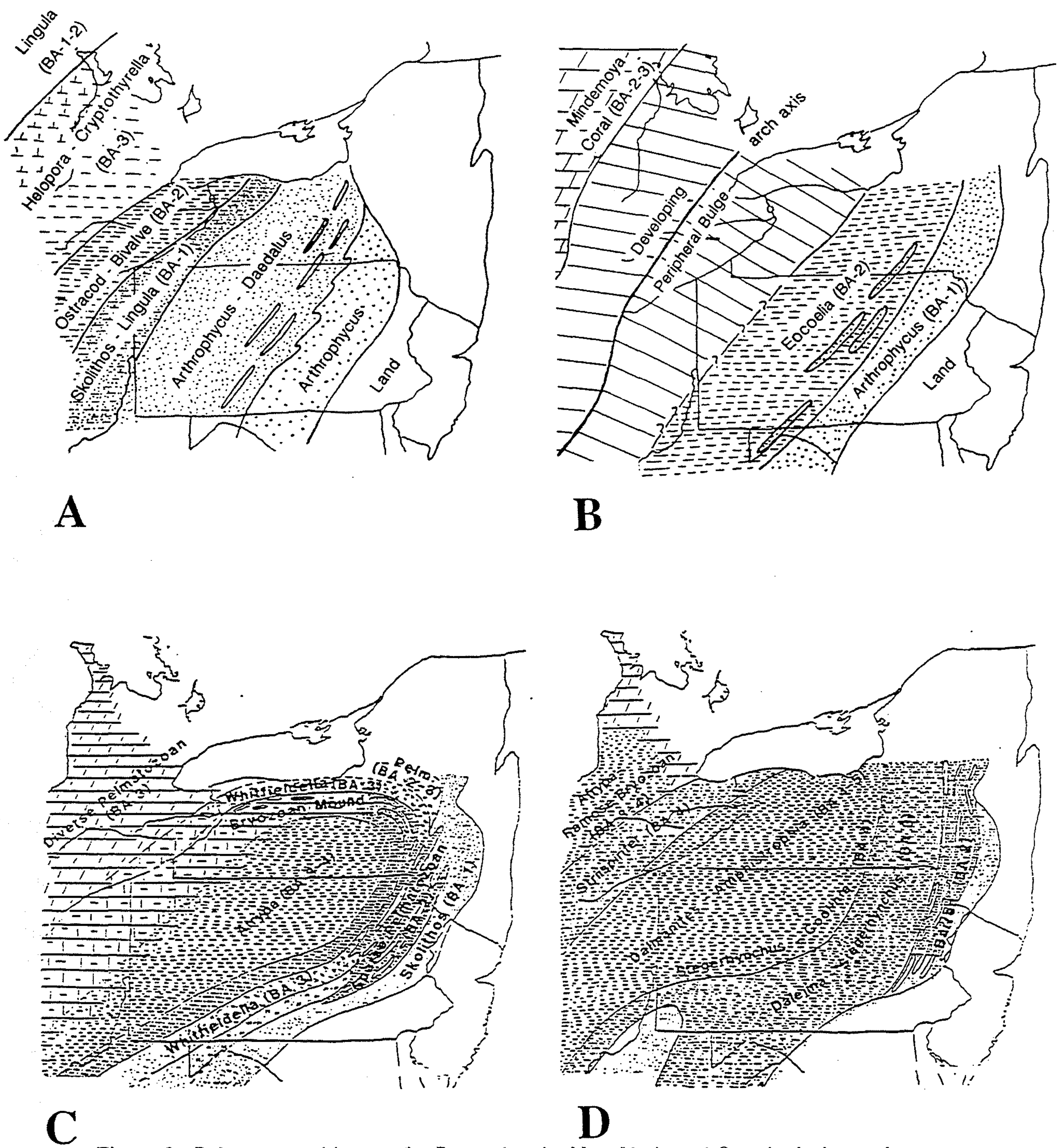

Figure 2. Paleogeographic map for Pennsylvania, New York, and Ontario during early and late Llandovery time. (A) Early Silurian (Rhudannian), Sequence I, Medina Group; note position of basin center in southern Ontario. (B) Mid Telychian time, during deposition of Sequence III, the Sauquoit-Otsquago-upper Rose Hill succession in central New York and Ontario. Note development of regional uplift (forebulge) along the Algonquin Arch (C) Early Wenlock time (Lower K. ranuliformis Zone), Note position of basin axis in western New York State during deposition of Irondequoit Limestone. (D) Mid Wenlock time (Low-mid K. ranuliformis Zone), relatively deep water occupies basin center during deposition of Rochester Shale.

As a broad generalization, Silurian strata in the northern Appalachian foreland display a trend from a) siliciclastic dominated units in the Early Silurian (Alexandrian or early Llandovery) Medina Group, to b) mixed siliciclastics and carbonates in the medial Silurian (lower Niagaran, upper Llandovery-Wenlock) Clinton Group, c) dolomitic carbonates in the Lockport Group (upper Niagaran; Wenlock-Ludlow), and d) mudrocks, dolostones and evaporites in the Upper Silurian (Cayugan, upper Ludlow-Pridoli) Salina-Bertie Groups (Fig. 3). These patterns reflect two major tectonic pulses: a late Taconic tectophase in earliest Silurian and the medial Silurian Salinic Orogeny; these times were dominated by prograding clastic wedges and westward migration of the foreland basin depocenter (Fig. 3; Goodman and Brett, 1994; Ettensohn and Brett, 1998). Intervening times of quiescence were marked by predominant carbonate deposition and eastward backstepping of the basin depocenters (Ettensohn and Brett, 1998).

PALEOECOLOGY

Throughout the Early to middle Silurian seas were of normal salinity and diverse marine invertebrate faunas formed a series of onshore-offshore biofacies. These biofacies formed extensive belts parallel to paleoshoreline that have been termed Benthic Assemblages (BAs; Fig. 2) by Boucot (1975). Benthic assemblages have been calibrated to approximate absolute depths by Brett et al. (1993). Following that model, Benthic Assemblage-1 (BA-1) constitutes peritidal biofacies typically dominated by lingulid brachiopods, bivalves, gastropods, or, in carbonates, stromatolites-thrombolites and ostracodes. BA-2 represents shallow, inner shelf sediments dominated by low diversity brachiopod associations (especially *Eocoelia* in the Early Silurian; Fig. 2), as well as tabulate coral and stromatoporoid biostromes and bioherms; tabulate -stromatoporoid patch reefs were particularly well developed in these settings during the Wenlock-early Ludlow of the Niagara region (Crowley, 1973; Armstrong and Johnson, 1990); BA-3 represents near-wave base environments, such as pelmatozoan shoals and pentamerid brachiopod banks; BA-4 encompasses shallow (30-60 m) outer shelf environments affected by storm wavebase and typified by diverse assemblages of brachiopods, bryozoans, trilobites, molluscs, and pelmatozoan echinoderms; BA-5 comprises deeper shelf settings below storm wavebase and is characterized by small brachiopods, a few bivalves, and, in some areas, graptolites. These benthic assemblages have proven to be widely mappable and useful in determining relative depths of the interior seas (Johnson, 1987). Events of storm-related deposition buried fossil assemblages intact producing spectacular obrution deposits of crinoids, rhombiferan cystoids, asteroids, and trilobites, especially in the Cabot Head and Rochester shales (Brett and Eckert, 1982; Taylor and Brett, 1996).

During Late Silurian (Cayugan or Pridoli) epeiric seas in the Appalachian and Michigan basins became restricted by barriers of the Bloomsburg clastic wedge (to the south) and barrier reef complexes (around the Michigan Basin) and developed hypersaline conditions under which evaporites formed and few organisms, other than rare ostracodes, occupied open shelf environments. In estuarine areas, where fresh water streams mixed with the hypersaline environments, distinctive brackish water biofacies developed (Clarke and

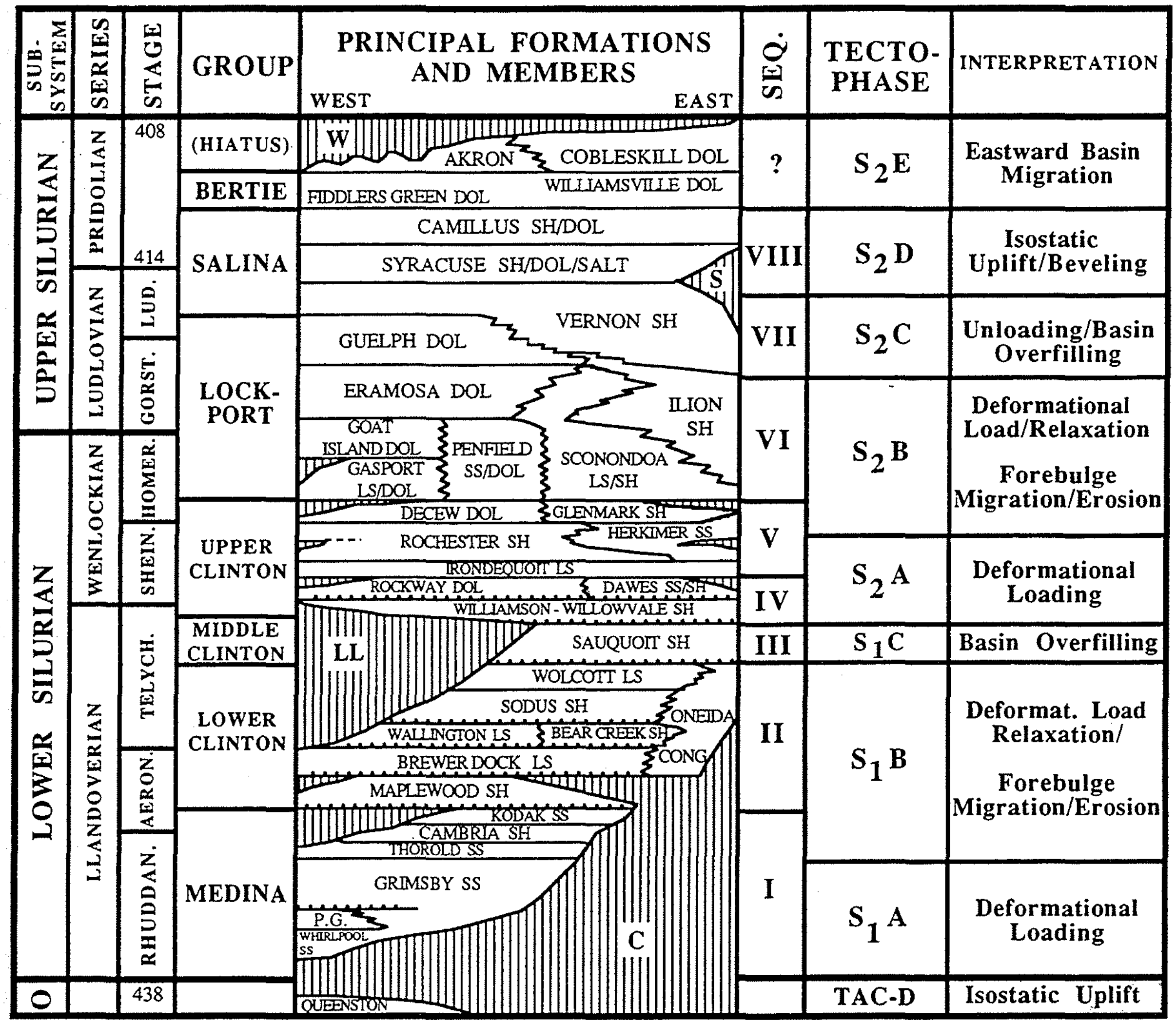

Figure 3. Generalized chronostratigraphic chart for the Silurian system along the east-west outcrop belt from Niagara Gorge to Utica, New York showing subdivision of stratigraphy into unconformity- bound sequences (I-VIII) and interpreted tectophases of the latest Taconic (S_1) and Salinic (S_2) orogenies. Symbols: dots indicate phosphatic/ironstone marker beds. Major unconformities indicated with letters: C: Cherokee; LL: late Llandovery ; S: Salinic; and W: Wallbridge unconformities. From Goodman and Brett (1994).

Ruedemann, 1912; Ciurca, 1973; 1990). These peritidal (BA-1 to 2) biofacies were dominated by eurypterids, and a few species of ostracodes, molluscs and algae. Only in the latest Silurian were normal marine salinities partially restored in the Appalachian Basin.

Silurian marine invertebrates and their biofacies exhibit long term concurrent evolutionary stability punctuated by abrupt intervals of extinction, immigration, evolution, and restructuring. Brett and Baird (1995) termed this pattern "coordinated stasis" and recognized distinctive stable faunas (or ecological evolutionary subunits) in the Silurian of the Appalachian Basin; these correspond very roughly to depositional sequences and were termed the: 1) Medina; 2) Lower Clinton: 3) Upper Clinton-Lockport; and 4) Salina faunas. The latest Silurian-Early Devonian E-E subunits are absent from the study area due to erosion at the Wallbridge Uncoformity. However, diverse coral and brachiopod faunas of the Scoharie (8) and Onondaga (9) stable faunas are well represented in the Bois Blanc and Onondaga formations in the study area of the Niagara Peninsula.

EVENT STRATIGRAPHY

A number of beds in the sedimentary record reflect single unique episodes of sediment deposition and/or deformation Where traceable, such beds provide not only evidence for catastrophic events but also form excellent time lines in local sections.

K-Bentonites

Altered volcanic ash beds provide some of the most valuable marker beds in the geologic record. In theory, these beds record single events of tephra deposition from explosive volcanic eruptions. Not only do they form excellent time lines but also many bentonites can be radiometrically dated. Few K-bentonites have been reported from the Silurian of the Niagara region. However, recently, thin clay layers that appear to be bentonites have been identified in the lower Lockport Group of western New York. These may correlate with probable K-bentonites that have been found in the medial Silurian on both eastern and western flanks of the Cincinnati Arch in Ohio, Kentucky, and Indiana (Brett and Algeo, 1999). Work on these beds is in very preliminary stages and will only be briefly discussed on this field trip.

Tempestites

Storms produce a distinctive suite of sedimentary deposits that range from coarse, amalgamated skeletal debris beds to hummocky laminated siltstones and sandstones, to distal mud layers. In some cases, particular conditions associated with a given storm bed may make it distinctive and usable for local or regional event correlation. Such applies to certain coarse skeletal debris layers, notably several bryozoan-rich horizons and a brachiopod bed in the Silurian Rochester Shale in the Niagara region.

Among more distal events, several other types of tempestites have proven to be regionally extensive and traceable. Particular thick calcisiltites with hummocky cross stratification have proven to be traceable in the Rochester Shale.

Obrution Deposits

Another type of tempestite related feature that provides very useful local markers are obrution or "smothered bottom", deposits. These are recognized taphonomically and may be traceable, at least locally. Excellent examples are provided by layers of beautifully preserved crinoids, trilobites, and other fossils (*Homocrinus* beds) that have been studied in detail from the lower Rochester Shale (Taylor and Brett, 1996). These rapidly buried surfaces have been correlated for tens of kilometers along outcrop strike of the Niagara Escarpment. The series of beds display much the same unusual characteristics over this area. Such evidence indicates that the smothering mud blanket was very extensive following a particular storm, resulting in mass mortality and burial on a regional scale.

LoDuca and Brett (1997) described laterally extensive horizons of extraordinarily preserved fossil green algae, annelid worms, and other non-skeletonized fossils from shaly dolostones in the base of the Goat Island Formation. Here rapid burial in organic-rich carbonate silts below an oxycline may have promoted preservation of soft bodied organisms as carbonized films.

Similar mass mortality beds of eurypterids are recorded in the Upper Silurian Bertie Group, especially in the upper Fiddlers Green and Williamsville formations (e.g. at Campbells Quarry; Ciurca, 1990; Batt, this volume; Stop 8, herein). Such beds appear to be persistent on a regional scale, although local areas, sometimes termed "pools" show greatly increased numbers of specimens. The eurypterids are sometimes associated with evidence of hypersalinity, such as salt hoppers, which suggest that the mass mortalities were associated with transport into hostile environments, such as hypersaline lagoons. Distributional data from eurypterids suggest that they actually lived in brackish water settings associated with estuaries. The "pools" may indicate proximity to such living sites. The briney condition of the sediments and pore waters may have aided in preservation of the chitinous exoskeletons by inhibiting chitinoclastic bacteria.

Seismites

Recently, a number of researchers have begun to recognize zones of widespread deformation that may be attributable to seismic shocking (e.g. Pope et al., 1997). These intervals are typified by beds of ball and pillow deformation that extend for tens to hundreds of square kilometers (Schumacher, 1992; Pope et al, 1997). Careful observation of these deformed intervals suggests, and that they resemble known seismically deformed sediments produced by liquefaction of muds and foundering of overlying coarser sediments, i.e. seismites. but detailed study of Pope et al. (1997) demonstrates that most deformed zones do not show consistent orientation of fold axes. Such evidence is consistent with a liquefaction triggered foundering as a opposed to slump model for the deformation.

Two excellent examples of possible seismites occur in the Silurian of the Niagara area. The first consists of a ball and pillow horizon in the reddish sandstones of the upper Grimsby Formation. The larger deformed masses up to 2 m across show overturned folds and flame structures; The deformation is not observed everywhere but seems to be concentrated in thicker areas of the sandstone bed that may represent shallow tidal channel fills (Duke et al., 1987). Basal surfaces of the pillows display small load casts, striations, deformed burrows and load crack casts indicating deformation of semiplastic muds by loading. To date, this horizon has been traced from Niagara Gorge near Lewiston, NY westward to Hamilton, Ontario.

The second example of a probable seismite horizon in the Niagara region is the well known "enterolithic" interval in the DeCew Dolostone. The DeCew consists of buff weathering, medium dark gray, hummocky laminated dolostone (originally fine calcarenite or calcisiltite) with scattered layers of small (1-4 cm) intraclasts. The lower 1 to 1.5 m of the DeCew displays extraordinary deformation that includes, ball and pillow style deformation and recumbent folds in the intraclasts beds. Overlying beds in the upper DeCew are unaffected. Again, preliminary study (Nairn, 1973) suggests that these folds do not show a consistent overturn direction. This suggests liquefaction possibly accompanied by some very local submarine sliding. A very similar, but much less extensive, bed of deformed dolostone in the upper Rochester Shale in the southern Niagara Gorge. The most impressive aspect of the DeCew deformed interval is its broad lateral extent. Similarly defomed dolostones are known to occur along nearly all Niagara Escarpment exposures from Penfield, east of Rochester, NY, to Hamilton, Ontario, where the DeCew has been erosionally truncated by erosion at the basal Lockport erosion surface (Sequence S-VI boundary). Similar deformation has been identified in a silty dolostone bed at the top of the Rochester Shale near Allenwood, Pennsylvania (Brett et al., 1990). Recently, a very similar zone of deformed dolostone has been identified in probably coeval strata mapped as upper Bisher or lower Lilly formation in southern Ohio (Brett and Algeo, 1999). This bed appears underlie the basal Sequence VI boundary at the base of the Lilly Formation (identified as upper Bisher Formation in some outcrops), At Hillsboro, Ohio it overlies a unit closely resembling, and probably equivalent to, the Rochester Shale. If the Pennsylvania and Ohio occurrences are indeed correlative with the DeCew, this would indicate and area of deformation of more than 200,000 km2, one of the most widespread deformed zones yet reported.

