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 (Fig.15). This second order "Wallbridge Unconformity" marks the boundary between the Tippecanoe and Kaskaskia supersequences (Sloss, 1963; Dennison and Head, 1975). It displays evidence of karst development, with irregular relief of up to 3 m. This unconformity apparently records a major late Early Devonian draw-down 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 (see Brett et al., 2000, for description of a similar surface in western New York). 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.

Lower to lower-Middle Devonian (Emsian-Eifelian) Sequences

The Emsian-early Eifelian succession in southern Ontario (Bois Blanc and basal Onondaga formations) consists of normal marine middle 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, phosphatic sandstone concretions. These sediments, termed Springvale Sandstone (Oliver, 1967), 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 crinoid-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 (Ver Straeten and Brett, 2000). They were ultimately drowned and buried by mud. Overlying Onondaga sediments are crinoid and small coral rich cherty packstones reflecting slightly shallowing conditions. The Onondaga and Bois Blanc show somewhat similar, though distinguishable faunas. They were regarded by Brett and Baird (1995) as representing separate ecological-evolutionary subunits.

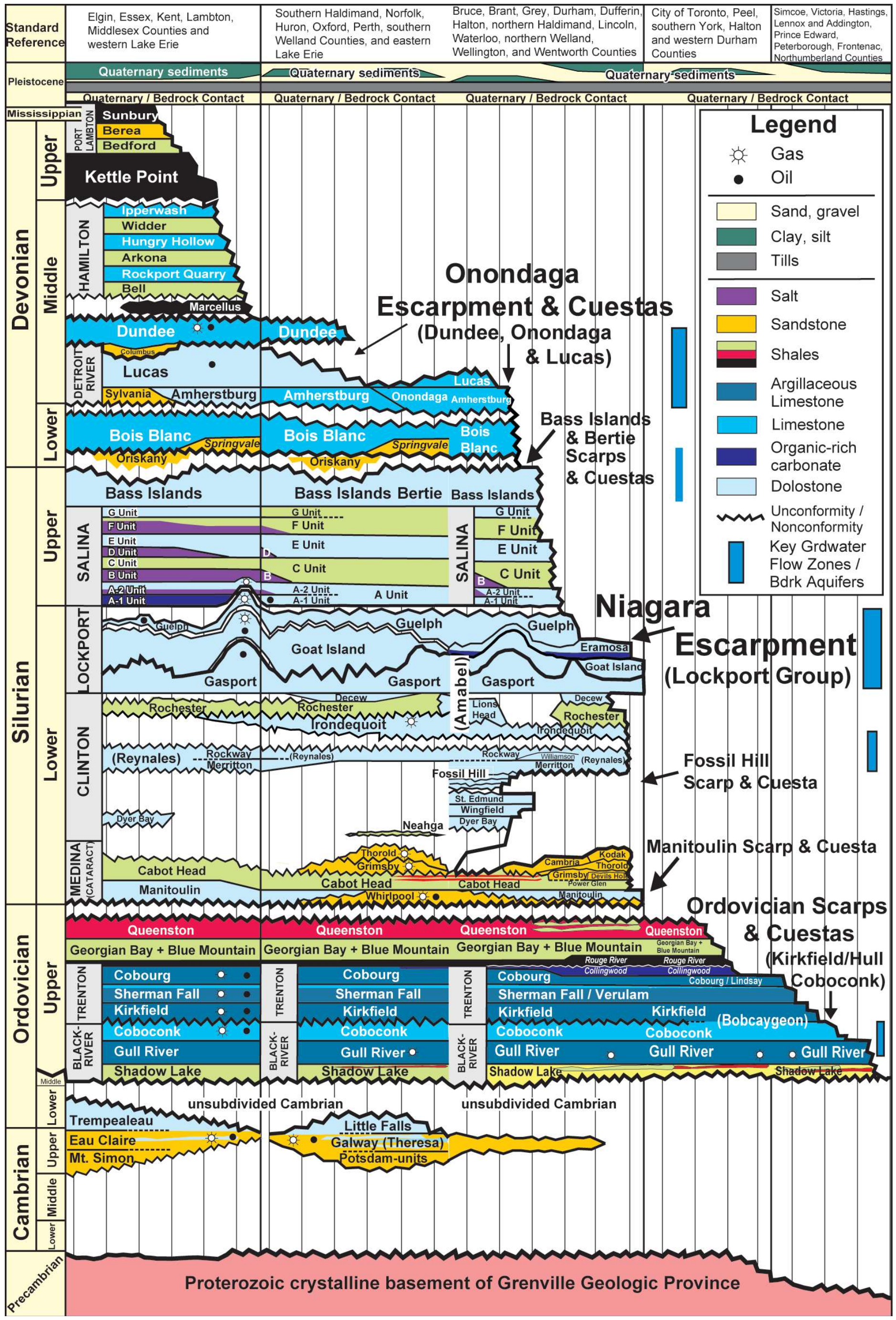

Figure 15. Revised terminology of Paleozoic strata for south-central and southwestern Ontario (*modified after* Winder 1961; Beards 1967; Winder and Sanford 1972; Armstrong and Carter 2010; Brunton et al. 2017; Carter et al. 2017). Group names are in capitals, members in italics, and abandoned or geographically restricted formation names in brackets (e.g., Amabel Formation, which comprises: Irondequoit and Rochester/Lions Head formations of Clinton Group and Gasport Fm and lower member of Goat Island Fm of Lockport Group, and Reynales which is older than Rockway and Merritton formations, but has been used for these terms away from Niagara region; Brunton and Brintnell 2011; Brunton et al. 2012). The change in position of the Ordovician–Silurian boundary is discussed in Bergström et al (2011) and Schröer et al. (2016). The relative thicknesses of rock units are not to scale.

