STRATIGRAPHY AND FACIES VARIATION OF THE ROCHESTER SHALE (SILURIAN: CLINTON GROUP) ALONG NIAGARA GORGE

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INTRODUCTION

The linear, east-west configuration of Paleozoic outcrop belts in western New York and Ontario imposes a strong two-dimensionality on our knowledge of the stratigraphy and facies relationships of these rocks. It is frequently assumed that the outcrop sections provide a reasonable transect from near shore clastic-dominated facies in the east to offshore carbonates and marine muds in the west. This view is overly simplistic and it ignores the fact that the Paleozoic epeiric seas had a northern as well as an eastern shoreline (directions based on modern geography). Furthermore, the idea of a simple east-west transect is contradicted by detailed examination of stratigraphy in western New York. Stratigraphic sequences such as the Silurian Clinton, Lockport, or Salina Groups exhibit vertical facies changes, manifest in the gradational contacts between beds, members, or formations. Walther's law predicts that such vertical sequences of litho- and biofacies should mirror arrays of laterally adjacent, contemporaneous facies belts. However, lateral gradation of lithologies is rarely observed along the outcrop belt of western New York. Rather, one observes that thin stratigraphic units representing distinctive facies, are traceable along the strike of the outcrop belt for tens to hundreds of miles (see, for example, Belak, 1980).

This "layer cake" aspect of New York stratigraphy has facilitated local correlation. However, it has also led to a common impression that the strata represent vertical stacking of time parallel facies units in a three dimensional sense, implying basinwide environmental changes. This non-Waltherian view of western New York stratigraphy is probably erroneous and it has greatly hampered attempts to decipher facies relationships and depositional environments. I contend that it is largely an artifact resulting from the east-west trend of the modern outcrop belts.

Niagara Gorge provides the longest continuous north-south section of Silurian rocks in western New York. As such, this exposure permits detailed examination of strata along a 10 km section normal to the dominantly east-west trending Niagara escarpment. Curiously, few, if any, previous workers have examined this transect in any detail, perhaps because of the general inaccessibility of exposures in the southern end of Niagara Gorge. Recent detailed examination of Silurian rocks in the gorge (Brett, 1978; in press) provide important new insights into understanding facies relationships and interpreting paleoenvironments. Most importantly, these studies indicate that facies belts within the Rochester Shale, and probably other units, are elongate east-west and subparallel to the present outcrop belt in western New York and the Ontario Peninsula. This single factor provides an important key for the development of a depositional model for the Rochester Shale, and perhaps other units with apparent "layer cake" stratigraphy. The present field trip examines various aspects of the stratigraphy and facies relationships of the Rochester Shale along Niagara Gorge (Figs. 1,7).

GEOLOGIC SETTING OF THE ROCHESTER SHALE AND ASSOCIATED FACIES

The medial Silurian Rochester Shale (Wenlockian; Clinton Group) is a classic unit in American stratigraphy, being among the first formally designated formations in North America (Hall, 1839, p. 20). This formation has been widely correlated in the northern and central Appalachian region, and serves as an important stratigraphic marker in subsurface studies (Schuchert, 1914; Chadwick, 1918; Caley 1940; Gillette, 1940, 1947; Berry and Boucot, 1970). The Rochester Shale is also noted as an important source of fossils; over 200 species of invertebrates have been reported from the unit, including some of the best preserved Silurian fossils in North America (Hall, 1852; Ringueberg, 1888; Grabau, 1901; Sarle, 1901; Bassler, 1906; Springer, 1920, 1926; Brett, 1978).

Yet, despite its historical, stratigraphic and paleontologic significance, the Rochester Shale has received little recent study. Preliminary studies of Rochester depositional environments and paleoecology were undertaken by Thusu (1972) and Narbonne (1977); however these papers are restricted in geographic scope, and their conclusions necessarily generalized and tentative.

In New York State and Ontario, the Rochester Shale constitutes the middle unit of three formations of the upper Clinton Group (Bolton, 1957), (Figs. 2,3). Throughout much of its extent, the Rochester is underlain conformably by the upper member of the Irondequoit Limestone - a light gray to pinkish gray crinoidal biomicrite or biosparite.