Detailed interpreatation of similar occurrences in the Upper Ordovician of Appalachian region by Pope et al. (1997) indicates that such widespread deformation over areas of a few tens of square kilometers would accompany large earthquakes with magnitudes in excess of 7 on the Richter scale. Pope et al. suggested that the ball and pillow horizons and related slumps might have been triggered by earthquakes in the Taconic Orogen or movements of local basement faults, In any case, these dramatically deformed intervals provide excellent stratigraphic markers. They also indicate that the Appalchian foreland basin was not tectonically quiescent through the Silurian (see Ettensohn and Brett, 1998).

Bioherms and Stromatolites

While not strictly examples of "event deposits", organic buildups, including small coral-stromatoporoid or algal mudmounds, thrombolites, stromatolites, and larger scale reef structures also appear to occur in very laterally extensive zones. For example, throughout western New York and Ontario, small fistuliporoid bryozoan-algal? mounds occur consistently near the top of the Irondequoit Limestone and project up to a meter into the overlying Rochester Shale (Cuffey and Hewitt, 1989). Similarly, stromatoporoid-tabulate bioherms occur at two horizons in the Lockport Group of western New York and Ontario: the top of the lower (Gothic Hill grainstone) member of the Gasport Limestone and extending upward up to 6 m into the overlying thin-bedded argillaceous Pekin Member (Crowley, 1973; Brett et al., 1995); and in possible channel fills on the top Gasport erosion surface and extending upward into thin bedded midle Goat Island formation (Brett et al., 1995). Not only are these horizons peristent over substantial distances in the New York-Ontario outcrop belt, similar thrombolitic mounds are present in probably corrrelative horizons in the McKenzie Shle in Pennsylvania to West Virginia (Brett et al., 1990). In a comparable way, small tabulate-rugosan bioherms in the Middle Devonian Onondaga Formation (see Stop 9) commence on top of a grainstone layer low in the Edgecliff Member and extend up into shaly, to cherty micritic limestones (Fig. 22). These bioherms also occur in this position consistently in the Niagara region and into central New York (Crowley and Poore, 1974; Woloscz, 1990).

Finally, very persistent zones of large stromatolites and thrombolites (non-laminated algal mounds) occur at several horizons, especially near the base of the Guelph Formation (Brett et al., 1990, 1995) and in the lower Fiddlers Green Formation of the Bertie Group (Ciurca, 1990).

Obviously these varied types of mounds have developed in very different environments. What these features appear to have in common is that they are in laterally persistent horizons and occur either immediately above unconformities or on the flooding surfaces at the tops of transgressive skeletal sands. We suggest that the non-random distribution of such organic buildups in the stratigraphic record reflects the dynamic interaction of sea-level and organism growth. Mounding commonly appears to be associated with transgressing or deepening successions. In particular, times of rapid deepening, as at maximum flooding surfaces. During these intervals rapid deepening created accomodation space and reef- or mound-forming organism built upward to keep pace with this increasing water depth. At the same time sequestering of sediments in coastal areas may have favored growth of algae and clonal organisms by reducing water turbiity and nutrient influx. Hence, widespread mound horizons are a signature of rising sea-level. In some cases the mounds were able to keep pace with deepening but in others they failed to keep up and were drowned. This explains the commonburial of bioherms by thin shaly sediments of deeper water facies.

SEQUENCE STRATIGRAPHY OF SILURIAN TO EARLY DEVONIAN SUCCESSIONS IN WESTERN NEW YORK AND SOUTHERN ONTARIO

The Silurian strata of western New York and the adjacent Niagara Peninsula of Ontario have been broadly subdivided into groups that correspond roughly to large-scale (third order of sequence stratigraphers, see Van Wagoner et al., 1988; Vail et al. 1991) depositional sequences (Figs. 3-5); they are divisible into smaller (fourth-order) sequence-like units; we have termed "subsequences" (see Brett et al., 1990, 1995, 1998).

Silurian sequences are bounded by unconformities, three of which, the I-II, II-IV, and V-VI boundaries, are regionally angular (Fig. 3). The magnitudes of these three unconformities (i.e., extent of beveling on the erosion surface) increases westward along the Niagara Escarpment. These surfaces appear to have been accentuated by uplift along the "Algonquin Arch", probably an intermittently active forebulge (Figs. 1-3). The I-II and II-IV boundaries are merged west of St. Catharines, Ontario, forming a compound unconformity (Figs. 3, 4). Conversely, the basal sequence I unconformity (Cherokee unconformity and base of Silurian system) decreases westward (Fig. 3). Varying east to west facies changes within each of the sequences along the Niagara Escarpment reflect differential subsidence and elevation of the Algonquin Arch and adjoining basins, as noted in the following sections. In each, the stratal unit name is followed by series/stage assignment based on biostratigraphy (see Brett et al. 1990, for details).

Sequence I: Medina Group, Lower Llandovery (Rhudannian)

The stratigraphically lowest Silurian interval (S-I) is the predominantly siliciclastic Medina Group (Cataract Group of some Canadian authors). In west central New York the Medina Group contains, in ascending order: the Whirlpool Sandstone (2.5-4.5 m)whitish gray, trough cross bedded quartz arenite, Power Glen Shale (10-15 m) dark gray shale with thin sandstones and dolomitic limestones, Devils Hole Sandstone (2-3 m) whitish gray, phosphatic quartz arenite, Grimsby Formation, (12-15 m) maroon to green shale and reddish and white mottled sandstone, Thorold Sandstone (2-3 m) reddish to whitish gray, bioturbated quartz arenite with greenish gray sandy, bioturbated mudstones, Cambria Shale (0-3 m maroon shales and muddy sandstones, and Kodak Sandstone (0-3 m) whitish gray sandstones and greenish to maroon shales (Figs. 4, 5). The Medina represents a large scale depositional sequence with lowstand (non-marine) to transgressive (foreshore to shoreface) Whirlpool Sandstone (Middleton et al., 1991), overlain by maximally highstand Power Glen Shale (offshore marine muds), and later highstand (progradational shoreface and tidal flat) Devils Hole through Kodak strata. However, the interval is also divisible into smaller subsequences at the bases of the Whirlpool, Devils Hole; Thorold, and Kodak transgressive quartz arenites (Figs. 4, 17).

The Medina Group exhibits relatively minor changes in thickness along the Niagara Escarpment, but all of its component units show westward changes in facies corresponding to increasingly open, fully marine conditions (Figs. 4, 5). Thus, the lower, fluviatile (braided stream) Whirlpool Sandstone (Middleton et al. 1991) apparently pinches out (or changes facies to marine) to the north of Georgetown, Ontario (Rutka et al., 1991). The

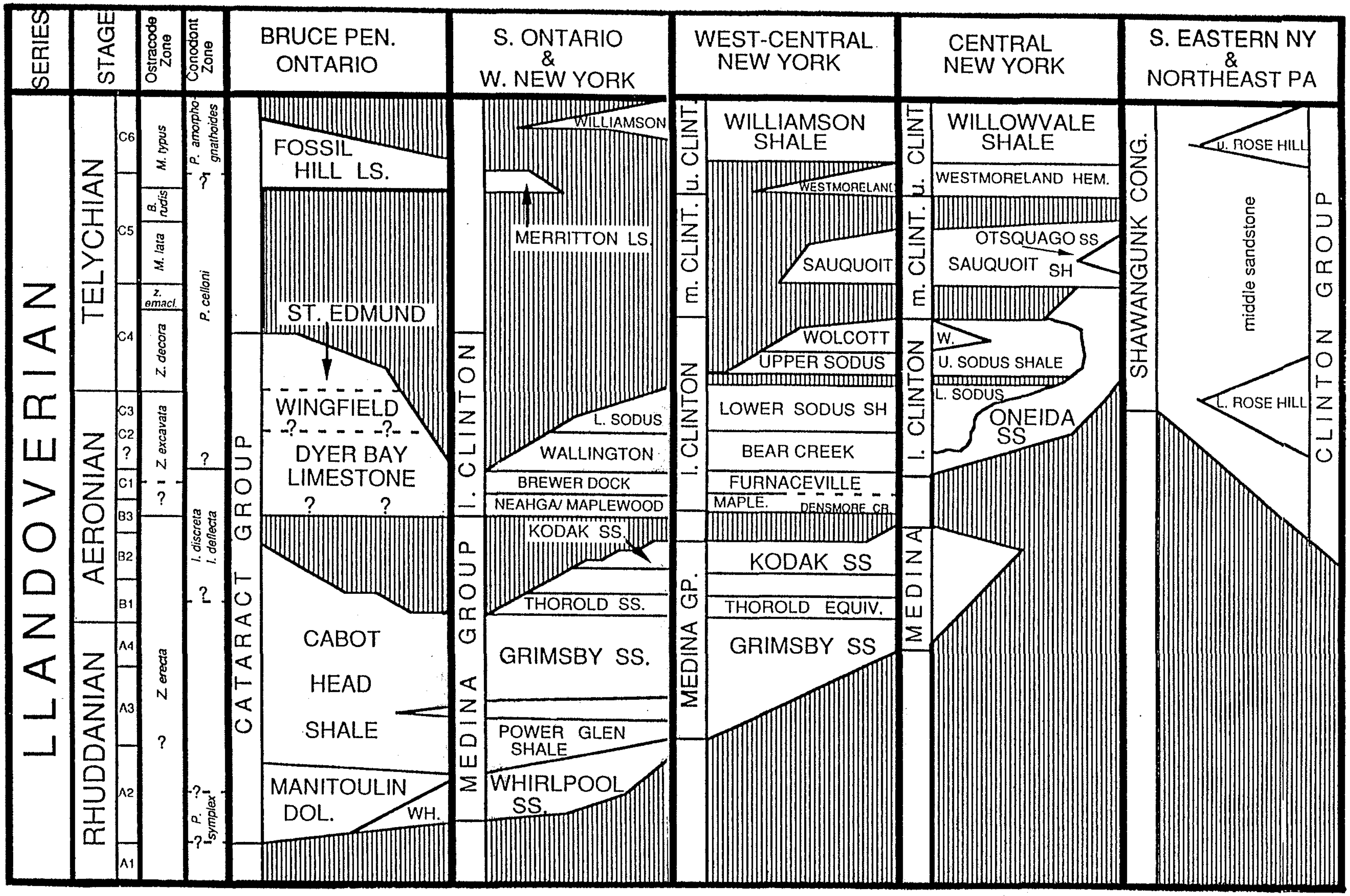

Figure 4. Correlation chart for Lower Silurian (Llandovery) stratigraphic units (Sequences I-IV) in Ontario and New York State. Abbreviations: BC: Bear Creek Shale; DOL.: dolostone; DW; SH: shale; SS: sandstone; WH: Whirlpool Sandstone; WO: Wolcott Limestone.

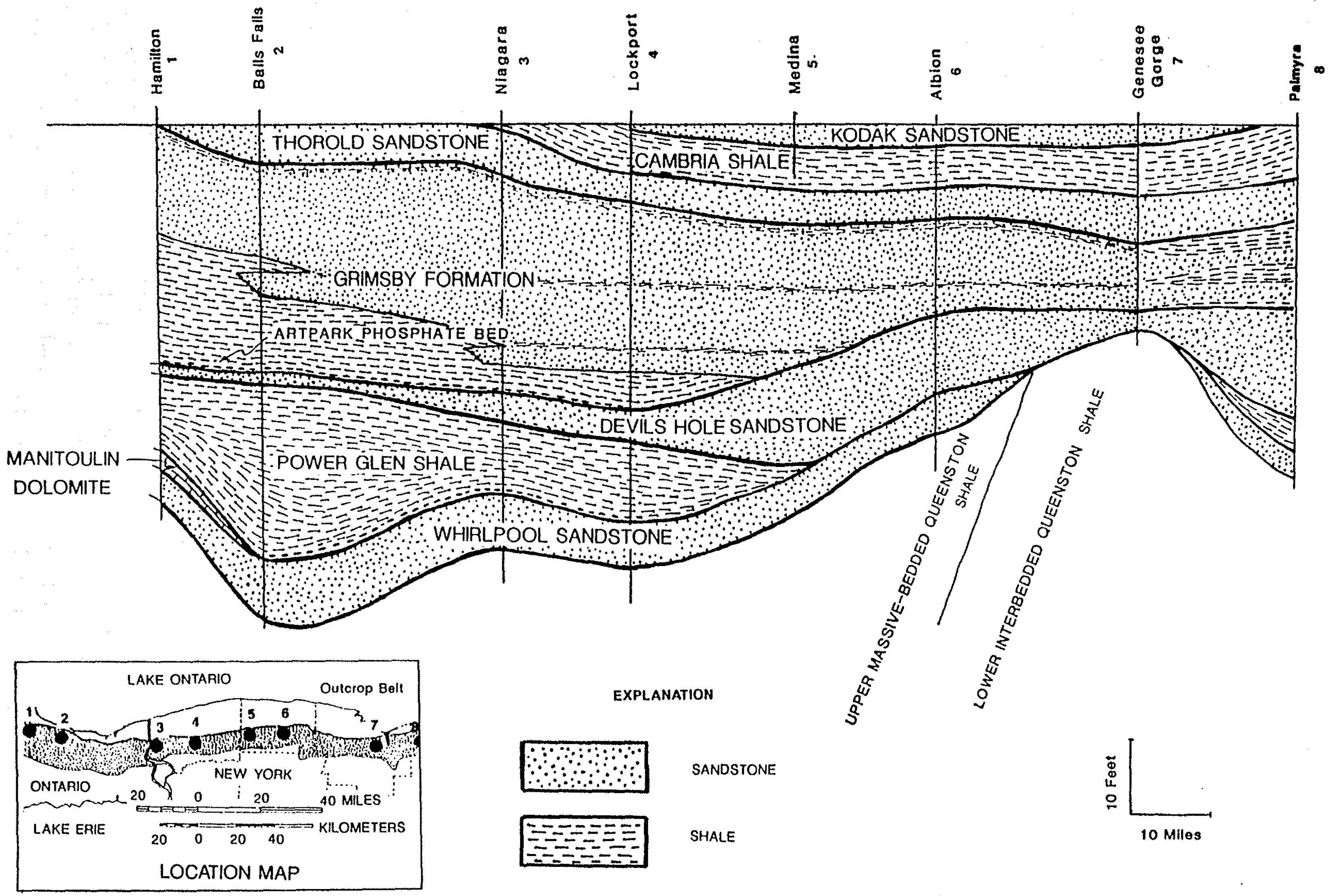

Figure 5. Regional cross-section of Medina Group (sequence I) in western New York and southern Ontario.

upper Whirlpool thickens and displays evidence of shoreface to shallow, sandy shelf deposition near Hamilton, and may be replaced laterally by the Manitoulin Formation open shelf carbonates (Fig. 5). Dark gray, sandy, sparsely fossiliferous Power Glen Shale in the Niagara region, grades westward near Hamilton into greenish gray shales with abundant bryozoan-rich carbonates, indicating open marine conditions. The Grimsby interval changes northwestward from red sandy mudstones and tidally influenced sandstones with a lingulid (BA-1) biofacies at Niagara Gorge (Martini, 1973; Duke and Fawsett, 1987) to red and green mudstone with only thin sandstones and hematitic bryozoan-rich limestones (BA-2-3) in the upper Cabot Head Formation (Duke and Brusse, 1987). Conversely, the Grimsby interval shows a return to marginal marine or non-marine red beds northward along the Bruce Peninsula (Fig. 2A). Thus, the Hamilton area was close to the deepest part of the foreland basin during Medina deposition (Fig. 2A; Ettensohn and Brett, 1998).

Westward erosion of the upper Medina Group below Sequence II beveled an upper fourth order cycle (Cambria-Kodak) between Rochester and Lockport, New York and culminated with removal of the Thorold Sandstone near Hamilton (Fig. 5). This pattern suggests an inversion of topography, with minor broad uplift on the Algonquin Arch region following Medina deposition.

Clinton Group, Middle Llandovery (Aeronian) to Middle Wenlock

The Clinton Group consists of mixed carbonates and shales, representing offshore storm-influenced shelf environments, and was informally subdivided into lower, middle, and upper Clinton by Gillette (1947). This convention is adopted herein because two of the three divisions correspond to depositional sequences (Figs. 3, 4).

Sequence II: Lower Clinton Group, Middle Llandovery (Aeronian)

The lower Clinton (Sequence II) is very incomplete in western New York, consisting only of the Neahga Shale (0-2 m of greenish gray shale marked at the base by a phosphatic dolostone) and Reynales Limestone (0-3 m of calcisiltite, nodular packstone and bryozoan-brachiopod-echinoderm grainstone, and minor shale) (Fig. 4).

So little remains of Sequence II in the Niagara Peninsula that it is difficult to determine facies trends. However, facies changes in the Neahga and Reynales formations in western New York suggest westward deepening patterns (LoDuca and Brett, 1994).