EVENT STRATIGRAPHY

A number of beds in the sedimentary record reflect single unique episodes of sedimentcatastrophic events but also form excellent timelines 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 timelines 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 might correlate with probable K-bentonites 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, 2001; Brett and Ray, 2005). 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 pavements or shingled shells of flattish to gently concavo-convex brachiopod shells and oriented them in edgewise clusters over a large area of seafloor; several such horizons have been identified in the Silurian Rochester Shale in the Niagara region, Chinici et al. (2015).

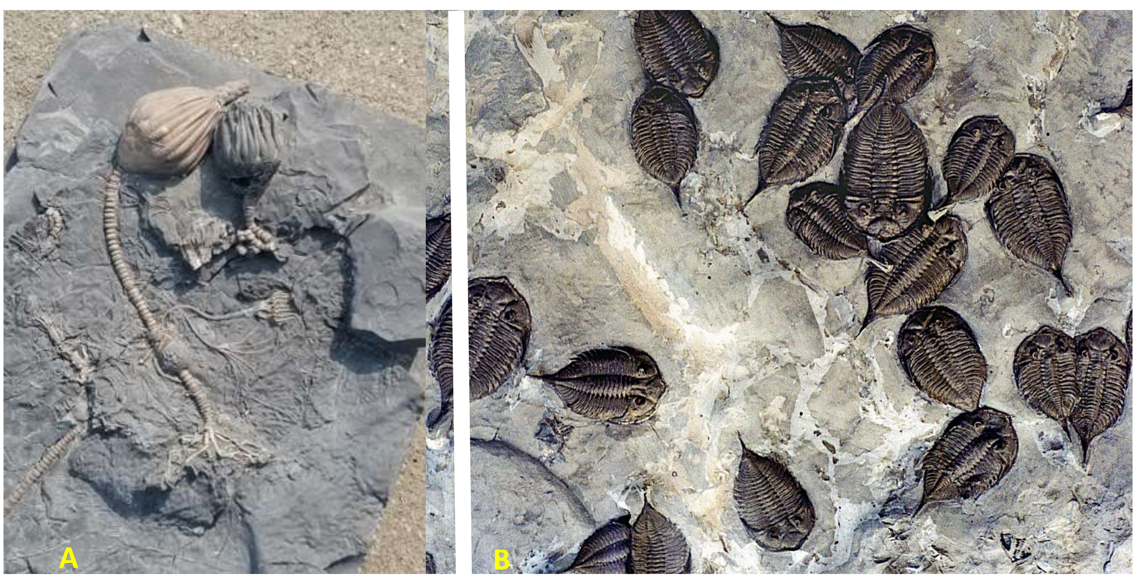

Figure 16. Obrution deposits from the Silurian Rochester Shale. A) complete specimens of *Eucalyptocrinites caelatus*; note holdfast with attached coral and two crinoids (*Dimerocrinites* sp.) attached to the column; surface covered with tiny columns of *Homocrinus parvus*; Jordan, Ontario. B) cluster of articulated *Dalmanites limulurus*, Middleport quarry, near Middleport, NY. Both views approximately X0.75. Photo A courtesy of Malcolm Thornley, Royal Ontario Museum; B courtesy of Paul Chinicni,

Among more distal events, several other types of tempestites have proved to be regionally extensive and traceable. Particular, thick calcisiltites with hummocky cross stratification have been traced for tens of kilometers 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; Fig. 16). 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 in a particular storm, resulting in mass mortality and widespread burial.

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. Such beds appear to be persistent on a regional scale, although local areas, sometimes termed "pools" show greatly increased numbers of specimens (see Ciurca,1973, 1990; Vrazo et al, 2016, 2017; Fig. 17). 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 (Vrazo et al., 2016). 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 briny condition of the sediments and pore waters may have aided in preservation of the chitinous exoskeletons by inhibiting chitinoclastic bacteria (Vrazo et al., 2017).

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; McLaughlin and Brett, 2004). Careful observation of these deformed intervals suggests 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 opposed to a 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 (Fig.17). The larger deformed masses, up to 2 m, across

Figure 17. Assemblage of articulated *Eurypterus remipes* from upper Silurian Phelps Member, Fiddlers Green Fm, Bertie Group. Herkimer, NY.

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 semi-plastic muds by loading. To date, this horizon has been traced from Niagara Gorge, near Lewiston, 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 (Fig. 18). The lower I 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) indicated that these folds do not show a consistent overturn direction. This suggests liquefaction possibly accompanied by some very local submarine sliding. Occurrences in the Upper Ordovician of the Virginia-Kentucky region by Pope et al. (1997) and McLaughlin and Brett (2004, 2006) indicate that such widespread deformation over areas of a few tens of square kilometers would accompany large earthquakes with magnitudes greater than 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 Appalachian foreland basin was not tectonically quiescent through the Silurian (see Ettensohn and Brett, 1998).