From Hamilton, Ontario eastward to Rochester, New York, the Rochester Shale is overlain by fine-grained, buff-colored DeCew Dolostone. Early workers, (Ulrich, 1911; Schuchert, 1914; Chadwick, 1918) postulated a major disconformity between the Rochester and DeCew but the completely gradational nature of the contact in nearly all localities argues against this. For this reason, the boundary between the Clinton and Lockport groups is now generally drawn at the sharp upper contact of the DeCew with the overlying Gasport Limestone in western New York (Gillette, 1947; Bolton, 1957). Crowley (1973) and Nairn (1971) have demonstrated that Gasport and DeCew are also gene-

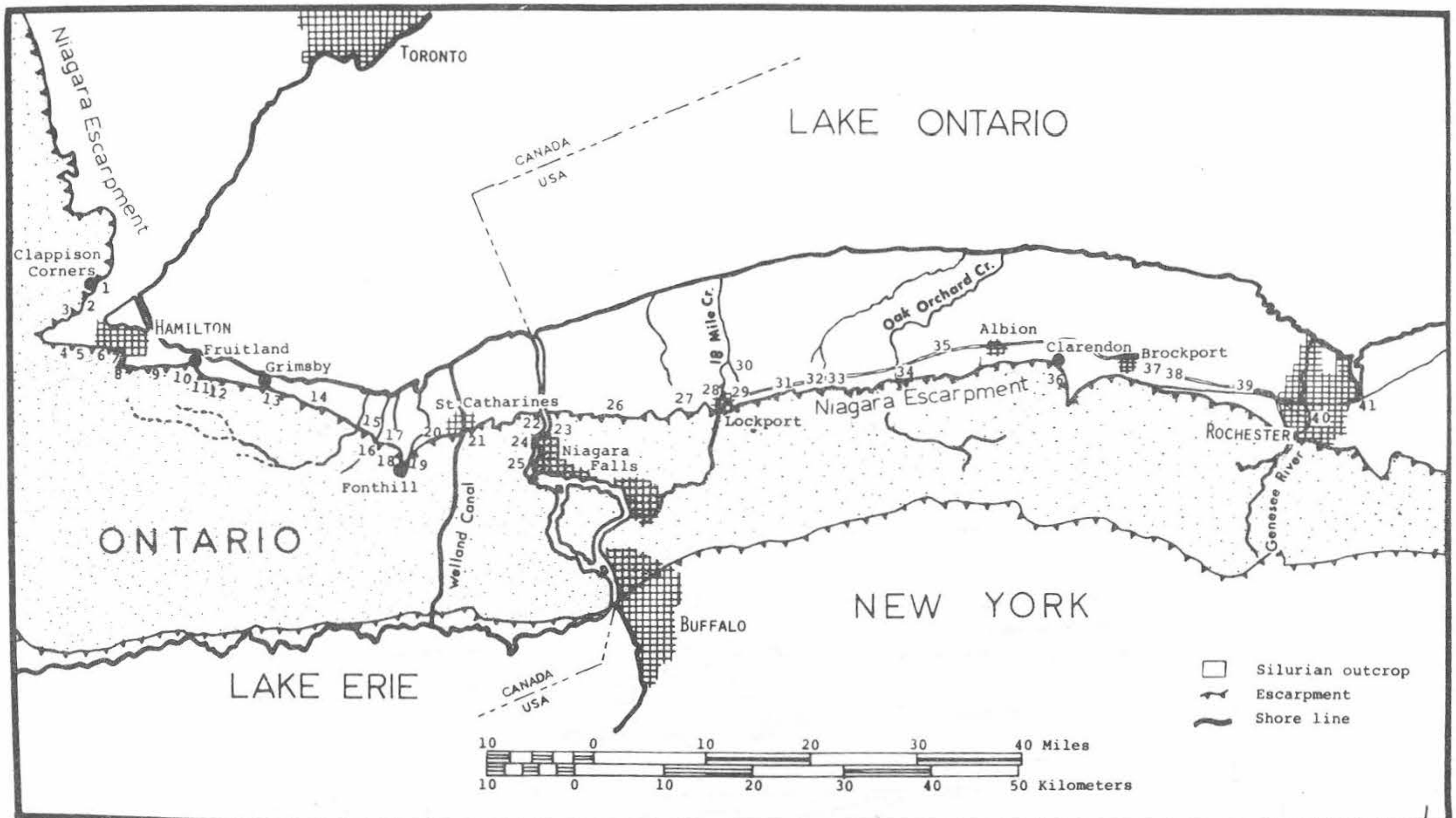

FIG. 1.--Location map for stratigraphic sections of the Rochester Shale in western New York and Ontario. Numbers refer to localities discussed in the text (Localities described in Appendix A of Brett, 1978).

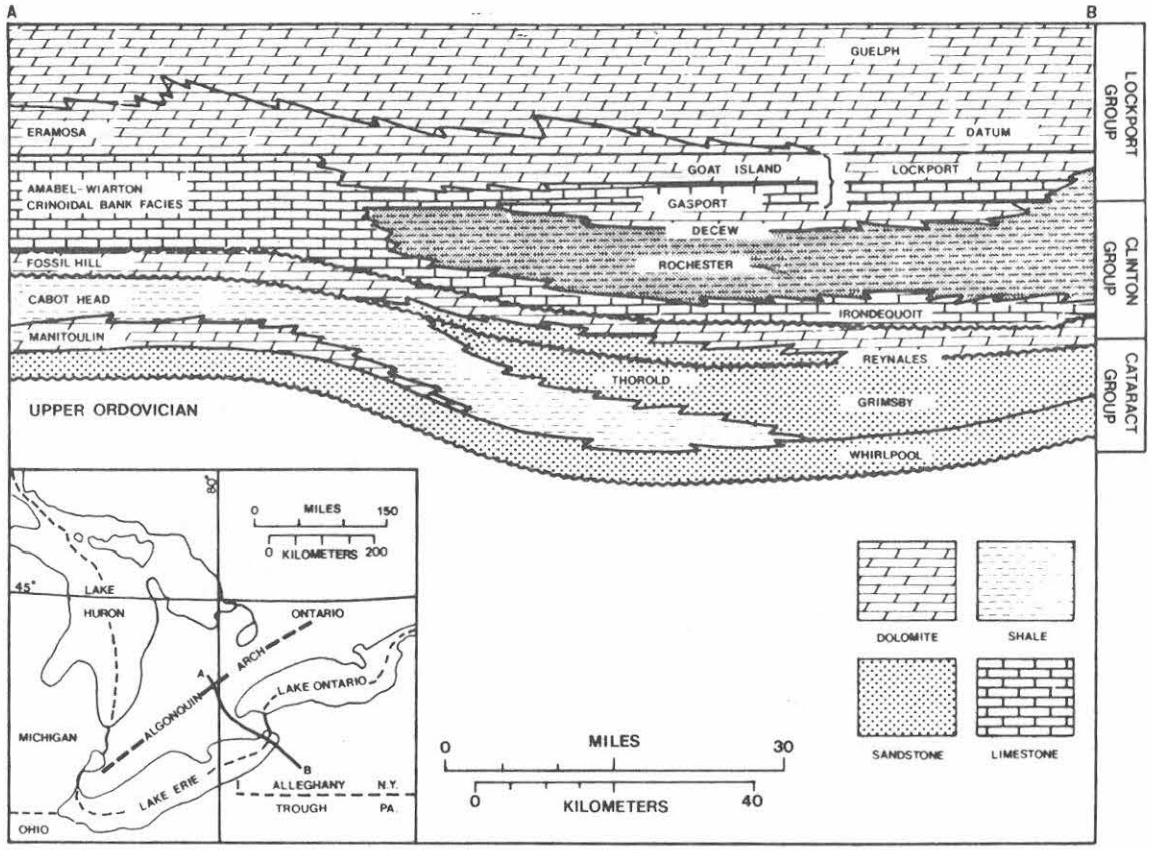

FIG. 2.--Cross-sectional diagram of the upper Clinton-lower Lockport Groups in Ontario and western New York; orientation of section line is indicated on the inset. Modified from Sanford (1969).

tically related facies so that the differentiation of Clinton and Lockport Groups is arbitrary.