Middle Clinton Unconformity: Upper Llandovery (Telychian)

Middle Clinton Group strata (Sequence III) are absent in the Niagara region, and a major regionally angular unconformity separates the lower Clinton Reynales Formation from the overlying Sequence IV (Figs. 3, 4, 6, 7). A major change in depositional topography of the Appalachian foreland occurred during the mid Llandovery; throughout west-central New York State and Ontario the middle Clinton Group is missing and an erosion surface beneath late Llandovery (Telychian) strata truncates lower Clinton units in a westward

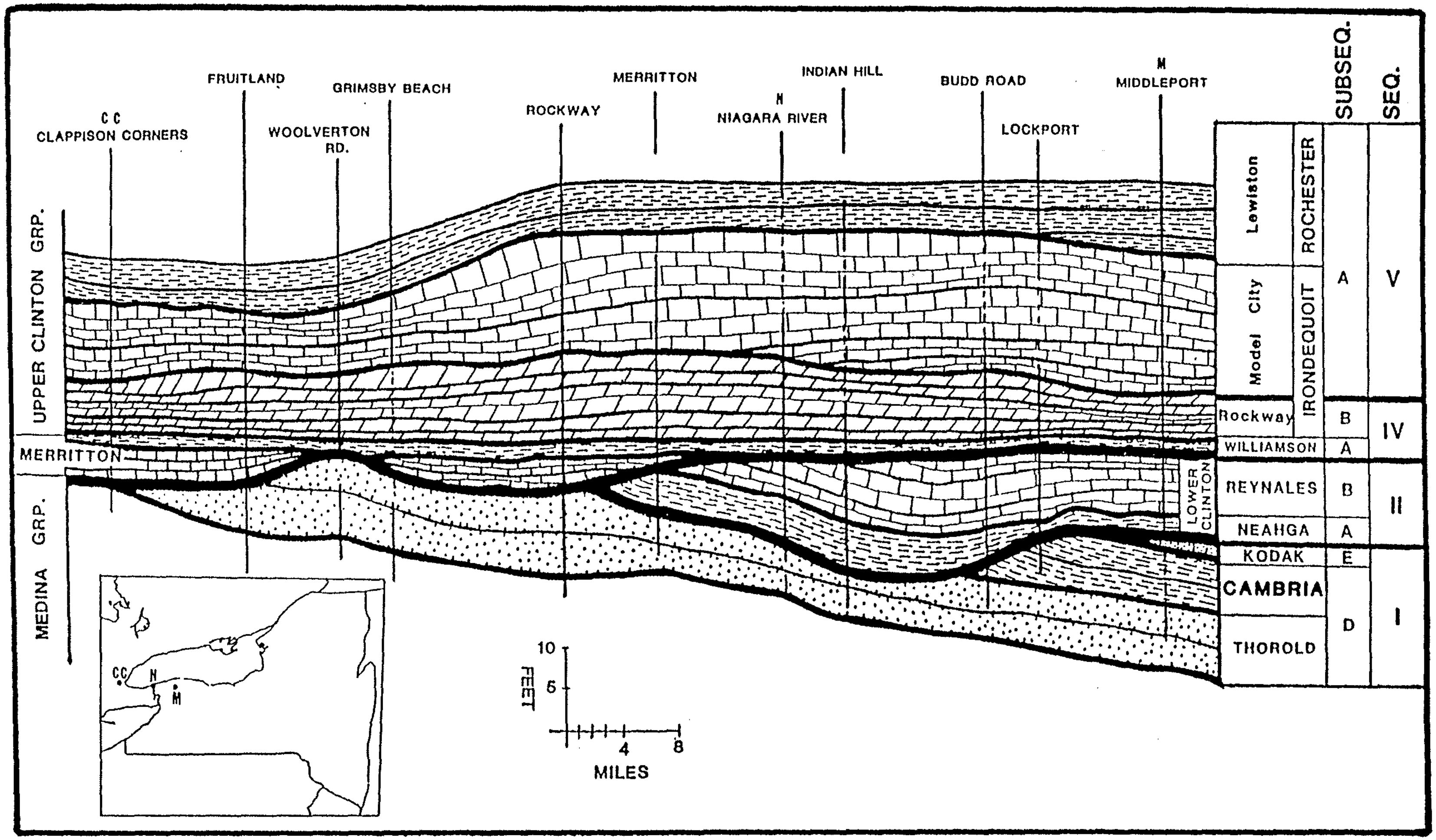

Figure 6. Regional cross-section of upper Medina (Sequence I), lower Clinton (Sequence II) and upper Clinton (sequences IV and V) through western New York and Ontario outcrops (see inset map). Modified from Kilgour (1963).

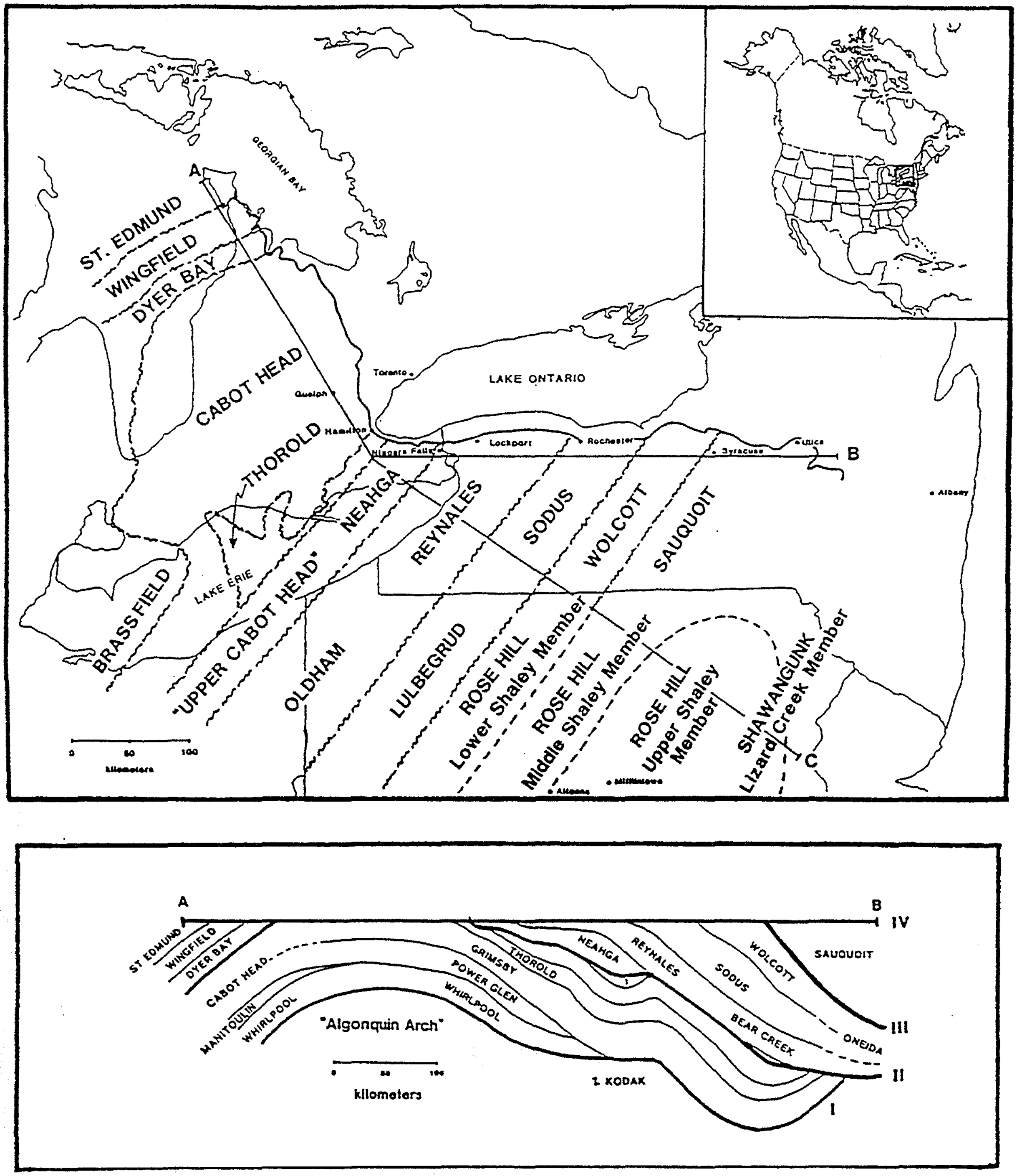

Figure 7. Subcrop map of strata beveled beneath Late Llandovery (S-IV) unconformity. Inset shows general location of map area. From Brett et al. (1998).

direction along the outcrop belt (Fig. 7; Lin and Brett 1988; Ettensohn and Brett, 1998). This substantial regionally angular unconformity suggests another period of broad regional uplift centered on the Algonquin Arch (Fig. 7). Development of the unconformity also coincides with a shift in basin axis migration from eastward (Medina-middle Clinton) to westward (upper Clinton); it may signal renewed tectonic activity in the eastern hinterland (Fig. 14; Ettensohn and Brett, 1998).

Sequence IV: Upper Middle Clinton Group, Upper Llandovery (Telychian)-Lower Wenlock

In western Ontario Sequence IV comprises the Merritton Dolostone and its apparent lateral equivalent, the upper Fossil Hill Formation in the Bruce Peninsula (0.5 to 5 m of dolomitic limestone with many corals and pentamerid brachiopods), a very thin tongue of Williamson Shale (0-20 cm), and the Rockway Dolostone-Lions Head Member (3-4 m) of the upper Clinton Group (Figs. 3, 6, 7).

In Ontario, the thin, condensed Merritton Dolostone overlies the major mid Clinton unconformity (Figs. 6,8); it is unknown in western New York State, although it is roughly equivalent in age (mid Telychian) to the Westmoreland Hematite of central New York (Fig. 8). In general, the Merritton displays a slight westward shallowing trend from glauconite-rich wackestones at St. Catharines to pentamerid- and coral-rich packstone (upper Fossil Hill Formation) northwest of Hamilton. A similar, though very gradual, westward facies change is seen in the overlying Rockway Dolostone, which becomes increasingly carbonate-rich from west central New York to southern Ontario. Biofacies change from *Clorinda*-dominated (BA-5) to *Costistricklandia*-dominated associations (BA-4) also suggest gradual westward shallowing.

Sequence V: Upper Clinton Group, Lower to Middle Wenlock (Sheinwoodian)

The Irondequoit Limestone (crinoidal grainstone; 3-5 m), Rochester Shale (gray, calcareous mudstone with interbedded calcisiltites and bryozoan-brachiopod-pelmatozoan packstone storm beds; 0.5-20 m) , and DeCew Dolostone (argillaceous laminated and typically heavily deformed dolostone; 3-4 m) together, form another genetically related sequence (Sequence V) in the upper Clinton Group (Figs. 3, 4, 8). The lateral equivalents of these units in the Bruce Peninsula are assigned to the Amabel Formation of the Albemarle Group (Fig. 8; Bolton, 1957; Armstrong and Goodman, 1990).

The basal Irondequoit disconformity (Sequence VI-V boundary) is nearly planar with little evidence for regional truncation (Figs. 3, 8). However, this contact becomes increasingly sharp westward from Rochester, New York (probable basin center) and the basal Irondequoit contains clasts of the underlying Rockway dolostones. The Irondequoit, changes from thin bedded skeletal wackestone and packstone in the basin center to massive, amalgamated grainstone to the northwest. The unit represents open shelf to crinoid shoal (BA-3) environments. The upper contact of the Irondequoit is an abrupt, but conformable flooding surface. Locally, in Niagara County, small thrombolitic-bryozoan

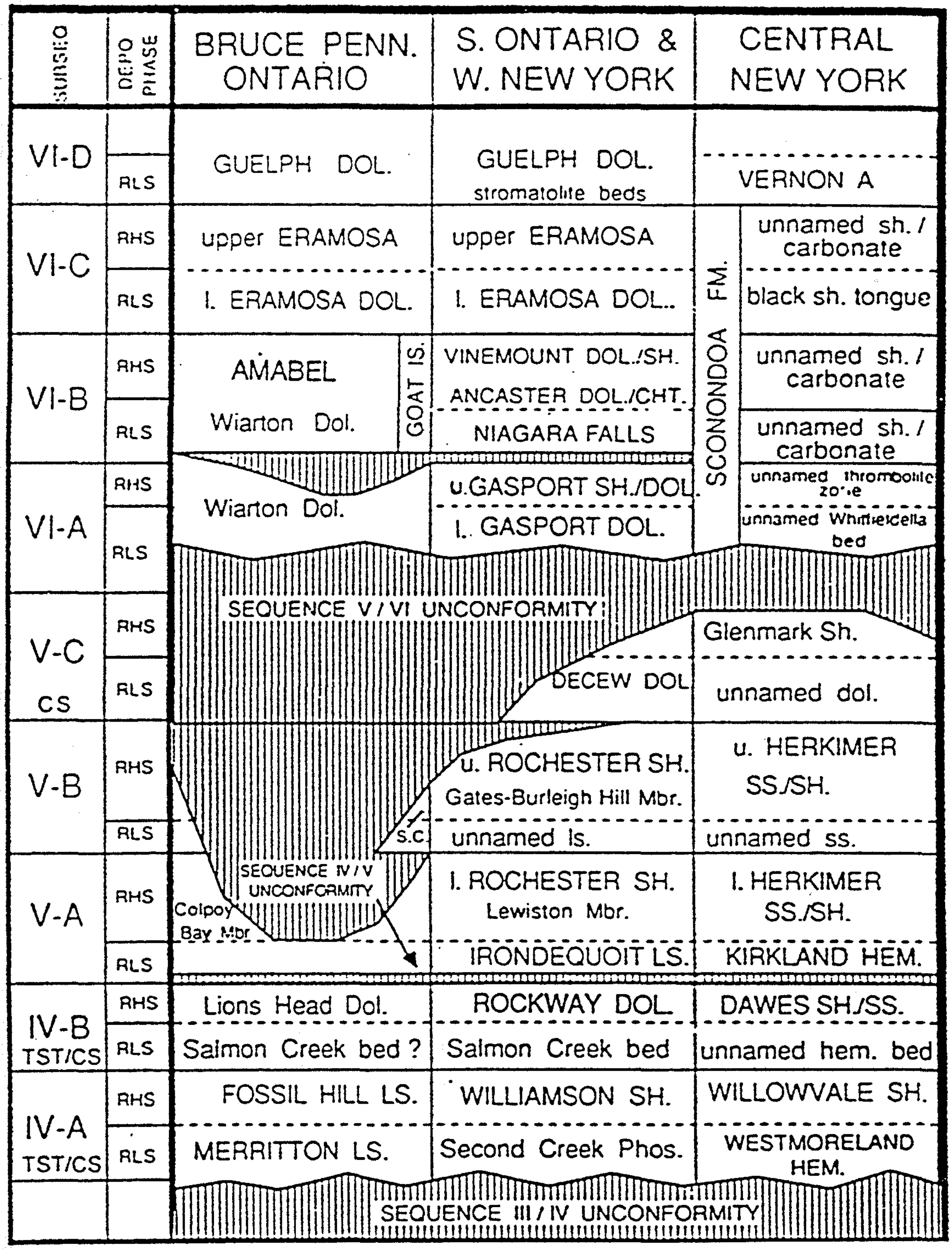

Figure 8. Correlation chart for stratigraphic units in the upper Clinton (Sequences IV, V) and lower Lockport Group (Sequence VI) in Ontario and New York State. Formation names upper case, members lower case. From Brett et al. (1998).

bioherms occur at the Irondequoit-Rochester transition zone; the mounding apparently associated with rapid deepening (Sarle, 1901; Cuffey and Hewitt, 1989).

The Rochester Shale is divided into two members (Brett, 1983a, b). The lower-or Lewiston Member- is highly fossiliferous along most of the Niagara Escarpment, with over 200 species of bryozoans, brachiopods, molluscs, crinoids, blastozoans, trilobites, and graptolites; bryozoan-brachiopod rich limestone beds occur near its base and top (Figs. 8, 9). This facies represents deeper, storm-influenced shelf environments (BA 3-4). However, to the south of the main outcrop, as in southern Niagara Gorge, the Lewiston becomes dark gray shale with sparse brachiopod-trilobite (BA-4 to 5) assemblages, indicating a southward dipping ramp (Brett, 1983a, b). The upper Rochester shows two distinct facies: the Burleigh Hill Member-dark gray, sparsely fossiliferous shale-east of Grimsby, and the Stoney Creek Member -banded dolomitic mudstone and argillaceous dolostone-to the west (Figs. 8, 9; Brett, 1983b). The Rochester Shale becomes increasingly carbonate-rich and thins dramatically to a feather edge from Niagara to Hamilton (Fig. 9). Thinning represents both condensation and erosion below the bases of the Stoney Creek Member, and overlying DeCew and Gasport formations. Rochester-equivalent strata may reappear to the northwest in the lower Amabel Dolostone of the Bruce Peninsula (Bolton, 1957; Armstrong and Goodman, 1994). Together, these observations indicate that during the late Llandovery to late Wenlock interval, the topographic center of the foreland basin lay to the southeast and that Hamilton was situated close to the crest of the Algonquin Arch (Figs. 1, 10).

The DeCew comprises hummocky laminated, dolomitic calcisiltite, probably derived from storm-winnowing of carbonate shoal areas north of the present outcrop limit. As noted above, a zone of extreme soft sediment deformation in the DeCew has been traced laterally along the Niagara Escarpment from east of Rochester, New York, westward to Hamilton, Ontario (Fig. 9) and possibly into southwestern Ohio. Thus, the DeCew deformed zone represents a widespread event, probably a seismite- a horizon of deformed strata associated with a severe seismic shock and consequent slumping on the south-dipping ramp.

Sequence VI: Lower Lockport Group, Upper Wenlock (Homerian) to Lower Ludlow (Gorstian)

The lower part of the Lockport Group (Sequence VI) comprises crinoidal pack- and grainstones, bioherms, and dolomitic wackestones near the base of the sequence (Gasport Formation), and vuggy grainstones, argillaceous, cherty wackestone and minor shales (Goat Island Formation). A clear-cut sequence boundary exists at the erosive base of the Gasport, and a minor, subsequence boundary at the sharp, erosive base of the Goat Island (Figs. 3, 8, 10). Tabulate-stromatoporoid bioherms typically extend upward from lower crinoidal grainstones into the argillaceous Pekin Member; this indicates that the upward growth of these reefs may have been stimulated by rising sea-level (Crowley, 1973; Brett, 1985; Brett et al., 1990). However, cap beds of fragmentary stromatoporoids suggest that the bioherms were extinguished and truncated by sea-level drop (Crowley, 1973).

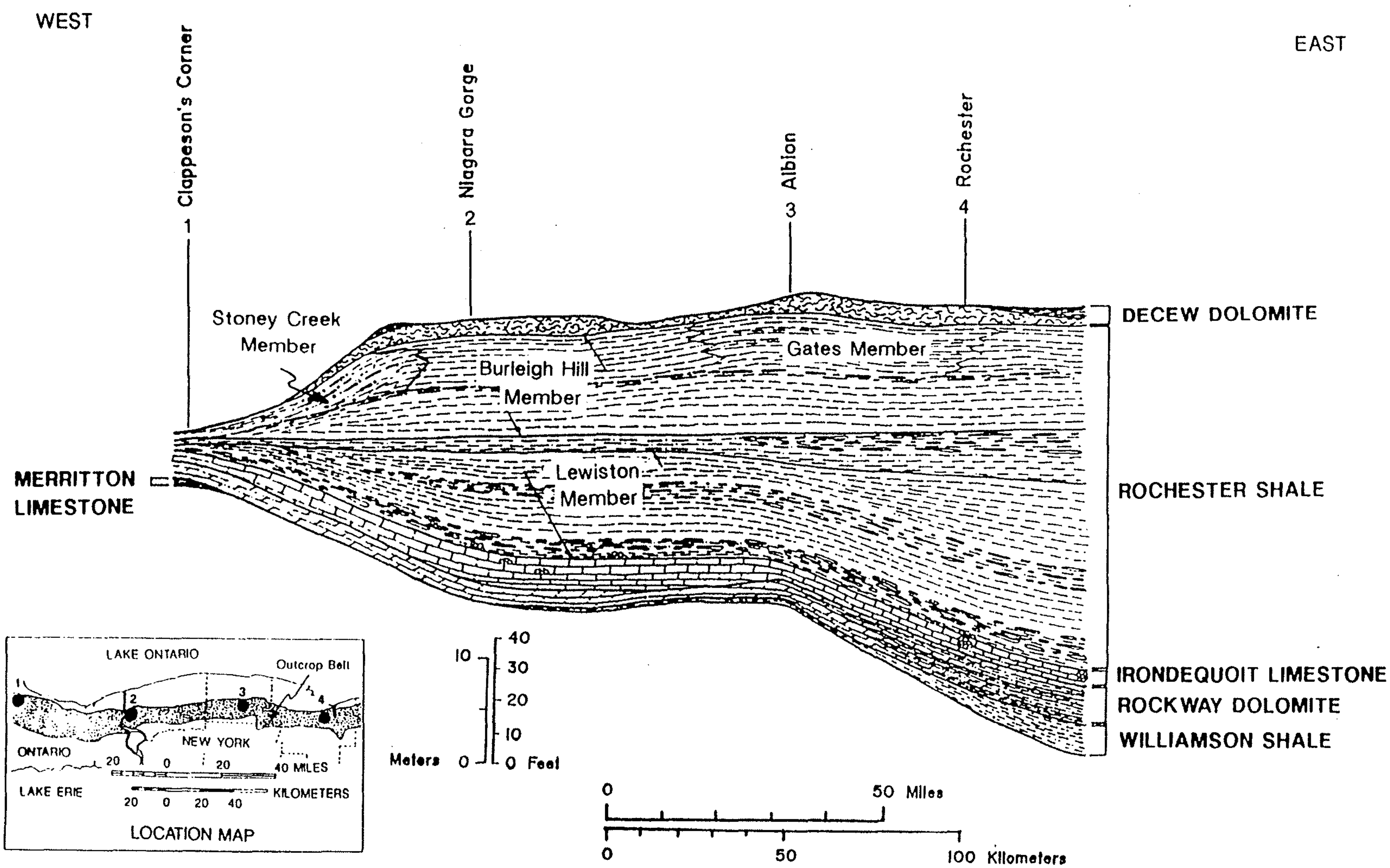

Figure 9. Regional stratigraphic cross section of the upper part of the Clinton Group between Clappisons Corners, Ontario and Rochester, NY. Datum is the contact between the Lewiston and Burliegh Hill members of the Rochester Shale. From Brett et al. (1995).