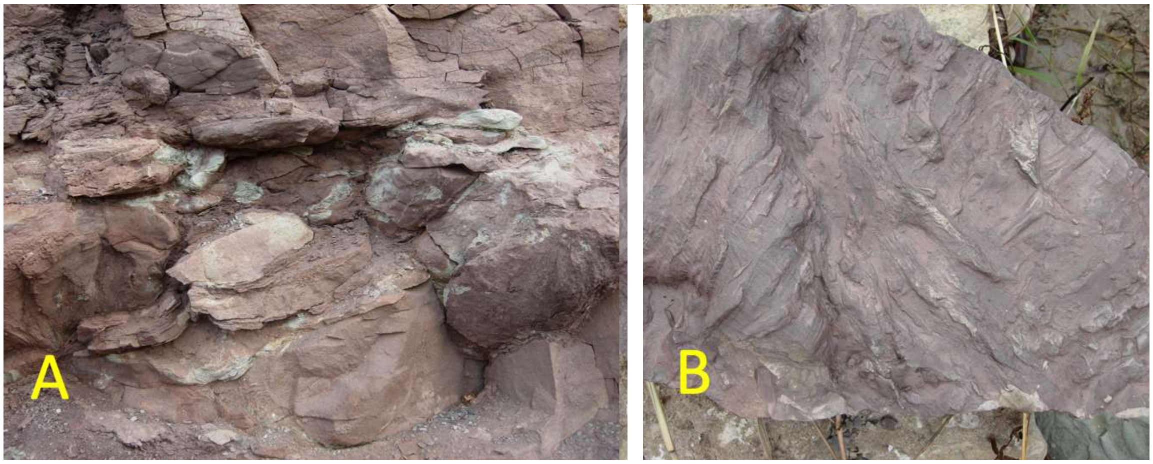

Figure 18. Soft sediment deformation in the upper Grimsby Formation interpreted as seismites. A) Ball and pillow red sandstone on shale; view is 1 m across. B) casts of shock cracking of muds and/or stretch marks on the base of pillow. Niagara Gorge ~0.5 miles S of Lewiston, NY

Lower Silurian deformed beds correspond with formation of shale basins and occurrence of K-bentonites (Fig. 18,19). The timing and degree of tectonic loading of the Laurentian cratonic margin during the Silurian has been established by analyzing the distribution of dark shale basins (Goodman and Brett, 1994). Ettensohn and Brett (2002) use the distribution of dark shale basins in the early Llandovery to recognize a late tectophase of the Taconic orogeny. Recent field work has recovered a series of thin altered volcanic ash deposits (K-bentonites) from this interval as well. It is significant that the only deformed beds of the Llandovery (Grimsby and Thorold formations), for that matter since the Upper Ordovician early Maysvillian stage (~5 million years older), are coincident with these indicators of resumed tectonism. Similarly, Wenlock strata were deposited during the so-called "Salinic orogeny" (Ettensohn and Brett, 1998), a period noted for widespread formation of dark shale basins, though with different geometries than Taconic basins. Recent field work has also recovered a series of thin K-bentonites from Wenlock age strata in eastern North America. Again, we emphasize that the reappearance of widespread deformed beds is coincident with the appearance of these shale basins and K-bentonites.

Figure 19. Deformed beds of laminated intraclastic sandy DeCew Dolostone including isoclinal fold sets to left of hammer suggesting plastic flow on slope during seismic shock at Devils Hole, Niagara Gorge, NY

PALEONTOLOGY AND PALEOECOLOGY

Silurian Faunas

The diverse and well-preserved faunas of the Silurian of western New York have been well documented since the time of James Hall (Hall 1852). Diverse and exceptionally well-preserved invertebrates are noted especially from the Rochester Shale; these include rugose and tabulate corals, bryozoans, brachiopods, mollusks, trilobites, echinoderms and graptolites (Figures 20 to 23). Recently the diverse Rochester Shale faunas with more than 200 species have been beautifully illustrated and documented (Chinnicci and Smith, 2015).

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 (EESUs) in the Silurian of the Appalachian Basin; these correspond very roughly to depositional sequences and were termed EESU: 1) Medina; 2) Lower Clinton; 3) Upper Clinton- Lockport; and 4) Salina 5) Keyser faunas. The latest Silurian-Early Devonian E-E subunits (Helderberg and Esopus) are absent from the study area due to erosion at the Wallbridge Unconformity. However, diverse coral and brachiopod faunas of the Schoharie (8) and Onondaga (9) stable faunas are well represented in the Bois Blanc and Onondaga formations in the study area.

BENTHIC ASSEMBLAGES

Throughout the early to middle Silurian marine waters in the foreland basin and mid- continent platform were of normal salinity and diverse invertebrate faunas formed a series of depth-related, onshore-offshore biofacies. These biofacies formed extensive belts parallel to paleoshoreline (Figs. 17-20) (Brett, 1999) that have been termed Benthic Assemblages; by Boucot (1975). Benthic assemblages have been calibrated to approximate absolute depths by Brett et al. (1993). Following that model, Benthic Assemblage- (BA-1) constitutes peritidal biofacies typically dominated by lingulid brachiopods (20.16), bivalves, gastropods, or, in carbonates, stromatolites/thrombolites and ostracodes (Fig. 22.7). BA-2 represents shallow, inner shelf sediments dominated by low diversity brachiopod associations (especially *Eocoelia* in the Early Silurian), as well as tabulate coral and stromatoporoid biostromes and bryozoan bioherms (Figs.20, 23). 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 deep storm waves and typified by diverse assemblages of brachiopods, bryozoans, trilobites, mollusks, and pelmatozoan echinoderms (Figs 20-23). BA-5 comprises deeper shelf settings below storm wave base and is characterized by small brachiopods, a few bivalves, and, in some areas, graptolites (Figs. 22, 23). These benthic assemblages have proven to be widely mappable and useful in determining relative depths of the interior seas (Johnson, 1987; Brett, 1999). 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; Figs. 21, 23).