The Rochester Shale consists of medium to dark-gray calcareous shale and thin limestones including micrites, pelmicrites, biomicrites, and intramicrites (Thusu, 1972). Along the outcrop belt in New York and Ontario, the Rochester thickens southeastward from a minimum of 0.6 m (2 ft) at Clappison Corners, Ontario, to a maximum of about 37 m (122 ft) near Walcott, New York. Eastward, it thins again slightly to about 30 m (100 ft) near Lakeport, New York, before grading into the Herkimer Sandstone (Gillette, 1947). Subsurface data reveal that the Rochester is thickest in an elongate northeast-southwest trending region from North Victory (Cayuga County), New York to Geneva, New York (Ontario County), where it attains a maximum thickness of 44.8 m (147 ft) (Gillette, 1940; Fig.2). Well logs indicate a southward thickening in western New York from 15-21 m (57-70 ft) in Niagara-Orleans counties to 30-35 m (100-115 ft) in southern Erie, Genesee and Livingston counties (Van Tyne, 1975).

The Rochester Shale maintains a thickness of 12-15 m (40-50 ft) in the subsurface along the southernside of the Ontario peninsula westward to Windsor, Ontario. However, well logs also reveal relatively rapid thinning and pinch-out of the Rochester into Wiarton crinoidal dolostone within 24-32 km northeast of this belt (Caley, 1940; Fig.2).

The northward thinning is apparently due to facies change with only minor, if any, erosive overstep of the Rochester (Bolton, 1957; Sanford, 1969). The Wiarton crinoidal facies is thus the northern equivalent of the entire Irondequoit-Gasport sequence. The line of abrupt facies change approximately coincides with Algonquin Axis, an area of relative uplift during the Paleozoic.

In north-south cross sections (Fig. 2), the Irondequoit and Gasport limestones appear as tongues of the crinoidal shoal facies which extend southeastward into the Appalachian Basin. These tongues are mutually separated by mudstone and argillaceous dolostone of the Rochester and DeCew formations.

STRATIGRAPHY OF THE ROCHESTER SHALE IN ONTARIO AND WESTERN NEW YORK

General Stratigraphic Subdivisions

Local subdivisions of the Rochester Shale were recognized by early workers (Ringueberg, 1888; Grabau, 1901), but subsequent authors tended to treat the Rochester Shale as a homogenous lithologic unit, lacking mappable subdivisions (Gillette, 1940; Bolton, 1957; Thusu, 1972). Detailed stratigraphic study of the Rochester Shale indicates the existence of several widely traceable units within the formation, and four new members have recently been proposed (Brett in press).