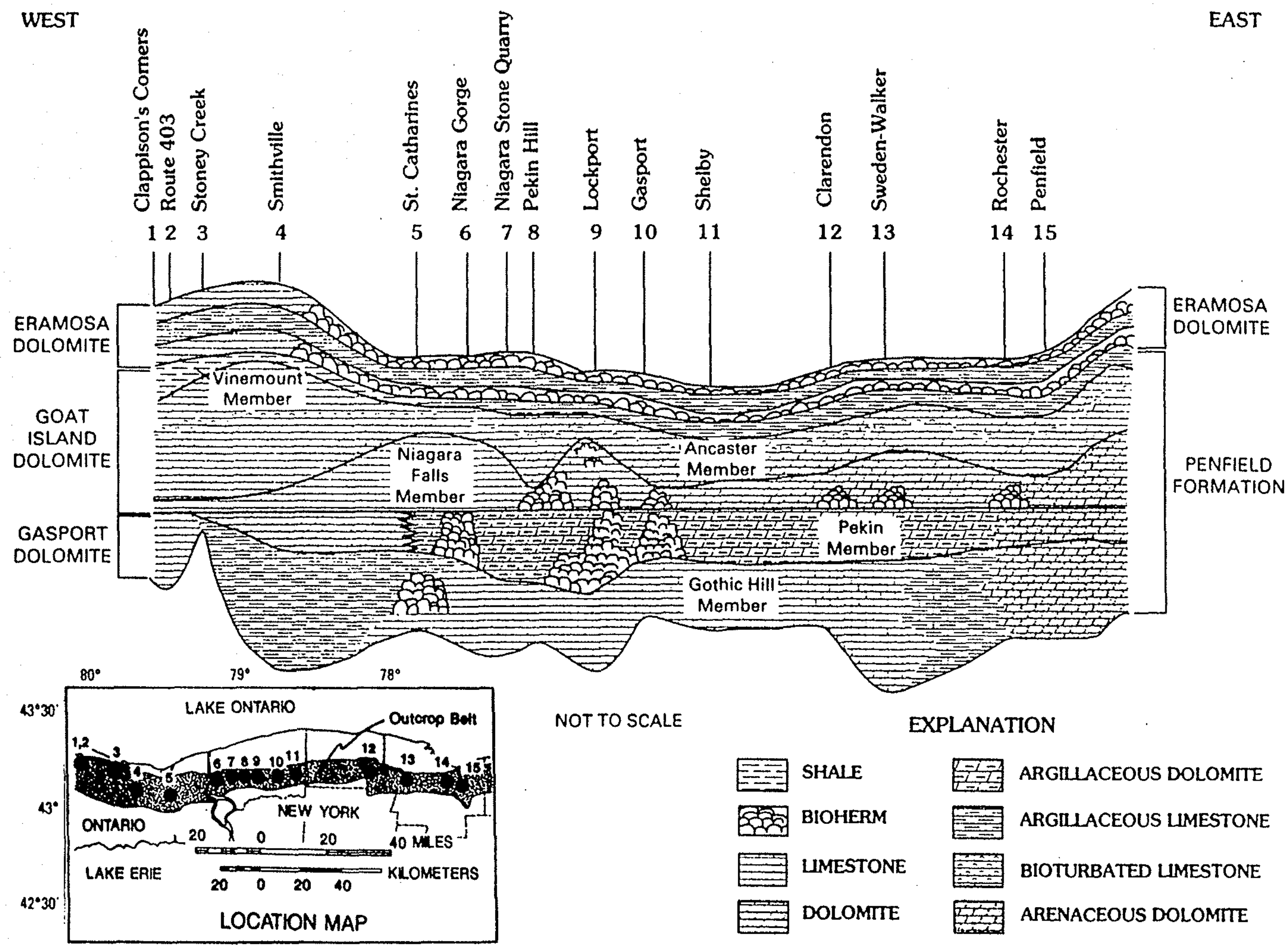

Figure 10. Regional stratigraphic cross section of the Lockport Group between Clappisons Corners, Ontario and Rochester, NY. Datum is contact between the Gasport and Goat Island formations. From Brett et al. (1995).

Westward thinning, coarsening, and loss of argillaceous, biohermal facies in the Gasport Dolostone also suggests shallowing in that unit toward the Algonquin Arch (Fig. 10). The merging of Gasport and Irondequoit grainstones and associated total truncation of the Rochester Shale-near Hamilton also appears to mark a relative topographic high.

Conversely, in, the Goat Island Formation, massive crinoidal grainstone shoal facies (BA-2-3) characteristic of the Niagara Gorge are replaced westward by thin-bedded, cherty wackestone (Ancaster Member; BA-3-4), which thicken to a maximum in the Hamilton area before passing laterally again into massive dolostones (Fig. 10). This westward deepening trend is also evident in the Vinemount Member, which is a slightly cherty dolowackestone to the east but is represented by dark, dolomitic shales near Hamilton, Ontario. These shales only persist northwest to near Dundas where they are replaced or pinched out against upper Amabel dolostones (Fig. 8).

The picture is not entirely straightforward, as small areas of shaly and/or cherty dolostone also occur locally in the Goat Island position in Niagara County, New York. This pattern suggests that minor fault block-controlled basins may have formed during Goat Island deposition. (Sanford et al., 1985) This irregular topography may have been associated with an abrupt westward migration of the main basin center to the Vinemount-Hamilton region (Fig. 10).

Sequence VII: Upper Lockport-Vernon Formation, Middle to Upper Ludlow (Ludfordian)

Biostromal to flaggy argillaceous, dolostones (Eramosa) and massive, buff, biostromal to biohermal dolostone (Guelph Formation) form the upper part of the Lockport (or Albemarle) Group (Fig. 3). The Eramosa, interpreted by Armstrong and Johnson (1990) as an interreefal, dysoxic environment (BA-2-3), has recently yielded assemblages of soft-bodied fossils, including algae, and unusual arthropods (Waddington and Rudkin, 1992; LoDuca, 1995, 1996; Tetreault, 1995, 1996, 1997). A disconformity at the base of the Eramosa Formation in New York is now interpreted as the boundary of a sequence (VII) not previously recognized by Brett et al. (1990). Still further westward migration of the basin axis (and final subsidence of the "Algonquin Arch") appears to have occurred during deposition of the Eramosa and Guelph Formations, in which deepest facies (BA-3) occur northwest of Hamilton, Ontario, while biostromal to stromatolitic facies (BA-2) occur in the Niagara region (Brett et al., 1995).

In drill cores the Guelph can be seen to pass gradationally upward through series of interbedded shaly dolostones and dolomitic shales of the Vernon Formation (upper Ludlow; Salina Group; Fig. 11). The Vernon Formation represents a tongue of siliciclastic sediments from the Bloomsburg-Vernon clastic wedge, that was shed from tectonic regions (Salinic Orogeny) in the mid-Atlantic region. Near its type area. In central New York, the Vernon consists mainly of red mudstones, but in western New York and Ontario the unit consists of over 60 m of greenish gray shales and buff dolostone with interbedded anhydrite.

Sequences VIII, IX: Upper Salina and Bertie Groups, Upper Ludlow-Pridoli

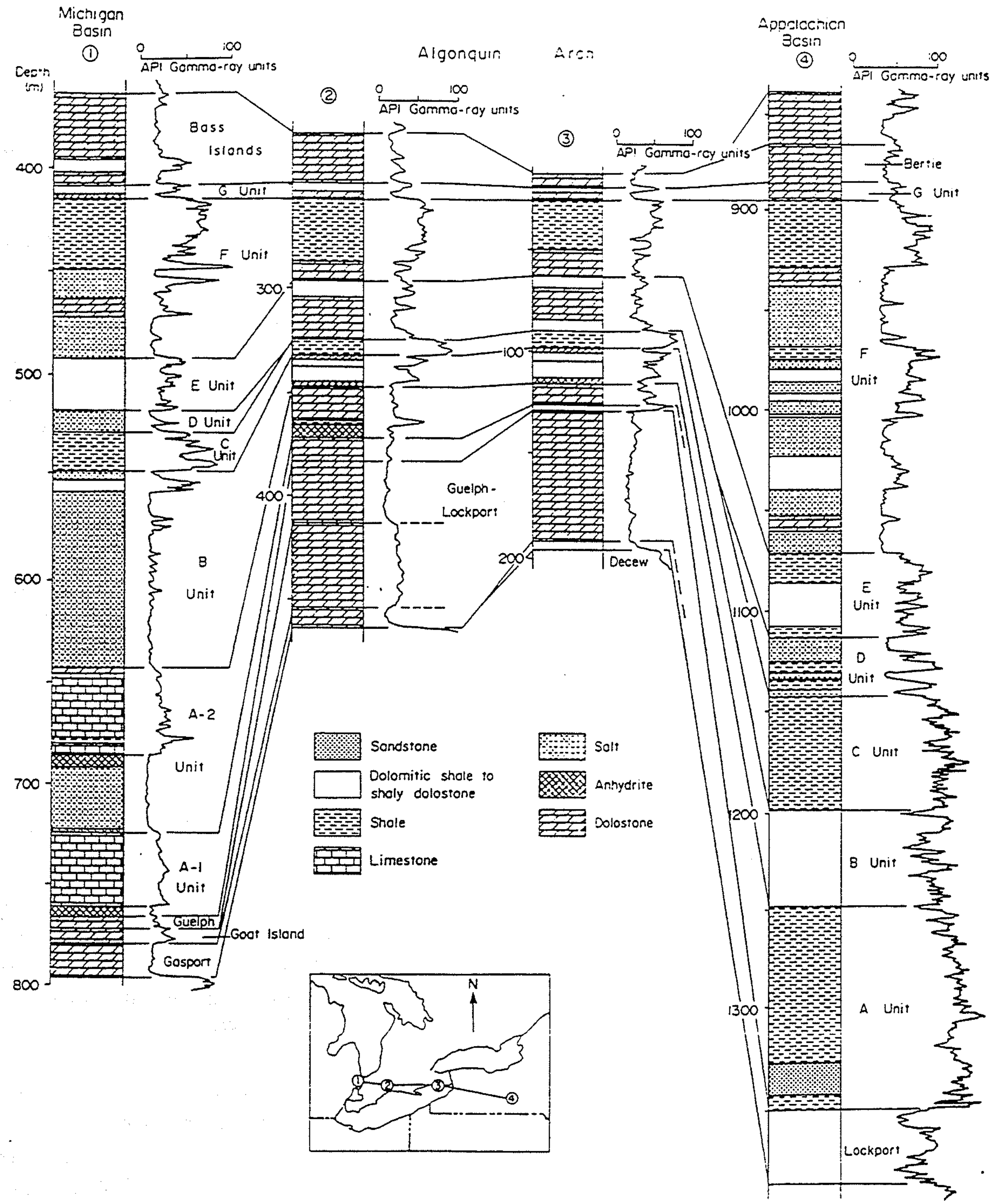

Figure 11. Correlated columns and gamma ray profiles of Upper Silurian Lockport, Salina, Bertie, and Bass Islands groups in southern Ontario to south central New York State. Note persistence of marker evaporite units in the Salina Group and the irregular Wallbridge Unconformity beneath Devonian. From Thurston et al. (1992).

In southern Ontario the upper Salina Group comprises over 60 m of dolostones, shales, and evaporites but it is very poorly exposed. Detailed sequence stratigraphy has not been undertaken. Brett et al. (1990) noted that an erosion zone and regionally angular unconformity exist between the Vernon and overlying Syracuse Formation in central New York and suggested that a sequence boundary exists at this level within the Salina Group (Figs. 3, 11).

The Syracuse and Camillus formations, each about 30 m thick, comprise gray to green-maroon mudstones, buff dolostones and evaporites (Fig. 11). Key salt-gypsum horizons within the Syracuse have been traced in subsurface through Ontario from the Appalachian foreland into the Michigan Basin (Fig. 11; Rickard, 1969; 1975; Milne, 1992). These strata were evidently deposited under arid subtropical climates in interconnected but restricted basins. The widespread nature of the evaporite-dolostone-shale alternations indicates both that topography (e.g. on the Algonquin Arch) was subdued and that the cycles were due to eustatic-climatic effects.

The highest Silurian strata (middle-upper Pridoli) in the western New York-Ontario areas are presently assigned to the Bertie Group (Figs. 3, 11, 12). They comprise a relatively thin (16-18 m) cyclic succession of distinctive, buff gray, slightly argillaceous dolostones ("waterlimes", so-named because of their geochemical properties of natural cement rocks) and dolomitic shales. The basal Oatka Formation is dominantly dolomitic shales and is gradational with the underlying Camillus Shale. The Fiddlers Green (6-8 m) contains both massive brownish waterlimes and some thrombolitic dolomitic limestone that represents the deepest water facies of the Upper Silurian. Scajaquada Formation is a thin unit of dolomitic mudstone, apparently of sabkha origin, while the Williamsville carries a repeat of waterlime facies resembling the Fiddlers Green. Both units are noted for the occurrence of excellently preserved eurypterids, phyllocarids, and others fossils that are suspected to represent a brackish water estuarine biofacies that bordered hypersaline shallow seas. Finally, the Akron Dolostone (2.8 –2.5 m) consists of massive burrow mottled, vuggy dolostone with molds of corals. This unit apparently records a return to somewhat more normal marine lagoonal environments. Locally, a higher (latest Silurian to earliest Devonian) dolostone, the Clanbrassil Formation has been identified above the Akron; it records a return to "waterlime" deposition (Fig. 12; Ciurca, 1973, 1990).

During deposition of the upper Salina and Bertie Groups there was a west to east displacement of depocenters (typically marked by thickest accumulations of halite in the Appalachian Basin) through central to east central New York State (Rickard, 1969). The Lower Devonian Helderberg Group was deposited in a basin the axis of which lay southeast of New York State, while western New York- Ontario were above sea level. The lateral consistency of upper Salina and Bertie Group units along the central New York-southern Ontario outcrop belt suggests also that the facies strike in this region is roughly east-west, parallel to the northern rim of the foreland basin.

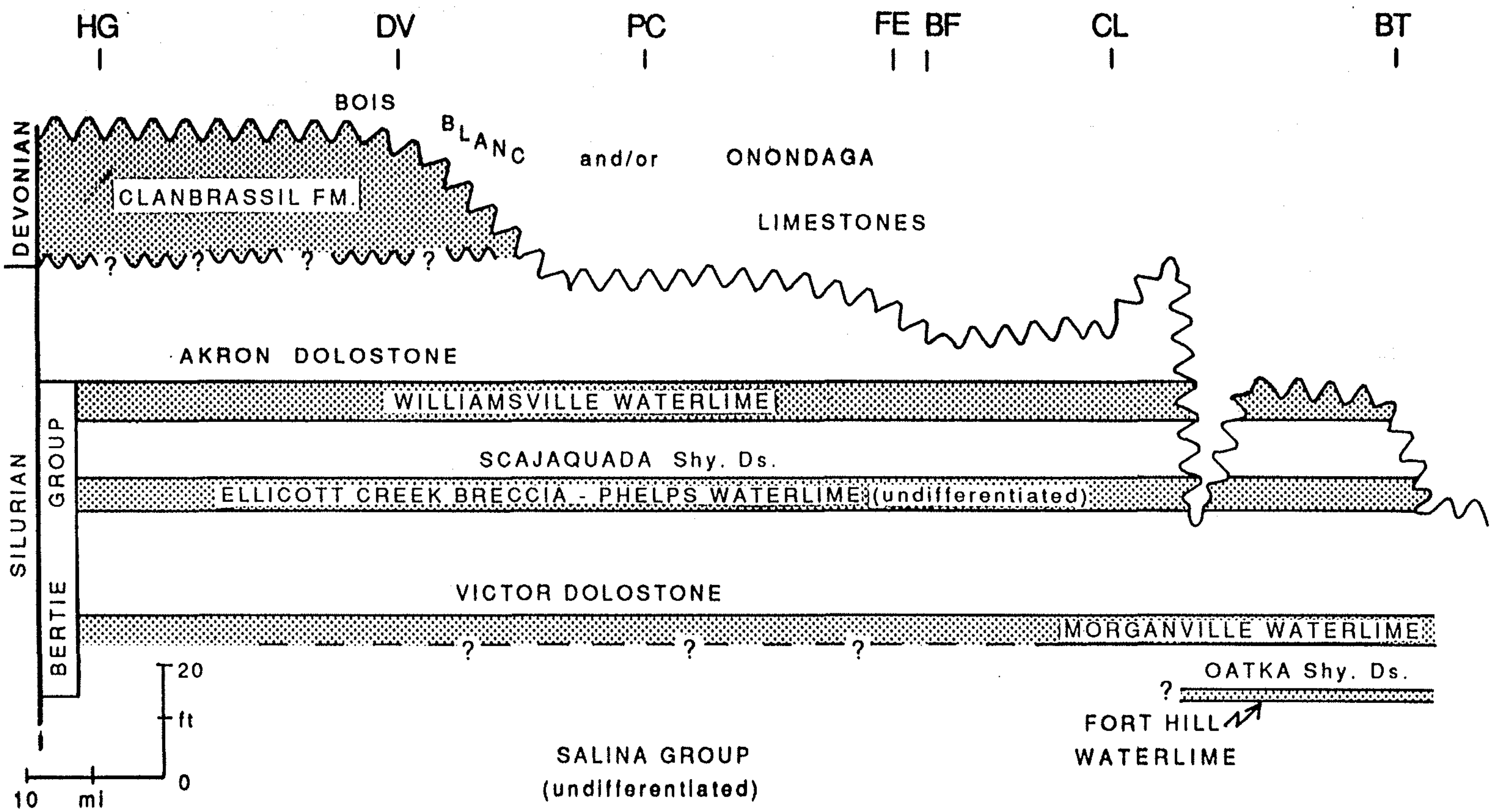

Figure 12. Cross section of Upper Silurian and Lower Devonian strata in western New York and southern Ontario; note the substantial relief on the sub-Devonian Wallbridge Unconformity. Abbreviations for localities along this west-east cross section are as follows: HG: Haggersville, Ont.; DV: Dunnville, Ont.; PC: Port Colbourne, Ont.; FE: Fort Erie, Ont.; BF: Buffalo, NY; CL: Clarence, NY; BT: Batavia, NY. Adapted from Ciurca (1973).