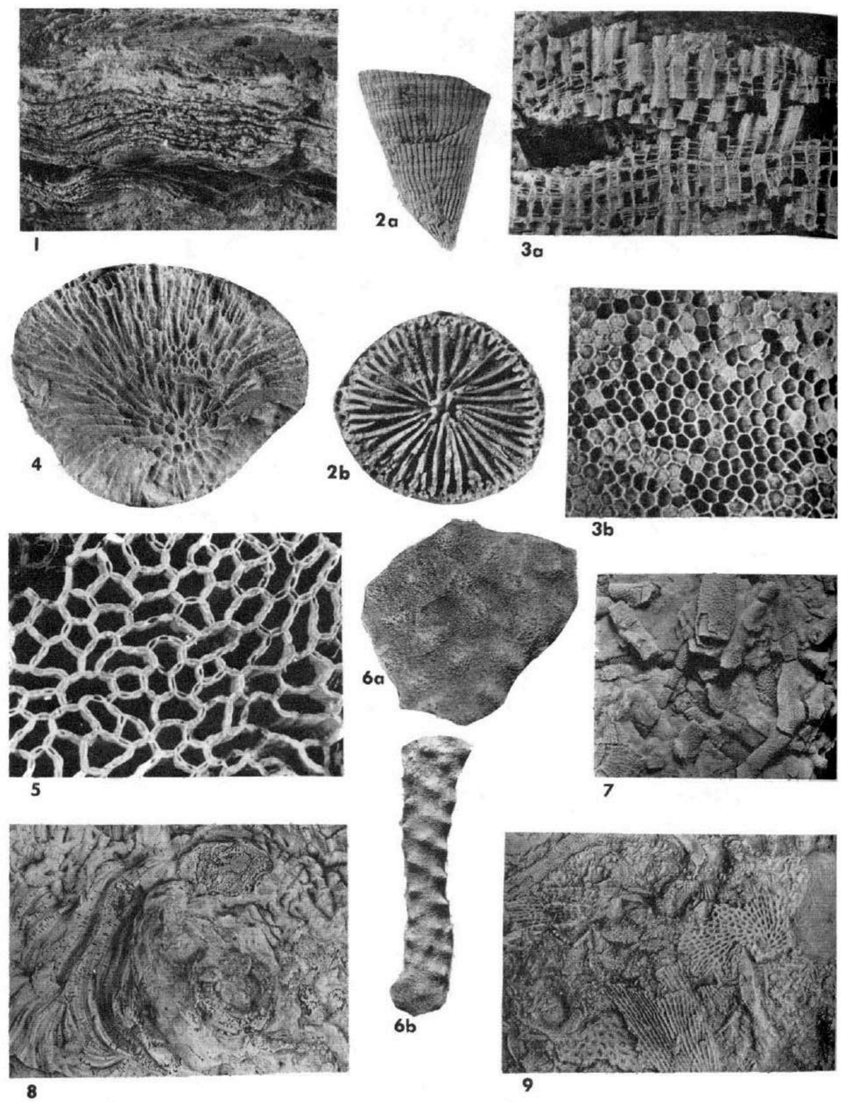

Figure 20. Niagaran (Middle Silurian) Fossils: Phyla Porifera (stromatoporoids); Cnidaria (corals); and Bryozoa (moss animals). From Brett (1981b).

1. *Clathrodictyon* sp. Lateral view of a stromatoporoid colony; note laminar structure; colonies of stromatoporoids now thought to be related to modern sclerosponges, are common in the Lockport Group where they may attain sizes upwards of two feet in diameter and form local patch reefs: Univ. Michigan Museum Paleontology (UMMP) 3712; X3.75.

2a. *Enterolasma caliculum* (Hall). Side view of a common rugose or horn coral, a solitary coelenterate skeleton found abundantly in the Clinton and Lockport groups, X.75.

2b. Top view of the calyx of *Enterolasma* sp. showing prominent radially arranged septa which represent partitions between folds in the body of the coral animal; they ·are arranged in multiples of four in the rugose corals; UMMP 51343; Xl.5.

3a, b. *Favosites niagarensis* (Hall).

a.) View of a typical Silurian favositid tabulate coral colony, note the partitions (tabulae) which subdivide the individual coral skeletons revealed in the cross section; such corals are abundant in the Lockport Group; UMMP 57014; X2.25.

b.) Top view of the same specimen showing close packing of hexagonal corallites (individual skeletons) to form a honeycomb-like colony; X2.25.

4. *Favosites pyriformis* (Hall). A hemispherical small coral colony found abundantly in the Rochester Shale; Xl.5.

5. *Halysites* cf. *H. catenularia* (Linnaeus). Top view of a chain-like array of tabulate coral corallites; note that the large, irregular dark areas are not corallite but are merely open spaces in the colony; corallites are much smaller. This tabulate coral occurs in the Lockport Group associated with *Favosites* in small patch reefs; UMMP 6402; X3.75.

6a,b *Trematopora tuberculata* Hall. A twig-like stony bryozoan colony skeleton.

a.) Enlargement of colony showing minute polygonal openings (zooecia) which were occupied by filter feeding bryozoan animals (zooids) during life; X2.25.

b.) View of the colony; note twig-like form and raised knob-like areas (monticules); Xl.5.

7. *Chilotrypa* sp. Another of the twig-like bryozoans; *Trematopora, Chilotrypa* and other bryozoans make up thin limestones called bryozoan beds in the Rochester Shale; these represent the remains of local patches of bryozoan growth on the sea floor; Xl.5.

8. *Fistulipora* sp. A sheet-like encrusting type of bryozoan which formed mats on the ancient sea floor and aided in trapping sediments to form small bioherms ("reefs") at the Irondequoit- Rochester contact; Xl.5.

9. A slab of limestone from bryozoan beds of the Rochester Shale, illustrating various kinds of lacy bryozoans as well as twig-like forms; (upper left: *Fenestella;* lower left and upper center:*Phylloporina;* lower center: *Semicoscinium);* X.75.