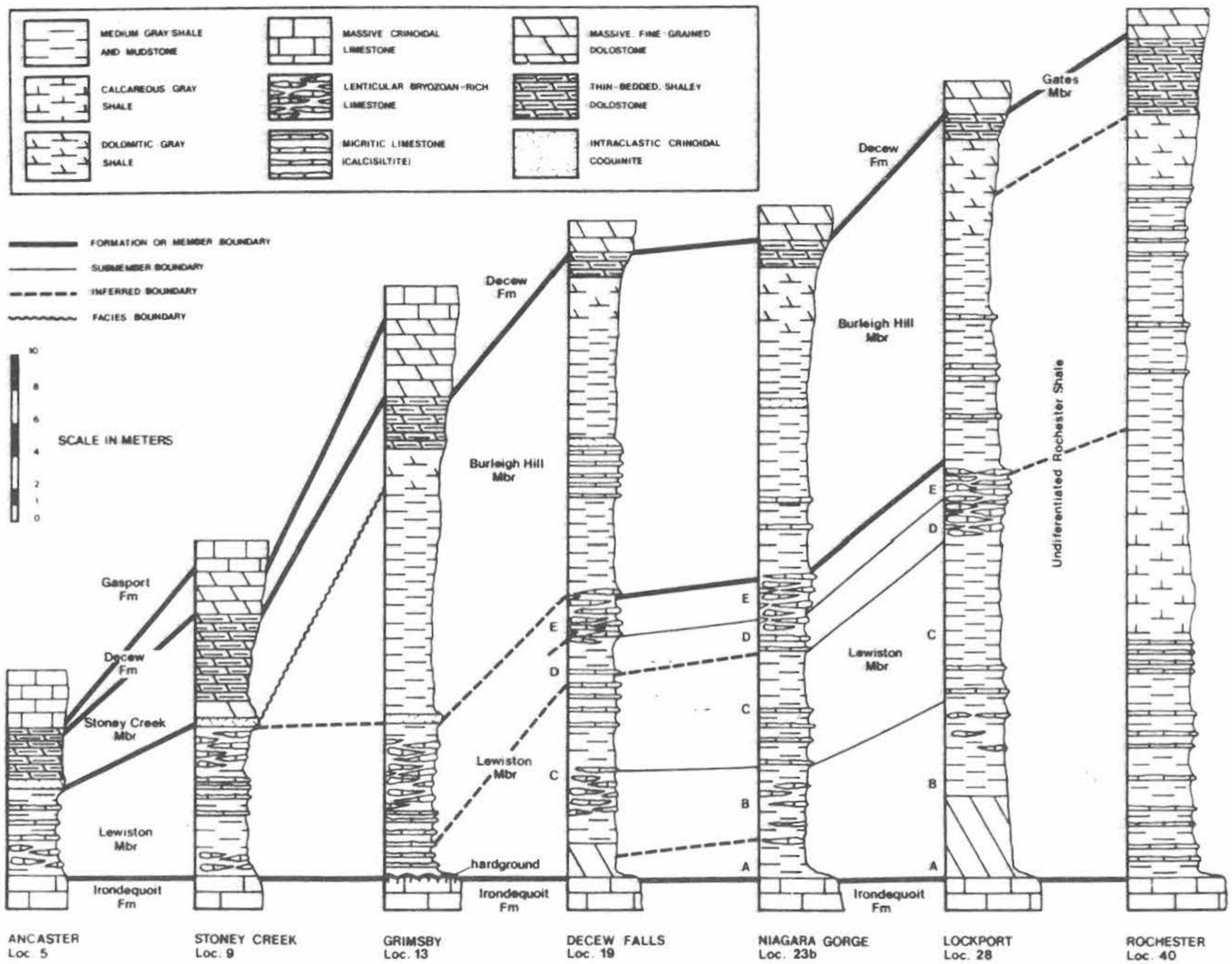

FIG. 3.--Stratigraphic sections of Rochester Shale at seven localities in Ontario and western New York. Locations of numbered sections are shown in Figure 1.

A twofold subdivision of the Rochester Shale is recognizable in outcrops along the Niagara Escarpment from Hamilton, Ontario (west) to Brockport, New York (east) (Fig. 3). The Rochester Shale can be differentiated into units of roughly equal thickness in nearly all exposures in this area.

The lower (= "lower shales" of Grabau, 1901) - previously termed the Lewiston Member (Brett, in press), consists of interbedded mudstone, lenticular fossiliferous limestones and barren calcisiltites. At its type section in Niagara Gorge, the Lewiston Member is 8.7 m (28.6 ft) thick and is divisible into five submembers, as follows (Fig. 3).

A) a basal transition zone, up to a meter thick, of brachiopod-crinoid-bearing silty, argillaceous biomicrite and biosparite lenses in shale.

B) a one-to-three meter interval of fossiliferous brownish-gray, slightly calcareous mudstone with abundant patches of ramose bryozoans and bryozoan-rich biomicrites.