Silurian-Devonian (Wallbridge) Unconformity

In western New York and southern Ontario Upper Silurian strata are unconformably overlain by upper Lower Devonian quartz arenites of the Oriskany Sandstone, and cherty, fossiliferous carbonates of the Bois Blanc and/or the Middle Devonian Onondaga Formation (Figs. 12, 13). This second order "Wallbridge Unconformity" marks the boundary between the Tippecanoe and Kaskaskia supersequences (Sloss, 1963; Dennison and Head, 1975). It displays evidence of karstic development, with irregular relief of up to 3 m. This unconformity apparently records a major late Early Devonian drawdown in sea-level which exposed older Silurian carbonates and evaporites to subaerial weathering and erosion. Sea-level rise in the late Early Devonian (late Pragian to Emsian) resulted in flooding of the irregular erosion surface. Kobluk et al. (1977) described rockground features of the *Trypanites* bored and glauconite-coated upper contact of the Silurian Akron Formation in southern Ontario. To the west, near Hagerstown, Ontario the basal fossiliferous quartz arenites of the Oriskany Formation (Pragian) rest unconformably on the Wallbridge Unconformity, but in the Ft. Erie-Port Colbourne area and in western New York the Oriskany has been removed by subsequent erosion and the basal Devonian unit is the Bois Blanc Limestone.

Early to Early-Middle Devonian (Emsian-Eifelian) Sequences

The Emsian-early Eifelian succession in southern Ontario (Bois Blanc and probably basal Onondaga formations) consists of normal marine mid to shallow shelf carbonate deposits (Fig. 15). The Bois Blanc consists of about 2 m of cherty dolomitic wackestone with thin packstone beds. The basal 0.3 m is sandy and contains spheroidal, phsophatic sandstone concretions. These sediments, sometimes termed Springvale Sandstone represent relict Oriskany sediments reworked into the Emsian Bois Blanc. The Bois Blanc interval is locally argillaceous and may be glauconitic. It contains a distinctive suite of brachiopods (atrypoids and *Leptaena* are most common), corals, and trilobites.

The Bois Blanc is sharply and probably unconformably overlain by the crinoidal grainstones of the basal Edgecliff Member of the Onondaga Formation This surface is locally iron stained. The Edgecliff locally shows small bioherms up to 4 m high, composed largely of favositid tabulates and rugosan corals. These reefs, well exposed at the Ridgemount Quarry in Ft. Erie, all appear to arise at a common level on top of the basal 0.5-0.7 m thick transgressive limestone of the Edgecliff. They are draped by greenish gray calcareous mudstones and cherty crinoiud rich wackestones and packstones. Thus these mounds, like those of the Silurian Lockport Group appear to have grown upward during times of rising sea-level Thet were ultimately drowns and buried by muds. Overlying Onondaga sediments are crinoid and small coral rich cherty packstones reflecting slightly shallowing conditions. The Onoindaga and Bois Blanc show somewhat similar though distinguishable faunas. They were regarded by Brett and Baird (1995) as representing separate ecological-evolutionary subunits.

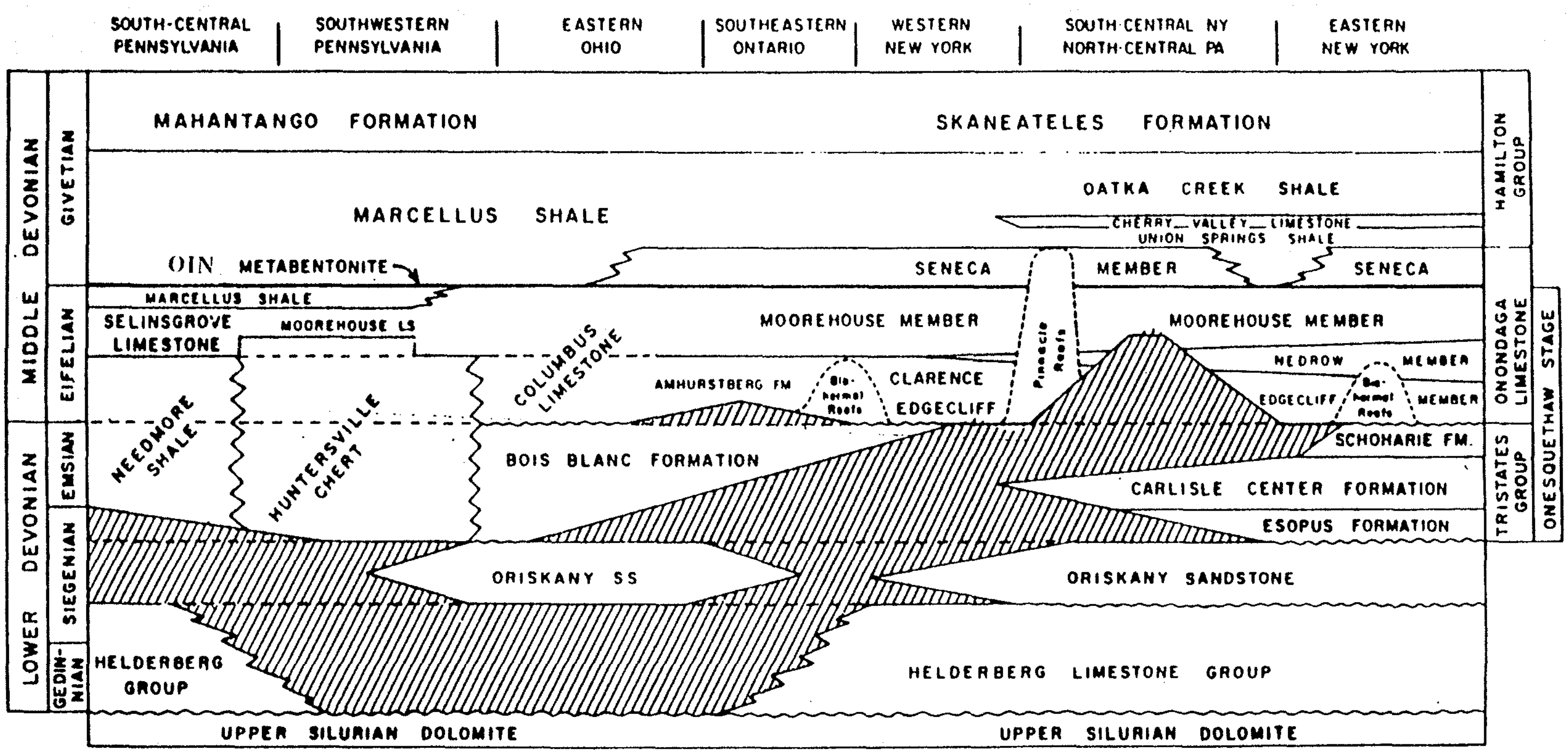

Figure 13. Middle and Lower Devonian stratigraphy of the northern Appalachian basin. (OIN= Onondaga Indian Nations K bentonite). Modified from Casa and Kissling (1982).

SUMMARY

The Silurian-Early Devonian strata of the Niagara Peninsula-western New York are richly fossiliferous, and display recurring depth-related benthic assemblages that aid in interpretation of relative sea-level fluctuation, as well as ecological-evolutionary history. Many fossil assemblages are exceptionally well preserved, reflecting event deposition. These fossils have also permitted relatively refined biostratigraphy. Newer approaches to refining our understanding of stratigraphy and facies relationships in these classic strata. These include identification and tracing of distinctive event beds, such as the DeCew seismite horizon and a hierarchy of disconformity bounded cycles of sequences.

Despite their classic status, these strata have only recently been considered from the standpoint of modern sequence and event stratigraphy (Duke and Fawcett 1987; Brett et al. 1990; Goodman and Brett, 1994; Brett et al., 1998). About nine unconformity-bound stratal sequences have been recognized within the Medina to Bertie groups (Llandovery to Ludlow Series) of the Ontario Peninsula-New York area (see Brett et al., 1990, for details) and two within the Devonian Emsian-Eifelian interval. These sequences and many of their component subsequences can be correlated regionally into Pennsylvania, Maryland, Ohio, Michigan, and the Bruce Peninsula of Ontario (Dennison and Head, 1975; Brett et al., 1990). Furthermore, some of the major events of relative sea-level fall and rise appear to be correlative with those recognized in other basins (see Johnson et al. 1985, for example), suggesting an underlying eustatic mechanism.

The ability to delineate and correlate thin sequence stratigraphic intervals also permits recognition of regional patterns that may be the result of minor tectonic adjustments and shifting depocenters within the Appalachian Foreland Basin (Goodman and Brett, 1994; Ettensohn and Brett, 1998). Within the Silurian as a whole, we recognize a large scale pattern of eastward-westward-eastward migration of the deepest water area and depocenter of the Appalachian Basin during the Early Silurian to Early Devonian time. This tectonically driven effect is superimposed on the more widespread (eustatically controlled) pattern of sea-level fluctuation manifest in the depositional sequences(Fig. 14).

In addition, minor abrupt facies changes within discontinuity-bound sequences, on the scale of a few kilometers, provide evidence for localized flexure of the crust, probably in the form of subsurface fault blocks, as described by Sanford et al. (1985). These local flexures may not be independent from the overall tectonic pattern but may record the local crustal response to migrating "waves" of compression due to episodes of tectonic loading and relaxation (Beaumont et al., 1988).

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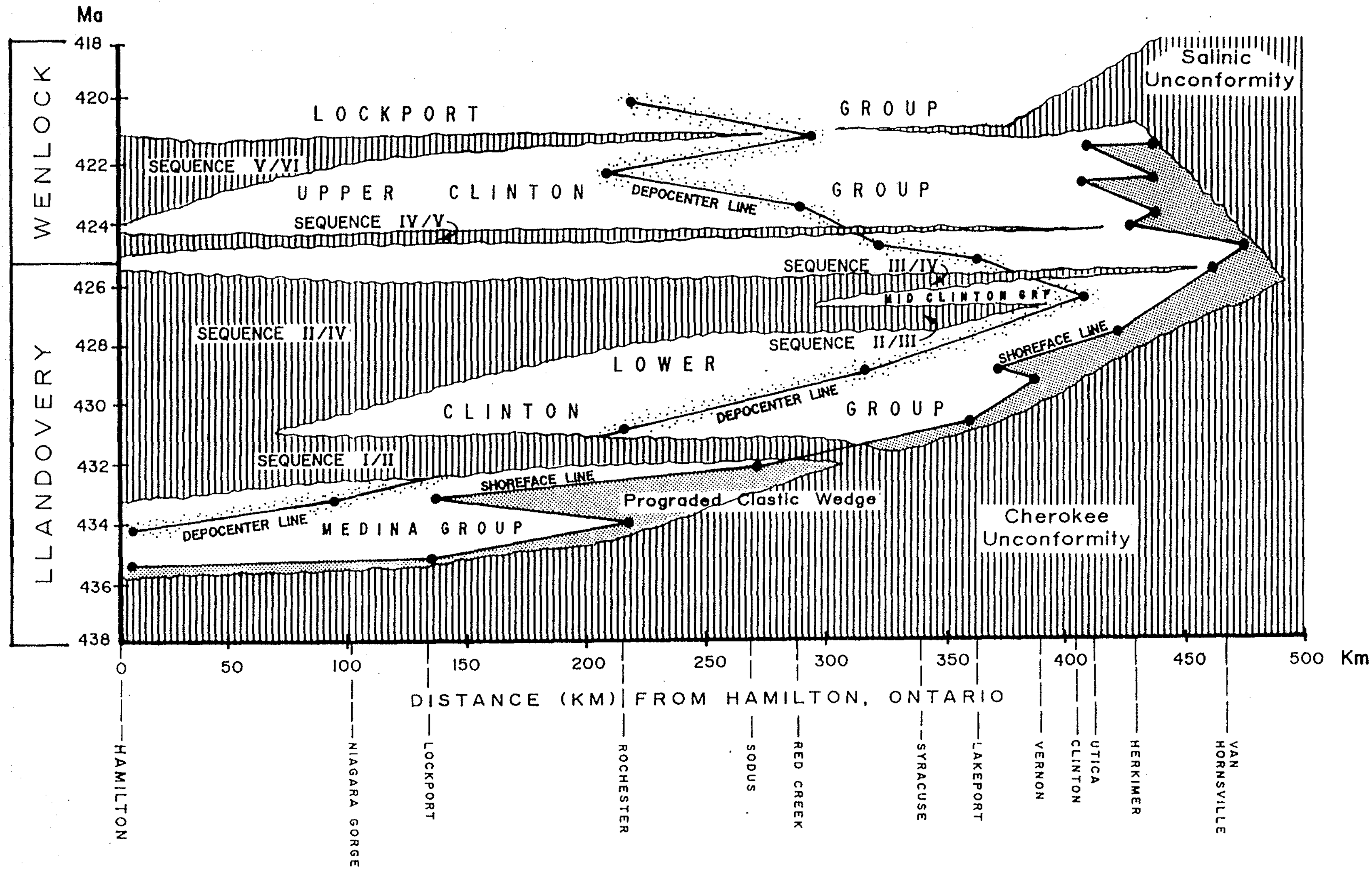

Figure 14. Migration of shoreface and depocenter facies for the Appalachian basin during early to middle Silurian time relative to locations along the east-west outcrop belt from Hamilton, Ontario to Van Hornesville (eastern New York State). Vertical ruling indicates major unconformities. From Goodman and Brett (1994).

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STOP DESCRIPTIONS

This field trip will take place in western New York State and in the Niagara Peninsula of Ontario. Figure 15 shows stop locations for the trip on a simplified geologic base map (Rickard and Fisher, 1970). Abbreviations used in the text and figures for inferred sequence stratigraphic units are as follows: for subsequences (fourth order sequences): RLS = relative lowstands (regressive deposits); RHS = relative highstands; MFS = marine flooding surface; SDS = sea level drop surface; CI, condensed interval, and for sequences: SMT = shelf margin systems tract (lowstand deposit); TST = transgressive systems tract; CS = condensed section; EHS = early highstand; LHS = late highstand; SB = sequence boundary; TS = transgressive surface. The sequences referred to in the previous text are abbreviated as S-I through S-VIII in the following.

ROAD LOG FOR SILURIAN-DEVONIAN SEQUENCES, CYCLES, AND EVENTS

Total Mileage	Incremental Mileage	Description
0.0	0.0	Leave SUNY Fredonia parking lot, turn left on Central Avenue
0.5	0.5	Junction Millard Fillmore Blvd.; turn left
1.6	1.1	Junct. Rts. 5 and 29; continue
1.8	0.2	Entrance to oll booth to NY State Thruway
1.9	0.1	Fork; bear right to I-90 north
2.2	0.3	Merge onto Thruway
14.0-14.2	11.8	Silver Creek Exit; note Portage Escarpment with cuts in gray Hanover Shale overlain by black Dunkirk Shale; Upper Devonian, near Frasnian-Famennian bondary
23.8	9.8	Eden-Angola Exit
33.0	9.2	Hamburg, NY
34.6	1.6	cuts in Rhinestreet Shale; note sulfurous black shale with large concretions; Upper Devonian (Frasnian)
35.6	1.0	Middlesex Shale
35.8	0.2	Ledge of North Evans Limestone on right; this is a highly

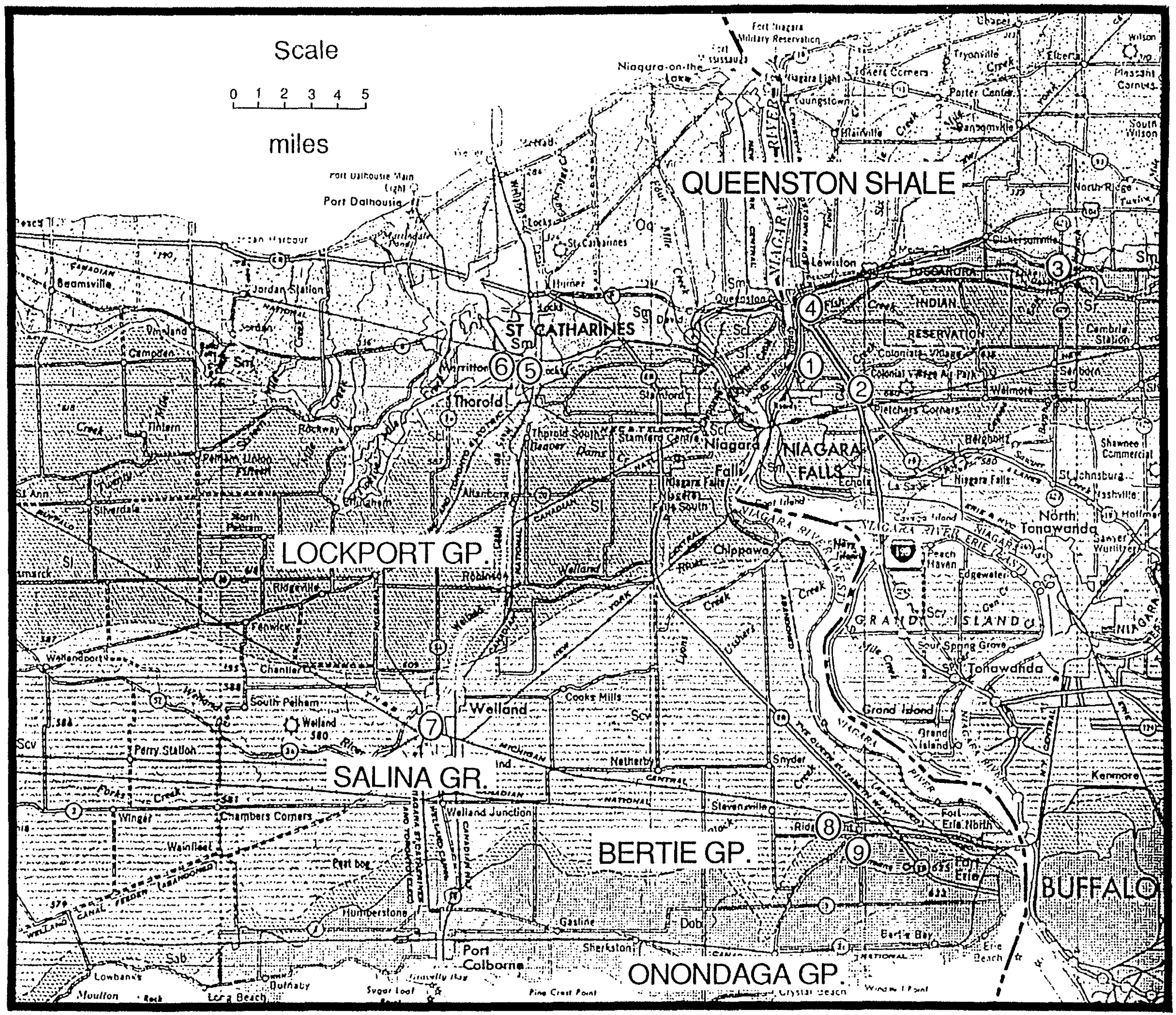

Figure 15. Location map for field trip. Numbers correspond to stop numbers discussed in text. of road log. Geologic base map modified from Rickard and Fisher (1970).