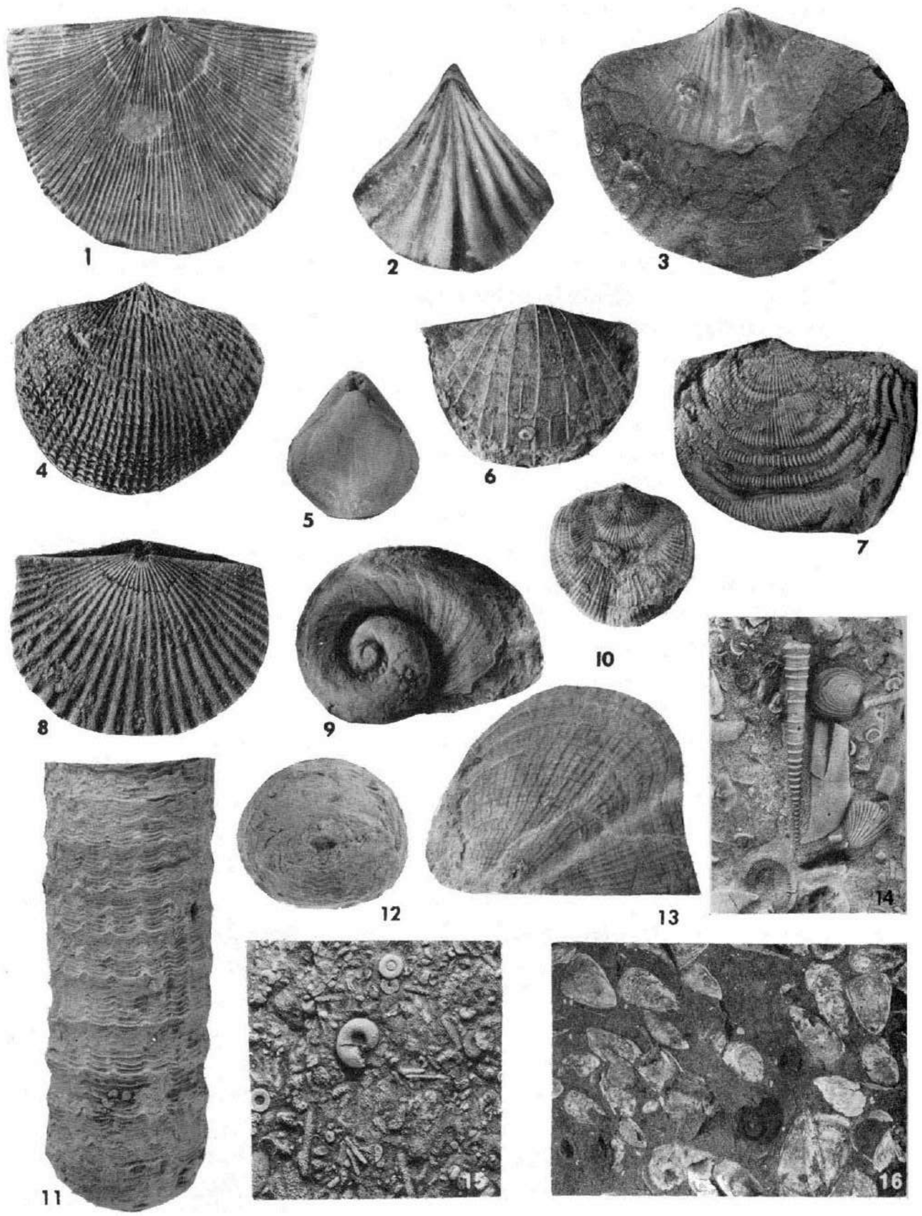

Figure 21. Niagaran Fossils. Phyla Brachiopoda (lamp shells) and Mollusca (Gastropoda: snails; Bivalvia: clams; Cephalopoda: nautiloid). From Brett (1981b)

1. *Coolinia (Fardenia) subplana* (Hall). A large piano-convex brachiopod (strophomenid) abundant in the middle and upper Rochester Shale; X.75.

2. Rhynchotreta americana (Hall). Brachial valve view of a complete (articulated) specimen; a rhynchonellid brachiopod; note very strong ribs or plications; Xl.5.

3. *Striispirifer niagarensis* (Conrad). Pedicle valve of a spiriferid brachiopod which occurs in small clusters in some beds of the lower Rochester Shale; note the presence of edrioasteroids *(Hemicystites parasiticus* Hall), a type of attached echinoderm, (see fig. 6-3) which have grown on the brachiopod shell; X1.5. Specimen from the Springer Collection of the U.S. National Museum.

4. *Atrypa reticularis* Linnaeus. A spiriferid brachiopod very abundant in the Clinton Group
and found in many Middle Silurian rock units around the world; Xl.5.

5. *Whitfieldella nitida* (Hall). Brachial (dorsal) view of a complete specimen; note opening(foramen) for pedicle at the tip of the beak and lack of ribs; X.75.

6. *Eoplectodonta transversalis* (Sowerby). A small concavo-convex strophomenid brachiopod which probably lived partially buried in muddy sediment; lower Rochester Shale; Xl.5.

7. *Leptaena rhomboidalis* (Wilkens). A concavo-convex brachiopod characterized by a strongly corrugated shell, very widespread in Silurian rocks; Xl.5.

8. *Dolerorthis* cf. *flabellites* (Foerste). A strongly ribbed orthid brachiopod found in the lower
Rochester; Xl.5.

9. *Naticonema niagarense* (Hall). Top view of a gastropod or snail common in the Clinton and Lockport groups; Xl.125.

10. *Resserella elegantula* (Dalman). Dorsal view of a small semicircular convexoplane brachiopod abundant in parts of the Rochester Shale; Xl.5.

11.12 *Dawsonoceras americanum* (Foord). Nautiloid cephalopod shell which attained lengths up to two feet; 11, side view; 12, end view of chamber showing siphuncle. The large, fluted shell is found in the Clinton and Lockport groups (this specimen from Silurian Waldron Shale at Newsom, Tennessee); UMMP 1968/5-1; X.375.

13.*Cornellites emaceratum* (Conrad). A bivalve mollusk or clam common in the Rochester Shale; Xl.5.