		condensed conodont, bone-rich limestone that straddles the Middle-Upper Devonian boundary
36.5	0.7	Blasdell Exit (52) of NY Truway; exit onto Mile Strip Road
36.8	0.3	Mile Strip Road (Rt. 179); turn right
38.1	1.3	Ford Plant on left; prepare to bear right
38.5	0.4	Rt. 170 ends at NY Rt. 5; bear right onto NY 5 East (north)
39.5	1.0	Lackawanna town line; note large steel mills
41..3	2.0	Father Baker Bridge; views of Buffalo Harbor and City Skyline
43.3	2.0	Skyway; Buffalo Harbor
44.8	0.5	Exit for I-190 North; bear right onto exit and continue around tight ramp to highway (caution; tight right hand exit loop)
44.9	0.1	Merge onto I-190 North
47.0	2.1	Underpass under Peace Bridge; views of Black Rock Channel of Niagara River
48.2	1.2	Scajaquada Expressway (Rt. 198); Squaw Island on left
52.7	4.5	Exit for I-290; continue on I-190 N
53.7	1.0	Toll Booth for South Grand Island bridge; views of east banch Niagara River (pay toll; $.50)
54.5	0.6	Enter Grand Island, NY; one of the largest river surrounded islands in the World; about 9 miles long north to south
59.9	5.4	North Grand Island bridge; views of broad Niagara River about 2 miles above the Falls.
60.0 61.5		I-190 enters Niagara Falls, NY; continue north; views of retaining wall of large toxic waste storage area
65.2	3.7	Exit for NY Rt. 31 (Witmer Road); bear right
65.5	0.3	Junction Rt. 31; turn left; underpass below I-190;
65.8		Pass under major power lines from hydroelectric plant

66.0	0.2	University Road; turn right (just before Rt. 31 makes major curve to left)
66.8	0.8	Junction Hyde Park Blvd. (NY Rt. 62) prepare to go straight across onto South Haul Road; access for Robert Moses Power Plant
66.9	0.1	Pass by fisherman's parking area (cars can be left here; we will continue on South Haul Road to the bottom of the gorge and allow passengers to disembark and return uphill on foot); ahead through underpass beneath Robert Moses Parkway are excellent views of the Niagara Gorge and a complete stratigraphic section from the mid Silurian Lockport Group down to the unconformable contact between the Silurian Whirlpool Sandstone and the underlying Ordovician Queenston Shale
67.5	0.6	Fishermen's access at bottom of Niagara Gorge, just outside gates for Robert Moses Power Plant; passengers will disembark and proceed back up the South Haul Road; vehicles will return back up the road to park

STOP 1: NIAGARA GORGE: SOUTH HAUL ROAD

Location: Large roadcuts in east wall of Niagara Gorge along South Haul access road for Robert Moses Power Plant, and ascending for about 1 km south to a tunnel beneath Robert Moses Parkway (Fig. 16). Parking is available in a fisherman's access parking lot just west of Rt. 62 (Hyde Park Boulevard) immediately south (uphill) from the tunnel. Lewiston, Niagara County, New York (USGS Lewiston 7.5' Quadrangle). Note: Access to the Haul Road exposure is strictly controlled by the Robert Moses Power Project and requires advance permission.

Description: This outstanding outcrop of Lower to mid Silurian strata shows important contrasts with sections of the comparable interval near Hamilton. The section begins near the Power Plant with about 8 m of the Upper Ordovician Queenston Shale (Fig. 17). Its sharp contact with the overlying Whirlpool Sandstone is the Cherokee Unconformity (Silurian Sequence I boundary). The units of the Silurian succession are described in ascending order, as follows:

Medina Group (Fig. 17).

Whirlpool Sandstone: (4.5 m)- White, trough cross bedded, quartz arenite facies which record a non-marine to marine transition. Excellent profiles of channels are visible.

Power Glen Shale: (~ 8 m)- Dark gray, friable shale, with very minor sandstone interbeds

Devils Hole Sandstone: (2 m)- Pale gray, massive, quartz arenite with a distinctive, meter-thick phosphatic, sandy dolostone, Artpark Phosphate Bed near the top (CI).

Grimsby Formation: (15 m)- Greenish gray to maroon shales and mudstones with bundles of thin reddish and white mottled sandstones (Fig. 17).

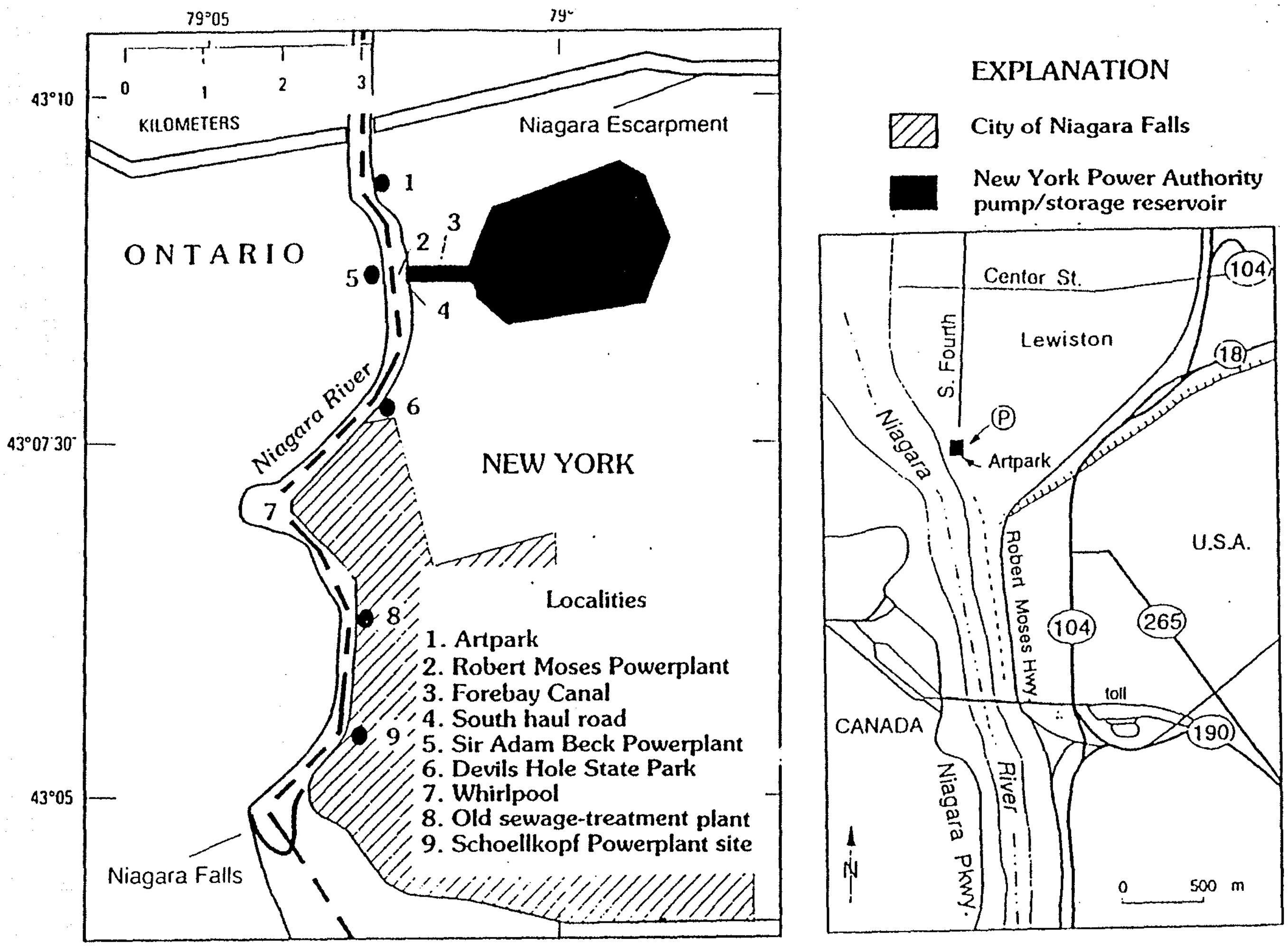

Figure 16. Location of pertinent features in the vicinity of the Niagara River Gorge. Detail of Lewiston area is shown in inset figure. Adapted from Brett et al. (1995).

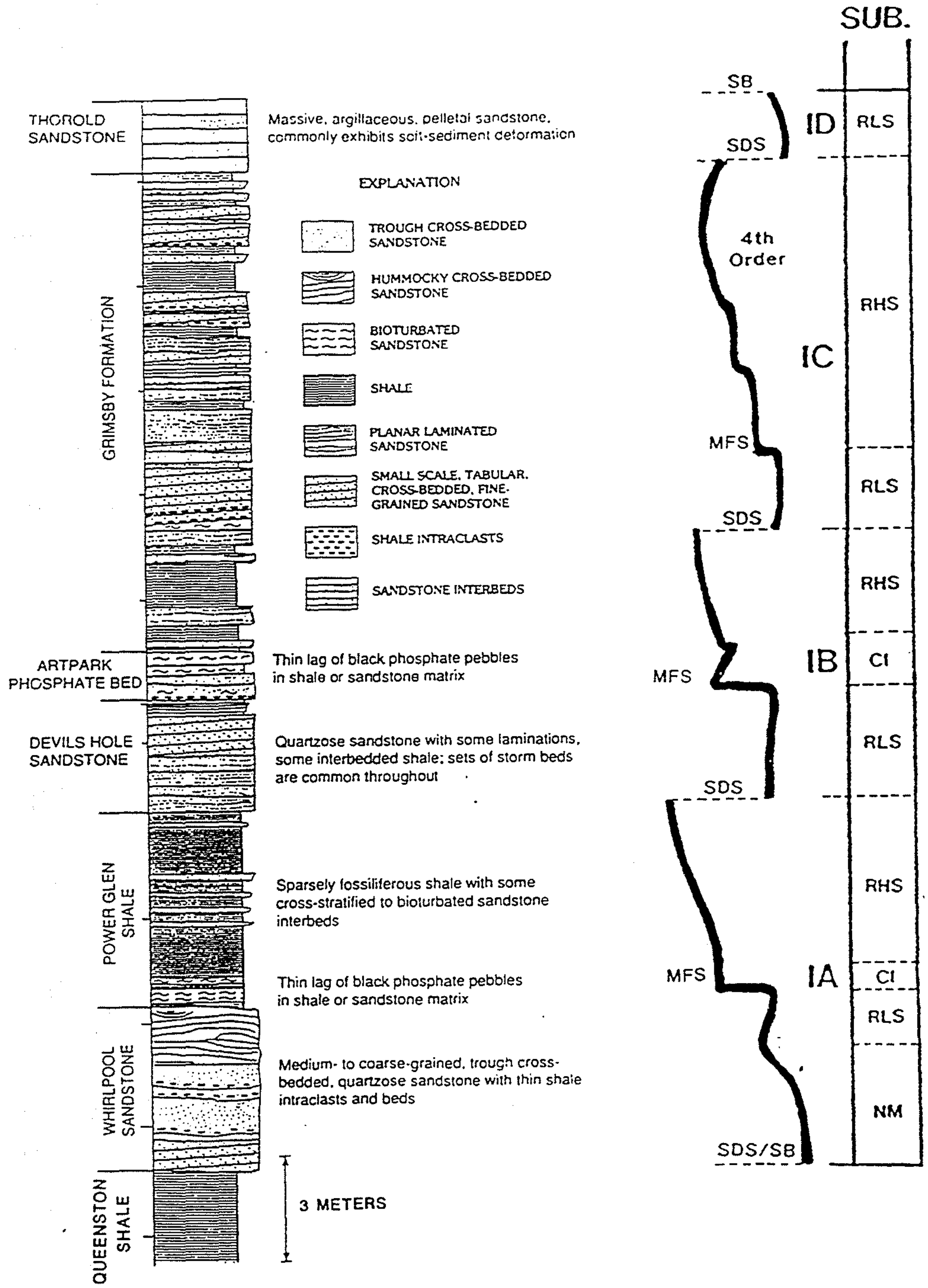

Figure 17. Lithostratigraphy, inferred relative sea level curve, and sequence terminology for Medina Group (Sequence I) at Niagara Gorge, Lewiston, New York. RLS-A = relative sea level curve for lower order cycles. RSL-B = relative sea level curve for large-scale fourth order cycles, generally asymmetrical upward deepening cycles of subgroup scale. Bars on the right side of figure indicate subdivisions of subsequences (SS; left bar) and, for system tracts, the sequence as a whole (SEQ; right bar). For sequence abbreviations see text.

Thorold Sandstone: (2 m)- White, cross-bedded quartz arenite. The Thorold has a sharp, erosive base which marks the base of the next Medina subsequence (IC). A thin (2-10 cm), sandy phosphatic bed, the Densmore Creek Bed (Brett et al. 1995) rests sharply on the Thorold (and on a Cambria Shale remnant north of the Power Plant), marking the base of the Neahga Shale.

Clinton Group (Figs. 6, 18)

Neahga Shale: (2 m)- Dark greenish gray, very friable shale (base sharp (S-II SB).

Reynales Formation (Hickory Corners Member): (~50 cm)- Medium gray, nodular, burrowed, bryozoan-rich wacke- to packstone. Conodonts indicate a mid Llandovery age for the Reynales (see LoDuca and Brett, 1994); this unit represents an erosional remnant of the Reynales.

Rockway Formation: (3 m)- Buff-weathering, argillaceous dolostone with thin dolomitic shales shows prominent rhythmic bands (10-50 cm) of sparsely fossiliferous argillaceous dolostone interbedded with thin gray shales. The Rockway shows a sharp upper contact(S-IV-V SB).

Irondequoit Formation: (2.5 m)- Massive, pinkish-gray, crinoidal pack-and grainstone. Clasts of fine-grained dolostone, derived from the underlying Rockway occur in the basal thin bed of the Irondequoit (Fig. 18). Its sharp upper contact (MFS) is marked by a 30 cm thick shell bed.

Rochester Shale: (18 m)- Medium dark gray mudstone with thin calcisiltites and lenticular fossil rich limestones; 1.5 m of bryozoan-rich limestone beds underlie the sharp top (MFS) of the Lewiston Member . The upper Rochester (Burleigh Hill Member) also displays a sharp contact (SSB) with the enterolithic DeCew Dolostone beds.

DeCew Formation: (3m) -Dark gray, buff weathering, laminated dolostone (calcisiltite). Here and, especially in weathered exposures in the adjacent Devils Hole Park section, the DeCew displays spectacular soft-sediment deformation with isoclinally folded beds (seismite?).

Lockport Group (Fig. 19): The sequence V-VI boundary at the DeCew-Gasport contact is well exposed near the entrance to the "tunnel" beneath the Robert Moses Parkway at the top of the cut; basal Gasport shows rip-up clasts of DeCew Dolostone (Figs. 19).

Gasport Formation: (5 m)-Pinkish gray thin bedded to massive dolostone, divided into a lower pinkish gray dolomitic crinoidal grainstone (Gothic Hill Member) and a 2.5 m upper argillaceous, bioturbated dolostone (Pekin Member) Weathered surfaces of the Gothic Hill grainstones display probable bipolar cross- stratification . The sharp upper contact is a subsequence boundary.

Goat Island Formation : (~10 m)- Buff weathering dolomitic, crinoidal grainstones, buff, thin bedded dolsotone with white chert, and dark brownish gray, argillaceous, banded dolostone; the basal unit (Niagara Falls Member) is massive crinoidal grainstone with scattered *Cladopora* corals and stromatoporoids; abundant vugs appear to be solution cavities in a stromatoporoid-rich zone.

The Ancaster Member is poorly developed here, thin (-2.5 m) and only sparingly cherty. Argillaceous and bituminous gray dolostones of the Vinemount Member form the uppermost unit on the access road. This member is much less shaly than at its type area near Hamilton.

Return to vehicles and proceed

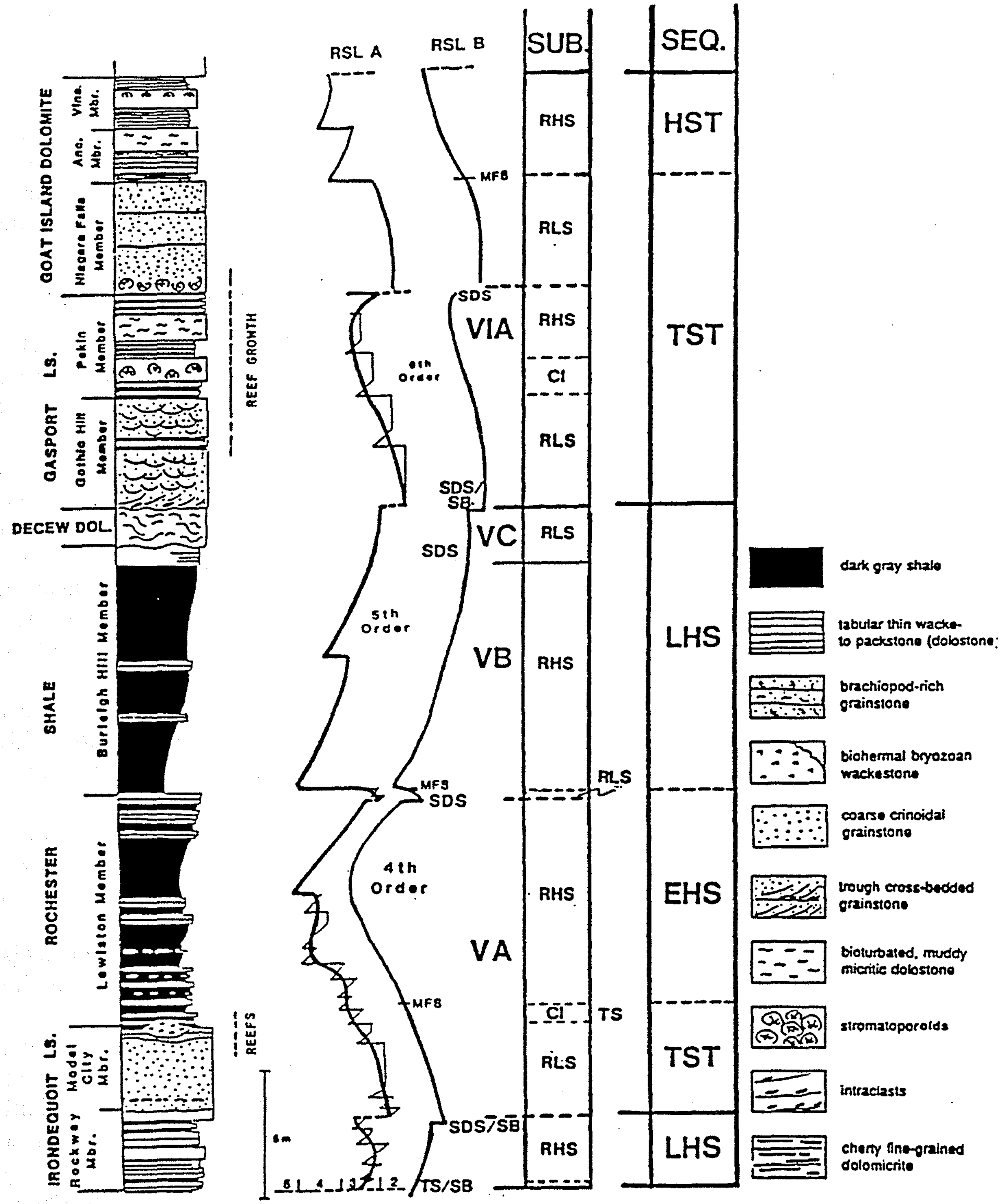

Figure 18. Lithostratigraphy, inferred relative sea level and sequence stratigraphic interpretation for upper Clinton and basal Lockport groups (sequences IV, V and basal VI) at Niagara River Gorge near Lewiston N.Y. Note two zones of reef growth corresponding to early highstand (condensed) phases. Relative sea level curve calibrated to benthic assemblages. For other abbreviations see text.

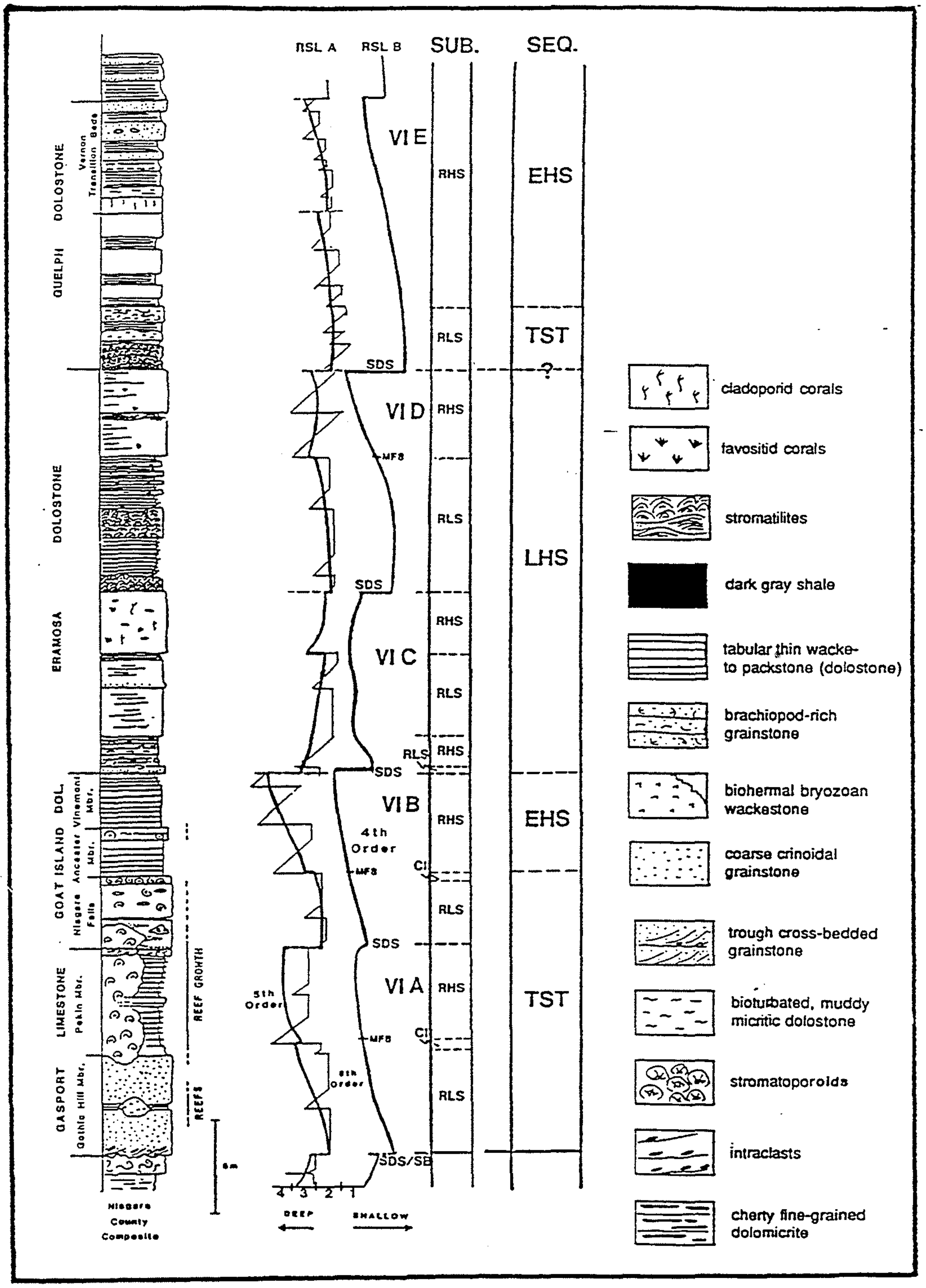

Figure 19. Lithostratigraphy, inferred relative sea level, and sequence stratigraphic interpretation of lower Lockport Group (base of sequence IV) at Niagara Gorge. Niagara Co., NY. Calibration of relative sea level curves based on benthic assemblages.

68.1	0.6	Turn right out of fisherman's parking lot
68.2	0.1	Junction Hyde Park Boulevard; again, proceed straight across onto University Road
68.9	0.7	as road curves to right; turn left onto unamed access road; note jungle of high tension wires ahead
69.3	0.4	T-intersection with Robert Moses Power Vista back entrance road; turn right
69.4	0.1	Pull off and park along road cuts just before underpas beneath I-190

STOP 2: ROBERT MOSES ACCESS ROAD AND FOREBAY

Location: Access road to the Robert Moses Power Plant, and adjacent forebay canal just west of Military Road and 1.2 km north of Route 31, Lewiston, Niagara Co., NY (Lewiston 7.5' Quadrangle).

Description: Higher units of the Lockport Group are visible along the forebay and consist of the upper Eramosa (new usage in New York) and lower Guelph formations (Fig. 19). Large algal bioherms characterize the uppermost units of the Eramosa Formation in the forebay. Exposures in the small road cut at the underpass of the access road beneath the lanes of I-190 show exceptionally large (2 m high) stromatolites, and some non-laminated thrombolites the stromatolitic interval at the base of the Guelph is traceable with subsurface data at least to Hamilton (Fig. 19).

		Pull forward under the I-190 overpass and proceed to Military Road
69.6	0.2	Junction Millitary Road; turn right (north)
70.1	0.5	Crossing east end of Robert Moses forebay area; Pump Generating Power Plant to right; note small thrombolitic mounds in Eramosa Formation exposed i n forebay cuts to left
71.0	0.9	Junction Upper Mountain Road at stoplight

Note For sidetrip to optional Stop 3 (Route 427 cut, Pekin, NY) turn right and follow log below; (approximately 16 miles round trip and about 40 minutes); otherwise proceed straght through the light on Military Road and pick up road log beginning at mile 87.1

71.0	0.9	Junction Upper Mountain Road at stoplight. Turn right onto Upper Mountain Road
73.0	2.0	Enter Tuscarora Indian Natiion

73.5	0.5	Dangerous curve on Upper Mountain Road at junction of Blackman Road; bear right continuing on Upper Mountain Road
78.6	5.1	Pekin, NY; note dolostone church on right at Grove Street; proceed on Upper Mountain Road on ridge over Rt. 429 at the Pekin cut
78.9	0.3	Old Pekin Road (on way) on left; hidden intersection; turn left
79.0	0.1	Junction Rt. 429; turn left (south) and move quickly to ward right shoulder of Rt. 429
79.1	0.1	Pull off on wide area of right shoulder of Rt. 429 and park

OPTIONAL STOP 3. "PEKIN BIOHERM" CUT ON RT. 427

Location: Cuts on both sides of NY 427, just north of underpas bneath Upper Mountain Road, Pekin, Niagara County, NY (Cambria 7.5' Quadrangle).

Description: This classic cut in the brow of Niagara Escarpment has recently been widened, and provides an excellent, but very fresh exposure of the upper Gasport (Pekin Member of Brett et al., 1995) and the lower portion of the overlying Goat Island Formation (Fig, 19). The large, massive mound exposed particularly on the west side of Rt. 427 was originally described as a Gasport bioherm and was considered to show reefal succession (Crowley and Poore, 1974). However, recent excavations have revealed that the mass of stromatoporoid bearing rock is almost entirely within the Goat Island Formation and is separated from older Gasport deposits (including a formerly exposed small bioherm, now detroyed by blasting) by a major erosion surface. The contact between the gray, thin bedded argillaceous dolostones of the Pekin Member of the Gasport and overlying massive, dolomitic crinoidal grainstone of the Goat Island (Niagara Falls Member of Brett et al., 1995), a sequence boundary, appears sharp. but horizontal in the northeastern portion of the cut. However, this contact abruptly descends to near road level just north of the Upper Mountain Road overpass. Here a mass of biohermal lithology overlies the unconformity. On the freshly blasted west side of the cut the irregular contact between the dark gray Pekin and light pinkish biohermal Goat Island is now very clear. The erosion surface separating the units has a relief of over 2 meters. The Goat Island "bioherm" appears to have developed in low areas on the unconformity. It consistrs of a mixture of crinoidal grainstones and light gray dolomicrite, rich in stromatoporoids, many of which are tumbled onto their sides or even inverted, indicating storm disturbance. This biohermal mass built up in "channels" along a sequence boundary during initial transgression.

		Reboard vehicles and proceed south on Rt. 429 through the tunnel beneath Upper Mountain Road; prepare to turn right
79.3	0.2	Junctiion Grove Road; turn right
79.4	0.1	Junction Upper Mountain Road; turn left and retrace route to Millitary Road

END OPTIONAL ROUTE

87.1	7.7	Junction Military Road (NY 265); turn right (north)
87. 8	0.7	Junction NY 104; turn right (north)
88.0	0.2	Brow of Niagara Escarpment; on clear days good views of the mouth of Niagara River and Lake Ontario to the north; cuts to right in Gasport-Goat Island formations
88.4	0.4	Skip Exit for Rt. 18F east, but stay right
88.9	0.5	Exit for Rt.104-18F west; bear right onto exit lane
89.1	0.2	Merge right onto Rt. 18F; Center Street, Lewiston, NY
89.9	0.8	Frontier House McDonald's; pull in for rest stop.
89.95	0.05	Pull out of parking lot and turn left onto Center Street
90.4	0.5	Portage Road; turn right and proceed to entrance for Artpark
90.6	0.2	Entrance to Artpark Road
91.3	0.7	Parking Lot B; bear right and then turn left immediately once in parking lot; proceed up to left on small road labled "Narrow" near Clay Studio
91.5	0.2	Fishermen's parking area; pull in and park; proceed south on foot to entrance of Niagara Gorge

STOP 4. NIAGARA GORGE, LEWISTON (ARTPARK): (LUNCH STOP)

Location: Sections in east wall of Niagara Gorge along old haulage road extending from north end of Niagara Gorge at Niagara Escarpment just south of Artpark (Fig. 16); off Fourth Street, southward to the Lewiston-Queenston bridge, Lewiston, Niagara County, NY (Lewiston 7.5' Quadrangle)

Description: The north-facing cuesta (Niagara Escarpment) stands 76 m above the adjacent Lake Ontario plain. Niagara Falls was initiated here about 12,000 BP.

Exposures of the Upper Ordovician Queenston Shale and its unconformable contact with basal Silurian Whirlpool Sandstone are visible along a short path, adjacent to the river, immediately south of the Artpark theater. Outcrops of the Lower Silurian stratigraphic units above the Whirlpool Sandstone (Fig. 17) are accessible along an old haulage road that leads southward from the Artpark Visitor Center into the gorge. At the entrance to the gorge (edge of Niagara Escarpment) an isolated "butte" of Lower Silurian strata (Power Glen-lower Grimsby; type locality of the Artpark Phosphate bed) between the path and the river, represents a remnant of a promontory in the gorge wall that was breached during excavation for the power plant. A 0.5 m layer of mottled sandstone with prominent ball-and-pillow structures, about 5.5 m above the base of the Grimsby, is well exposed in the cliffs about 200 to 700 m north of the Lewiston-Queenston Bridge. Caution is required in this exposure, as rock falls are common. Abundant fallen debris also provides an excellent look at varied lithologies of the upper Medina, as well as Clinton and Lockport units.

Reboard vehicles and retrace route to parking lot B;

91.7	0.2	Bear right out of parking lot onto exit road and proceed to exit from park.
92.4	0.7	Proceed straight through onto Portage Road
92.8	0.4	Junction Rt. 18F; turn right (east)
93.0	0.2	Junction Rt. 104 West/Robert Moses Parkway; turn right
93.1	0.1	Fork; bear left onto entrance for Rt. 104; DO NOT go onto Robert Moses Parkway
93.9	0.8	Juntion Military Road; proceed straight on Rt. 104
94. 7	0.8	Exit for I-190; bear right onto exit
95.1	0.4	Merge onto I-190 south
95.3	0.2	follow signs for exit to Canada; follow exit ramp around onto I-190 north and entrance to bridge
95.6	0.3	Merge onto -190 north and entrance to bridge
96.0	0.4	Enter Lewiston-Queenston bridge
96.2	0.2	Excellent views of Niagara Gorge from bridge; Canadin border
96.5	0.3	Customs Booths; residents of countries other than US or Canada must show passports
96.8	0.3	Toll booths; cars US $2.50; pay and then proceed straight ahead on to Highway 405
102.4	5.6	Merge onto Queen Elizabeth Way (QEW)

102.5	0.2	Exit for Glendale Road St. Catharines; bear right onto ramp
105.8	0.3	End of ramp; turn left onto Glendale Road
107.5	1.7	Lift bridge over Welland Canal
107.6	0.1	Stoplightbat end of bridge
107.7	0.1	Junction Government Road on left; turn left
108.4	0.4	Welland Lock # 5; parking area adjacent to canal; pull in and park; railroad cuts are to right on opposite side of th road; cautiously cross road and proceed down embankment to railroad cuts

STOP 5: MERRITTON RAILROAD CUT

Location: Cuts along Canadian National Railroad tracks 0.1 km west of Government Road (Canal Street) along west side of the Welland Canal, opposite locks 4 and 5, Village of Merritton, Thorold Township, Ontario. (NTS 30M/3g, St. Catharines Sheet).

Description: This locality is the type section of both the Thorold Sandstone and the Merritton Dolostone (Kilgour, 1963; Fig. 20).

Units exposed along this cut include, in ascending order :

Thorold Formation: (3m)- White and greenish sands and shales with small scale cross stratification, scour and fill stucture, load casts and oscillation ripple marks. The lower 1.5 m of Thorold Sandstone, interbedded pale buff-weathering argillaceous sandstone and thin greenish sandy shales with excellently preserved spreiten of the trace fossil *Daedalus*, while undersurfaces show the annulated trace fossil *Arthrophycus* ; both traces may have been the work of the same organisms. This is a widespread marker interval.

Unnamed limestone: (30 cm) Gray, argillaceous, phosphatic limestone with bryozoans.

Neahga Shale: (24 cm)- Dark gray shale with bored hardground clasts in basal 5 cm.

Merritton Limestone: (50 cm)- Pale gray, glauconitic, phosphatic wacke- to packstone with three major beds as in the Hamilton area . Basal contact sharp, with abundant small phosphatic nodules. The upper contact of the Merritton is also a sharp, shows truncated in situ *Pentameroides* a (Telychian index fossil) and is stained black with phosphatic material.

Williamson Shale: (12 cm)- Greenish gray shale tentatively correlated with the Williamson Shale of New York on the basis of recovered acritarchs (C.E. Brett and M. Miller, unpublished data).

Rockway Dolostone: (~2 m)- Buff to gray, thin bedded argillaceous dolostone with an abundance of the large pentamerid brachiopod *Costistricklandia*..

This cut is crucial in establishing the stratigraphic succession of the lower to mid Clinton rocks in Ontario. The Merritton (often called "Reynales" in Ontario) overlies the major late

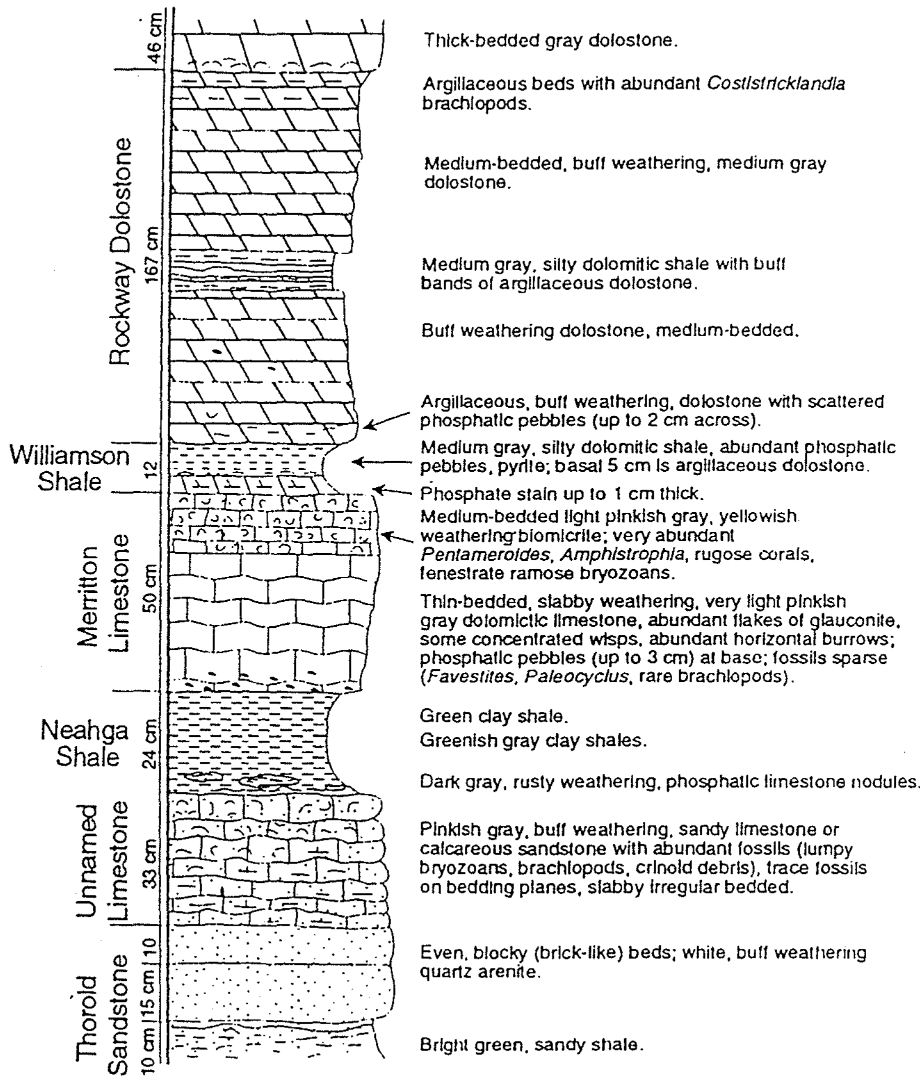

Figure 20. Details of upper Medina and Clinton sequences at Merritton, Ontario.

Llandovery (Sequence IV basal) unconformity, which at this locality has removed the true Reynales Limestone (Figs. 6, 20).