14.*Tentaculites* sp. The conical shell of an extinct worm-like organism associated with brachiopods, fragments of trilobites, crinoids and ostracodes; upper Rochester Shale; X3.75.

15. Pleurotomariid snail with associated twig-like bryozoans *(Helopora)* and crinoid columnals, Artpark Phosphate Bed, X1.5.

16. *Lingula cuneata* Conrad. Inarticulate brachiopod common in certain beds of the Grimsby Sandstone; note whitish appearance of the phosphatic shells and associated small snail (right of center); a very shallow near-shore environment is inferred; X.75

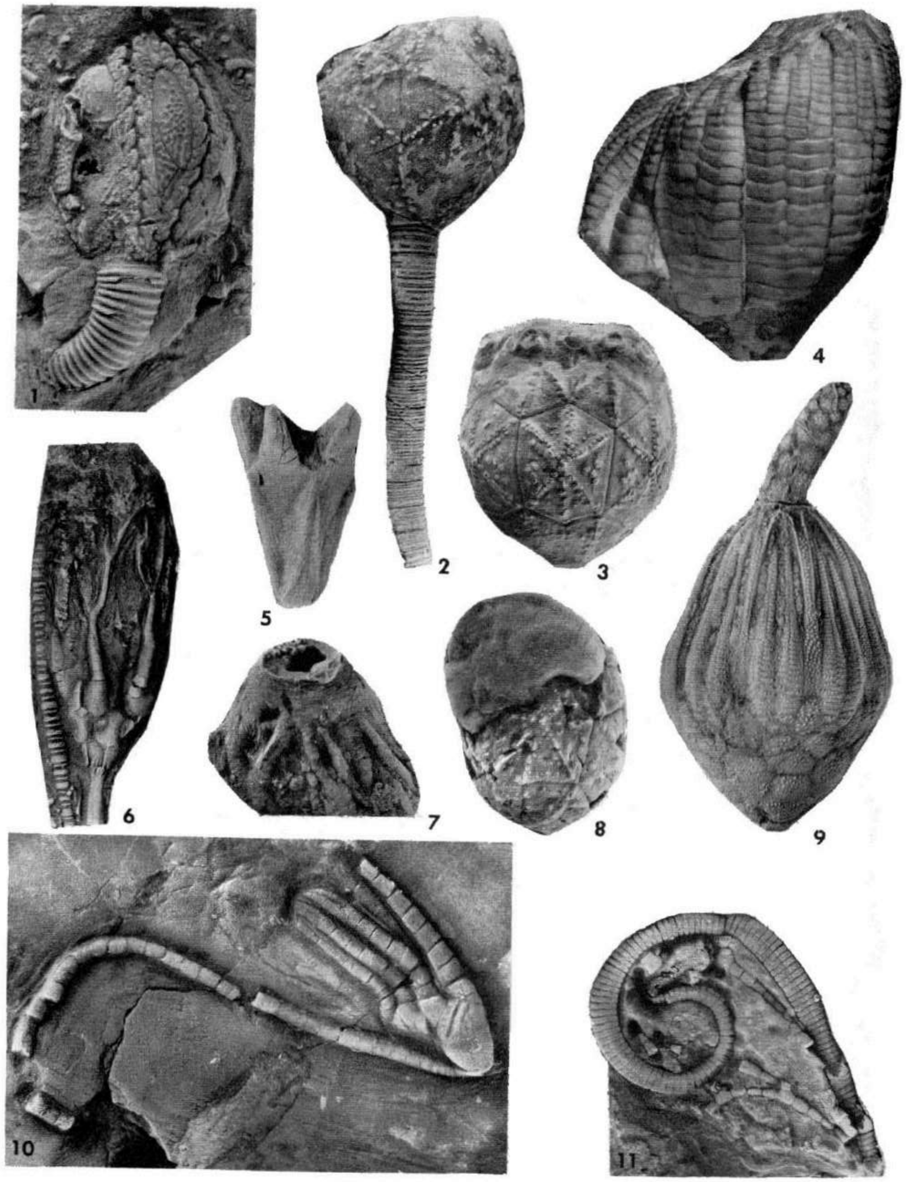

Figure 22. (Niagaran fossils. Phylum Echinodermata. From Brett (1981b).

1. *Callocystites canadensis* Billings. A rhombiferan cystoid; note ambulacral (food) grooves on the sides of the theca; also note elliptical-shaped pore rhombs, which are thought to have been respiratory structures. Specimen from Rochester Shale at Grimsby, Ontario, UMMP 47190; Xl.6.

2, 3. *Caryocrinites ornatus* Say. The theca and stem of the most abundant Niagaran cystoid; the nut-like thecae of this species occur abundantly in the lower Rochester Shale in Niagara Gorge; note large hexagonal plates with radiating series of pores that lead to internal rhombs, UMMP 63092; Xl.6.

3. *Jcthyocrinus laevis* Conrad. The crown (calyx and arms) of a large flexible crinoid (Subclass Flexibilia) which occurs rarely in the lower Rochester Shale. Specimen from collection of M. Miecznikowski; Xl.2.

4. *Stephanocrinus angulatus* Conrad. A pyramidal theca of a stemmed echinoderm of uncer- tain classification, somewhat resembling a blastoid; these pyramidal thecae are among the most abundant echinoderm remains in the lower Rochester Shale; note prong-like structures at the top of the theca possibly used for respiration; Xl.2.

5. *Dendrocrinus celsus* (Ringueberg). Crown of an inadunate (cladid) crinoid showing slender branching arms and stem; from a colony of crinoids in the upper Rochester Shale at St. Catharines, Ontario; Royal Ontario Museum, Toronto (ROM) 35835; Xl.6.

6. "Root" or holdfast of *Caryocrinites;* such root-like structures were utilized in anchoring the cystoids on the sea bottom; common in Rochester and Gasport formations; Xl.6.

7. *Caryocrinites ornatus* Say and *Platyceras niagarensis* Conrad. In this unusual specimen a commensal snail has been preserved in living position as it attached over the anal vent of a cystoid; the snail apparently fed on fecal material discharged by its host; Rochester Shale; Xl.2.

8. Eucalyptocrinites caelatus (Hall). Crown of a camerate crinoid; note bowl-shaped calyx, numerous arms, and elongate anal proboscis; from a colony of well-preserved crinoids; lower Rochester Shale at Jordan, Ontario; ROM 35832K; Xl.2.

9. *Calceocrinus chrysalis* (Hall). Side view of a specialized inadunate crinoid; these crinoids had columns which lay horizontally on the sea bottom (as in orientation of the photograph); the crown (right side) was hinged on the stem and could be rotated upward into favorable currents for feeding; ROM 35735; Xl.6.

10. Crinobrachiatus brachiatus (Hall). Another unusual inadunate crinoid, common in the lower Rochester Shale; in this form the column was recurved, enclosing the small fragile crown within the coil; note side branches or cirri, probably used for attachment; Xl.6.

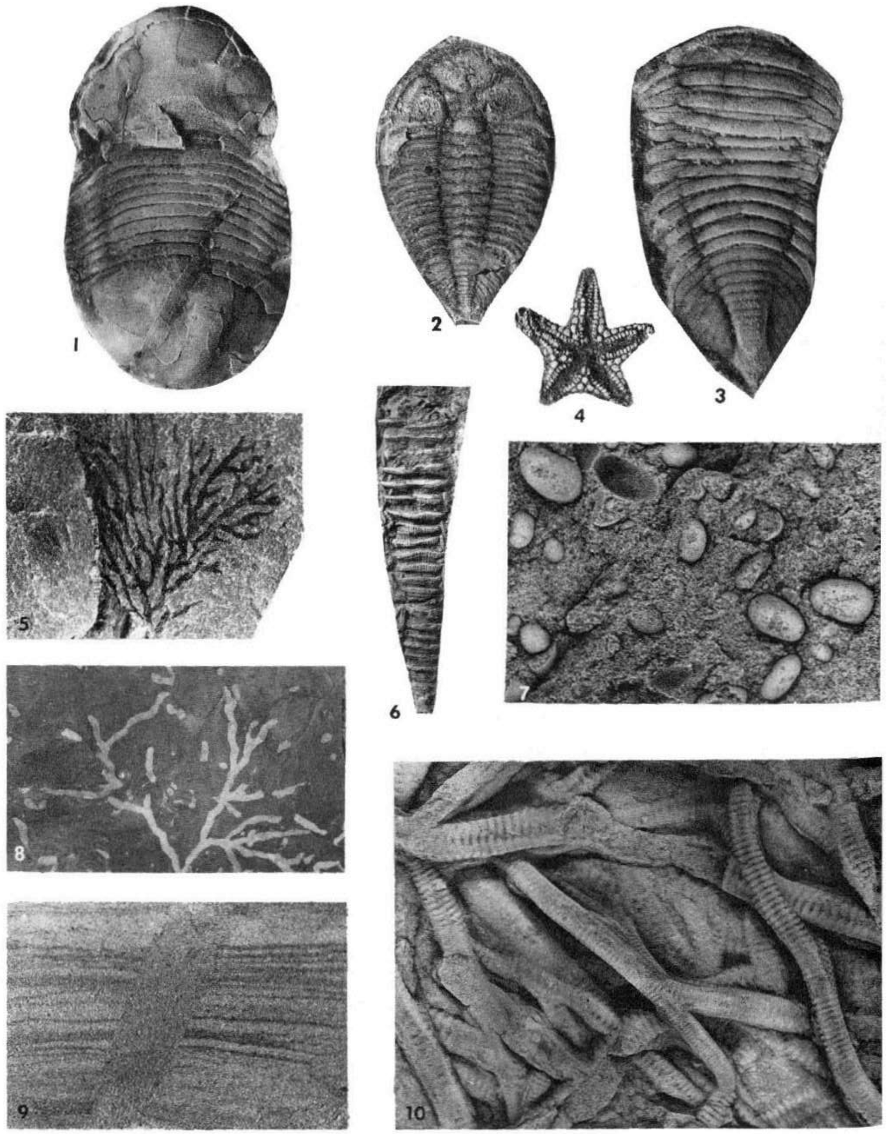

Figure 23. Niagaran fossils: Echinodermata (starfish or asteroid); Arthropoda (trilobites and ostracods; Annelida (worm tubes); Hemichordata (graptolites); and trace fossils. From Brett (1981b).

1. *Bumastis ioxus* Hall. Effaced (subdued axial lobe), rounded cephalon (head shield) and pygidium (tail shield) and the broad central (axial) lobe; X 1.0

2. *Dalmanites limulurus* (Green) one of the best known and most widespread Silurian trilobites, characterized by well- developed eyes, a pygidial spine and long genal spines

3. *Trimerus delphinocephalus* Green. A trilobite, which is commonly quite large (>15 cm), with triangulate pygidium and cephalon and broad axial lobe, perhaps adapted to digging in sediment, often associated with *Dalmanites*; X0.75.

4. *Mesopaleaster granti* Schuchert. A starfish from the Lower Silurian Power Glen Formation at Balls Falls, Jordan, Ontario; Xl.5

5. *Dictyonema retiforme* (Hall). A bushy or dendroid graptolite, comprising the carbonized tubes of a colonial, probably filter-feeding organism which may be related to modern pterobranchs, a distant relative of animals with a well-developed dorsal nerve cord and backbone, the vertebrates; graptolites such as this are common in lower Rochester Shale; Xl.5.