		Pull out of parking area and turn right, retracing route along Government Road to Glendale
108.1	0.7	Junction Glendale Road; turn left
108.6	0.5	Cross railroad tracks
108.8	0.2	T-junction at Merritt Street; turn left (Caution, no light)
108.9	0.1	Junction continuation of Glendale; turn right
109.2	0.3	Junction Burleigh Hil Road; turn left
109.5	0.3	Pull off on shoulder at top of roadcut and walk back to cuts

OPTIONAL STOP 6. BURLEIGH HILL ROAD CUT.

Location: Exposures in long roadcut in brow of Niagara Escarpment along Burleigh Hill Road about 2 km south of Glendale Avenue, Thorold, Ontario (NTS 30M/3g, St. Catharines Sheet).

Description: This long cut exposes the upper portion of the Rochester Shale and its contact with the overlying DeCew Formation (Figs. 9; 18). This is the type locality of the Burleigh Hill Member of the Rochester Shale (Brett, 1983b); which is here about 9 m thick. It is divisible into lower shaly and upper somewhat thicker bedded, dolomitic shale and argillaceous dolostone. Thin calcisilitites display sharp bases and smal scale grading and hummocky cross stratification indicative of deposition as tempestites (storm beds); fossils are generally sparse although rare Stegerhynchus and *Coolinia* brachiopods and the trilobites *Dalmanites* and *Trimerus* can be found. The DeCew Formation is less than a meter thick and displays typical highly convoluted bedding as seen at Niagara Gorge. The contact with a thin 40-50 cm ledge of atypically fine gained Gasport Dolostone is sharp; locally a very thin remnant of a fossilifewrous shale (the St. Catharines shale lentil) are present between the DeCew and Gasport but that unit is largely removed by sub-Gasport erosion.

		Return to vehicles and continue south on Burleigh Hill Road
109.9	0.4	Junction St. Davids Road; turn right
110.9	1.0	Overpass over Highway 406; prepare to turn left
111.0	0.1	Entrance to Hwy 406 South ; turn left onto ramp

111.2	0.2	Merge onto Hwy 406 southbound
114.4	3.4	Junction Rt. 58/ 20 (alternate route to Stop 7); continue on Rt. 406
117.5	3.1	Cross Welland River
119.7	2.2	Highway 406 ends at Main Street, Welland, Ontario; turn left onto Main Street
120.0	0.3	Tunnel beneath Welland Canal
120.2	0.2	Junction Rt. 1440 South (toward Pt. Colbourne); turn right
122.8	2.6	Junction Netherby Road, conector to Rt.. 58A ; turn right
123.3	0.5	Junction Rusholme Road; turn left
123.5	0.2	Junction Town Line Road; turn right
124.0	0.5	Small parking rea on right next to roadcut, slightly before tunnel under Welland Canal; pull in and park to view outcrop

OPTIONAL STOP 7 : TOWN LINE (NETHERBY) ROAD (RT. 58A) CUT NEAR TUNNEL BENEATH WELLAND CANAL

Location: East entrance to the Town Line) Netherby Road and railway tunnel beneath the Welland Canal Bypass, southeast edge of Welland, Ontario (NTS 30L/14g, Welland Junction Sheet)

Description: Strata here are assignable to the Upper Silurian Salina Group (Fig. 21).

Camillus Formation - (5 m exposed) - Interbedded fine-grained blocky to laminated, gray to buff dolostone, shaly dolostone, and gypsum. Much of the dolostone has numerous gypsum crystal molds. Salt hopper impressions are also common. The upper Salina Group (Syracuse and Camillus) is over 60 meters in thickness in drill cores (Fig. 21; Caley 1940); however, because the Salina is such an easily eroded unit, this is represents the only exposure in southern Ontario.

		Pull out off parking area and turn left back onto Town Line Road (58A)
125.7	1.7	Town Line changes name to Netherby Road; continue straight on Netherby
126.1	2.4	Enter Ft. Erie

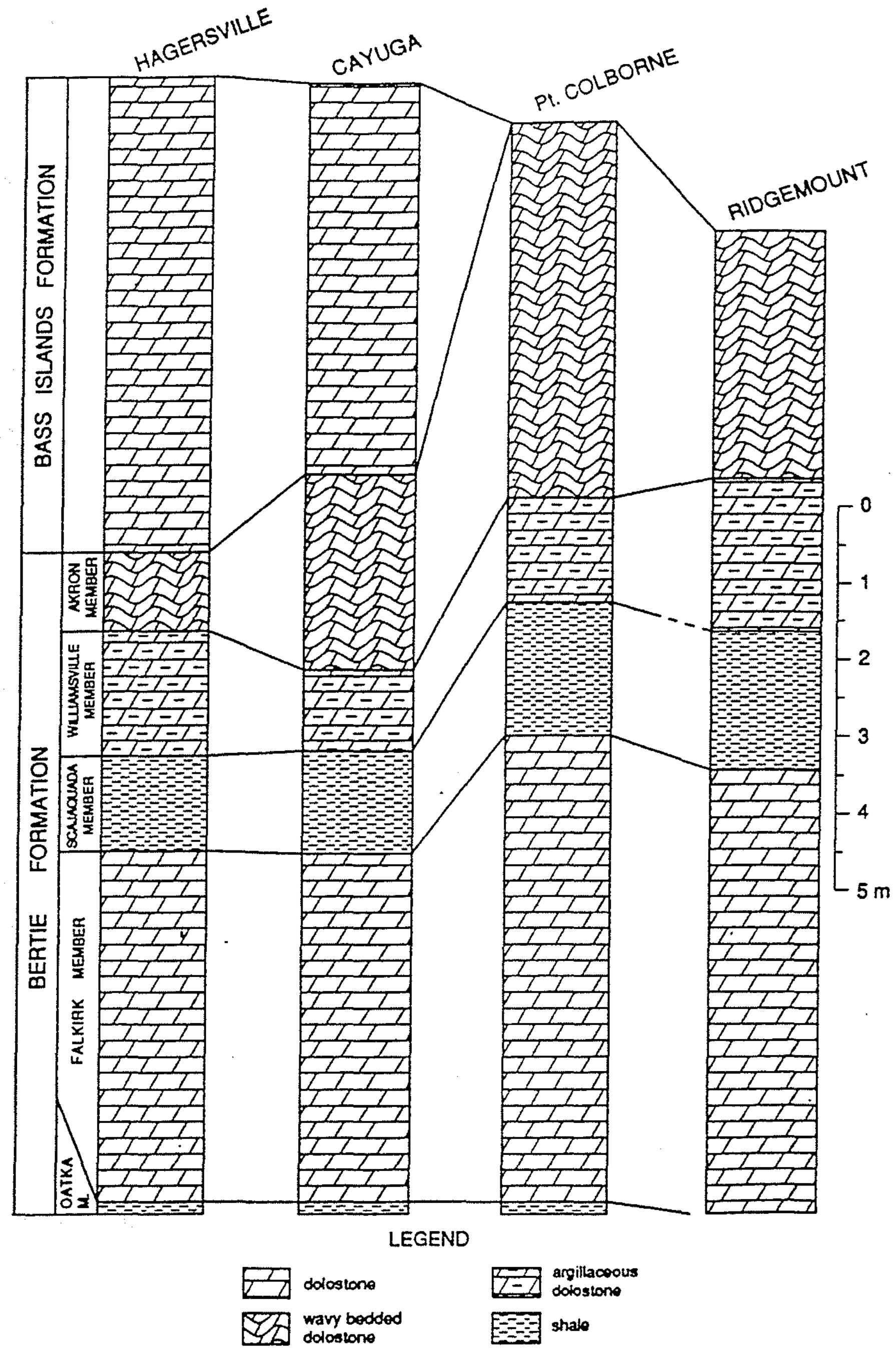

Figure 21. Correlated columns of Bertie Group and Bass Islands Group in southern Ontario, including Campbell Quarry, showing continuity of units. From Milne (ed., 1992).

129.4	3.3	Sodom Road
131. 4	2.0	Ridgemount Road; <u>turn right</u>
133.9	2. 5	Bowen Road
134.1	0.2	Entrance to Campbell Quarry on right; <u>turn into drive and register</u>; then return to vehicleds and drive back to Ridgemount Road; <u>turn right</u>
134.4	0.3	Bridge Street; <u>turn right</u>
134.7	0.3	<u>Pull off and park</u> past vbridge over quarry road connecting north and south parts of Campbell Quarry' walk down dirt road into south quarry

STOP 8. CAMPBELL QUARRY

<u>Location</u>: Large, active quarry just west of Ridgemount Road, south of Bowen Road (Regional Road 21) and north of Garrison Road; the quarry is divided into a northern (old) portion, containing crushers and quarry buildings and an active south portion by a wall that supports Bridge Road; a tunnel under the road connects the two areas. Approximately 4 km northwest of Fort Erie and 1 km south of Ridgemount, Ontario (NTS 30L/14h, Stevensville Sheet).

<u>Description</u>: Campbell Quarry is the northern of two adjacent quarries operated by Ridgemount Quarries Ltd., a division of Walker Industries. This quarry contains one of the most complete sections through the Upper Silurian Bertie-Akron strata (Cooper and Plewman 1983; Figs. 12, 21). A glacially-striated surface is visible at the top of an active area of the quarry. In ascending order, the following units are exposed in the quarry faces:
Bertie Group

Fiddlers Green (Falkirk) Formation (4.5 m)- Dark gray to brown algal-laminated dolostone, weathering yellowish brown and characterized by a coarse conchoidal fracturing; large domal stromatolitic structures 2 to 6 meters in diameter separated horizontally by nonlaminated, fine-grained dolostones containing eurypterids, leperditian ostracodes and small bivalves. The lowest meter contains meter scale thrombolites with *Whitfieldella*. brachiopods.

Scajaquada Formation (1.7 m)- Unfossiliferous dark gray shales and shaly dolostone. The unit is well laminated and some bedding surfaces feature casts of salt and gypsum crystals.

Williamsville Formation (1.25 m) - Planar-laminated fine-grained dolostone, weathering light gray and characterized by a pronounced conchoidal fracture. The lower, massive half-meter bed ("Buffalo Waterlime"), exposed in the quarry floor, contains the famous Bertie eurypterid fauna typified by *Eurypterus lacustris* (see Clarke and Ruedemann, 1912, Copeland and Bolton, 1985).

Akron Formation (3.6 m) - Greenish-grey to light brown, fine grained, thin-,wavy-bedded burrow mottled dolostone with an irregular fracture. The Akron contains a sparse and poorly preserved fauna including corals, brachiopods, and cephalopods (Buehler and Tesmer, 1963).

The contact between the Late Silurian Akron Formation and the Lower Devonian Bois Blanc Formation, well shown near the tunnel, is sharp and shows channels of 1 to 3 meters across and up to 1 meter in depth, with glauconitic sand and gravels at their bottoms. Cracks and fissures reaching as much as 4 meters down into the top of the Akron Formation can sometimes be found and are often infilled with a well-sorted white sandstone, probably representing an erosional remnant of the Lower Devonian Oriskany Sandstone (Caley, 1940). The Devonian Bois Blanc Limestone is exposed high in the quarry wall and can be studied to better advantage in the Ridgemount Quarry to the south (see below). However, fallen blocks of cherty, fossiliferous, and heavily bioturbated Bois Blanc may be seen in the Campbell Quarry.

		Return to vehicles and turn around proceed back on Bridge Street to Rdgemount Road; <u>turn right</u>
135.0	0.3	Junction Ridgemount Road, <u>turn right</u>
135.9	0.9	Entrance gate to now abadoned Ridgemount Quarry on right; <u>pull in and park;</u> proceed on foot into quarry along gravel road

STOP 9. RIDGEMOUNT QUARRY

<u>Location</u>: Large abandoned quarry about 2 km south of Campbell Quarry on west side of Ridgemount Road; and north of Highway 3; a gravel ramp road leads down into quarry from locked gates at a disused weigh station; Ridgemount, Ontario, (NTS 30L/14h, Stevensville Sheet).

<u>Description</u>: Because of the regional 0.5° southward dip, this quarry exposes higher strata than does the Campbell, although the two sections overlap. The Silurian-Devonian (Wallbridge) unconformity (Fig. 12) is spectacularly displayed in the southern part of the quarry and in patches of the quarry floor in the southern area. A *Trypanites*-bored rockground is developed on the upper surface of the Akron Dolostone; borings have been infilled with a bright green glauconitic matrix (see Kobluk et al., 1977).

The overlying Devonian Bois Blanc and Onondaga formations are exposed in the higher walls:

Bois Blanc Formation (2.5 m) - Cherty, dolomitic limestone with shale partings and containing local brachiopod coquinas and coral debris. The lower Bois Blanc contains glauconitic sandy sediments. The Bois Blanc is Early Devonian (Emsian) in age (Uyeno et al, 1982; Telford and Johnson 1984). The Bois Blanc is separated from the overlying Onondaga Limestone by a sharp, limonite-stained unconformity.

Onondaga Formation. Edgecliff Member (5-6 m) - Crinoidal and coral-rich, variably cherty wacke- and packstones and biohermal limestone. Emsian-early Eifelian (Oliver, 1976; Uyeno et al., 1982). The lowest meter consists of interbedded crinoidal grainstone and green, shaly limestone. A second unit is highly variable in thickness along the eastern quarry walls due to the local development of favositid-rugose coral bioherms, particularly well developed in the northeast corner of the quarry (see Wolosz, 1990). The bioherms show abundant colonial rugosans: *Eridophyllum*, *Acinophyllum*, and large hemispherical and ramose favositids (Fig. 22).The bioherms locally rest on a thin greenish shale with fossil debris. They are draped by a cherty wackestone which locally pinches out over the tops of the "reefs"; a thin (5-10 cm) dark gray shale bedcaps the cherty interval and drapes the tops of the bioherms. The higher Edgecliff, above the bioherms, consists of crinoid rich shaly packstone with dark gray cheryt nodules, The highest ubits consist of non-cherty crinoidal grainstones.

135.9		Return to vehicles and <u>turn left (north)</u> out of parking area onto Ridgemount Road
137.2	1.3	Junction Bowen Road; <u>turn right</u>
138.1	0.9	Entrance to Queen Elizabeth Way (QEW) southbound to Peace Bridge
142.3	4.2	Ramp to Peace Bridge to USA
143.4	1.1	Customs booths; have passports ready; no toll this way
143.5	0.1	Ramp to I-190 south; <u>bear right</u>
145.3	1.8	Exit from I-190 to Rt. 5 west; bear right
145.6	0.3	Skyway; view of Buffalo Harbor
148.1	2.5	Tift Street
151.2	3.1	Enter Hamburg
152.2	1.0	Junction Mile Strip Road (Rt. 179) entrance ramp; <u>bear right</u> onto ramp
153.6	0.4	Ford Plant
154.7	1.1	Entrance to NY State Thruway (I-90); <u>turn left</u>
155.0	0.3	Fork for I-90 east and west; <u>bear right</u> onto I-90 west (south) Approximately 34 miles to Fredonia Exit.

END FIELD TRIP

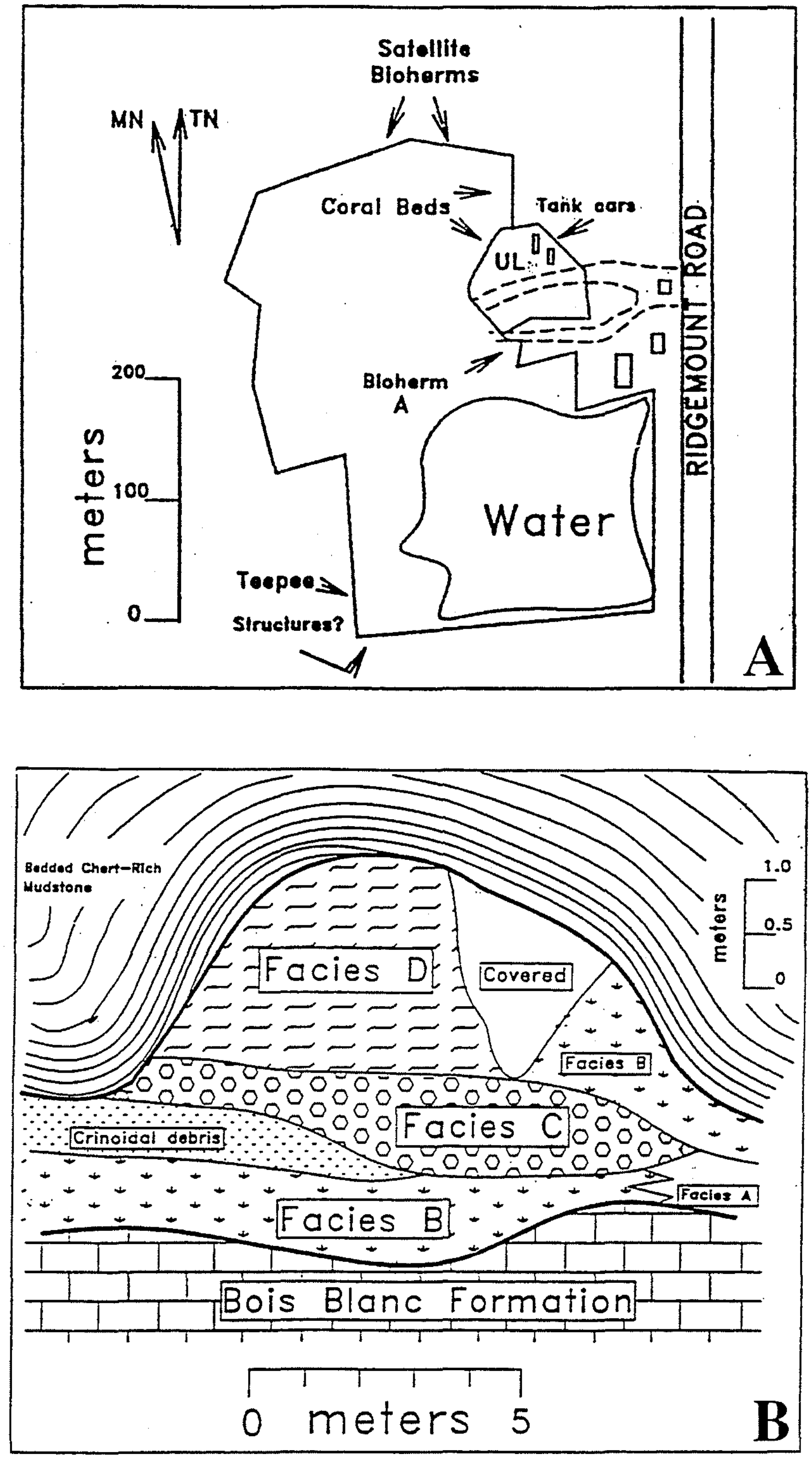

Figure 22. A) Map of Ridgemount Quarry. B) Detail of bioherm A; facies include: A) biostromal packston with intraclasts; B) *Acinophyllum* rich biostrome with small favositids; C) Large phaceloid colonial rugose corals and large solitary rugose corals; D) coral debris, include branching tabulates, *Acinophyllum* and solitary rugose corals; overlying beds are cherty wacke- and packstones with abundant large crinoid columns; these beds drape the bioherms. Adapted from Wolosz (1990).