6. *Cornulites* cf. *niagarensis* Hall. The conical limy tube possibly secreted by a fan-worm; note strengthening rings; Xl.5.

7. *Leperditia* sp. Bean-shaped valves of a relatively large ostracode common in some layers of the Grimsby Formation; X2.25.

8.*Chondrites* sp. A trace fossil once believed to be the remains of a plant; probably produced as feeding burrows of a soft-bodied worm-like animal; X 0.75.

9. Trace fossil. Vertical burrow, cutting across laminae, in a slab of sandstone from the Power Glen Formation; this probably represents the living site of an infaunal suspension feeding organism; X1.5.

10. *Arthrophycus harlani.* Horizontal feeding burrows of a worm-like organism; very abundant in some beds in the upper Grimsby; X0.75

During Late Silurian (Cayugan or Pridolian) epeiric seas in the Appalachian and Michigan basins became restricted by barriers of the Bloomsburg elastic wedge (to the occupied open shelf environments. In estuarine areas, where freshwater streams mixed with the hypersaline environments, distinctive brackish water biofacies developed (Clarke and Ruedemann, 1912; Ciurca, 1990). These peritidal (BA-1 to 2) biofacies were dominated by eurypterids, and a few species of ostracodes, mollusks and algae. Only in the latest Silurian were normal marine salinities partially restored in the Appalachian Basin.

Figure 24. Reconstruction of the seafloor of western New York during deposition of the mid Silurian Rochester Shale. Photo courtesy of Emily Damstra; from Brett (2015).

BIOSTROMES AND BIOHERMS

Organic buildups, including small coral- stromatoporoid or algal mud mounds, thrombolites, stromatolites, and larger scale reef structures, 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; Fig. 25). 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 extending upward up to 6m 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 extending upward into thin bedded middle Goat Island Formation (Brett et al., 1995). Not only are these horizons persistent over substantial distances in the New York-Ontario outcrop belt, similar thrombolitic mounds are present in probably correlative horizons in the McKenzie Shale in Pennsylvania to West Virginia (Brett et al., 1990). In a comparable way, small tabulate-rugosan bioherms in the Middle Devonian Onondaga Formation commence at the top of a grainstone layer low in the Edgecliff Member and extend up into shaly, to cherty micritic limestones. These bioherms also occur in this position consistently in the Niagara region and into central New York (Crowley and Poore, 1974; Woloscz, 1990).

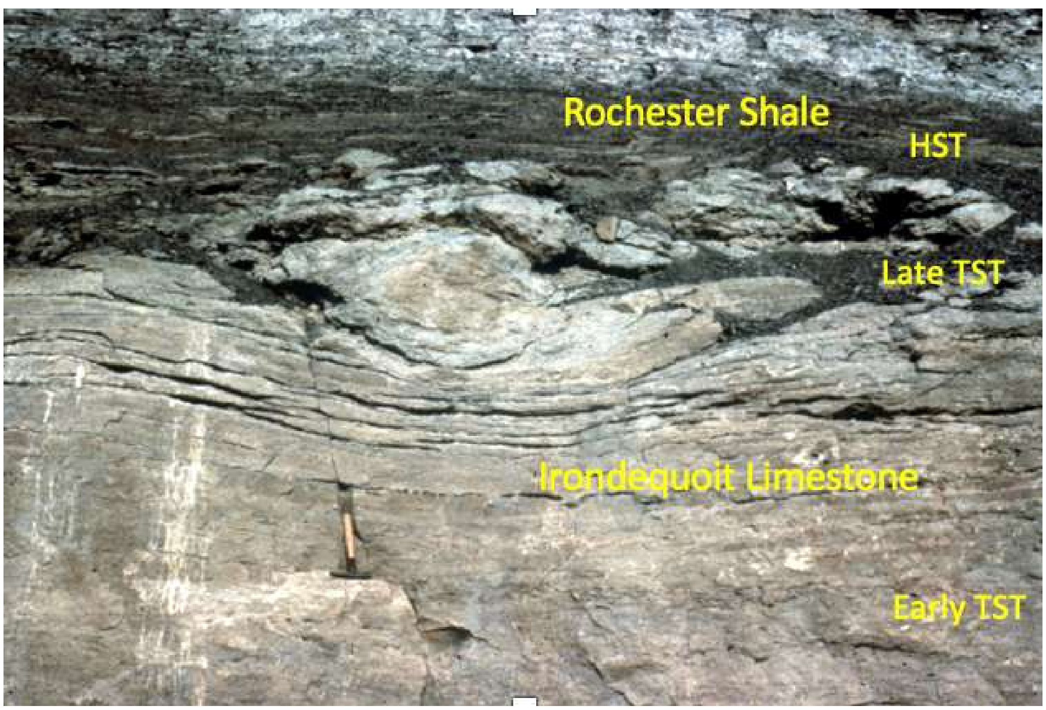

Fig. 25. "Sarle reef": small micritic-fistuliporoid bryozoan bioherm at contact between Irondequoit grainstone and Rochester Shale; inferred maximum starvation interval; Niagara Gorge 0.25 mi south of Lewiston-Queenston bridge.

Finally, very persistent zones of large stromatolites and thrombolites (non-laminated algal mounds) occur at several horizons, especially near the base of the Salina Group (Brett et al., 1990, 1995; Fig. 14) and in the lower Fiddlers Green Formation of the Bertie Group (Ciurca, 1990).

Obviously, these 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 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 accommodation 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 turbidity 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 common burial of bioherms by thin, shaly sediments of deeper water facies.

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.

These strata have been studied extensively from the standpoint of sequence and event stratigraphy (Duke and Fawcett 1987; Brett et al. 1990; Goodman and Brett, 1994; Brett et al., 1998). About nine unconformity-bound strata) 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.

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