C) a middle unit of sparsely fossiliferous shale and interbedded dark gray laminated calcisiltites (pelmicrites).

D) an interval, up to two meters thick, resembling submember B, and gradational into Unit E.

E) an upper unit two meters or less in thickness, of closely-spaced lenses of bryozoan-rich biomicrites and biosparite with thin interbedded shales. The uppermost bed of this interval, up to 30 cm thick, is, locally, glauconitic and contains shale clasts and abraded fossil debris. Submember E, which corresponds to the "bryozoa beds" of Grabau (1901), forms a readily recognizable upper unit of the Lewiston Member.

All of the Lewiston submembers can be recognized from St. Catharines, Ontario to near Brockport, New York, and their thicknesses remain proportionally constant, despite thinning of the Lewiston Member, as a whole, from over 12.2 m to 7.9 m (40-26 ft) (Fig. 3).

Although the Lewiston Member is recognizable to Hamilton, Ontario, it becomes highly condensed and contains an increased abundance of calcisiltite, calcarenite and intraclastic limestone. Differentiation of submembers (B-E) becomes obscure in this region.

The upper portion of the Rochester Shale is consistently distinct from the Lewiston Member, and in western New York comprises sparsely fossiliferous platy and highly calcareous or dolomitic shale, the Burleigh Hill Member. At most localities, this member is gradational upwards through about 1 to 2 m of dolomitic shale into the overlying DeCew dolostone. The contact between the Burleigh Hill and the underlying Lewiston Member is generally sharp and is placed at the top of bryozoan-rich limestones, (submember E) the "bryozoa beds" of Grabau (1901). Bryozoan biomicrites are absent from the Burleigh Hill Member.

Bryozoan-rich limestones and bryozoan clusters are also lacking from the lower Rochester east of Brockport, New York, where the entire formation thickens considerably and consists of a more homogeneous sequence of shales and barren calcisiltites. This undifferentiated and less fossiliferous Rochester Shale of Monroe County closely resembles the Burleigh Hill Member (or Lewiston-C submember) throughout.

A 3-5 m (10 to 15 ft) interval, near the middle of Rochester Shale at Genesee Gorge which exhibits a concentration of barren calcisiltites and calcareous shales, may correspond to the bryozoa beds farther west. Again, the upper Rochester Shale grades upward into an interval of about 20 m of argillaceous dolostone and dolomitic shale, which Chadwick (1918) designated the Gates Member.

North-South Facies Variations in the Rochester Shale

Detailed studies of Rochester Shale stratigraphy in Niagara Gorge demonstrate very rapid north-south facies changes, contrasting to the continuity of facies along the east-west oriented outcrop belt (Brett, in press, Fig. 4, herein). Indeed, the section at Niagara Falls more closely resembles the undifferentiated Rochester Shale at Genesee Gorge, some 130 km (70 mi) to the east, than it does sections in the north end of Niagara Gorge, only 10 km (7 mi) to the north (see Fig. 1).

Units B and D of the Lewiston Member diverge from one another southward as the barren middle shales (Unit C) thicken rapidly toward the south end of Niagara Gorge. Unit C changes lithologically somewhat, containing thicker and more closely-spaced calcisiltite bands in the northern end of Niagara Gorge. Near Niagara Falls, the unit is more than doubled in thickness and consists almost entirely of barren shale.

The bryozoan-rich intervals of the Lewiston Member (units B,D, and E) die out southward and are replaced, laterally, by calcisiltite-shale units (Fig. 5). This is most notable in the case of Unit E, the "bryozoan beds" of Grabau (1901). Nearly two meters thick near Lewiston (loc. 23), this bryozoan biomicrite-shale interval thins to less than 0.5 m at Whirlpool State Park, 2 km to the south. At this point, the lower bands of bryozoan-rich limestone grade into dolomitic calcisiltites with only scattered bryozoans and other fossils. Farther south, at the Niagara Sewage Plant exposure (Stop 5) bryozoans are completely absent from all but one uppermost band, the remainder of Unit E consisting

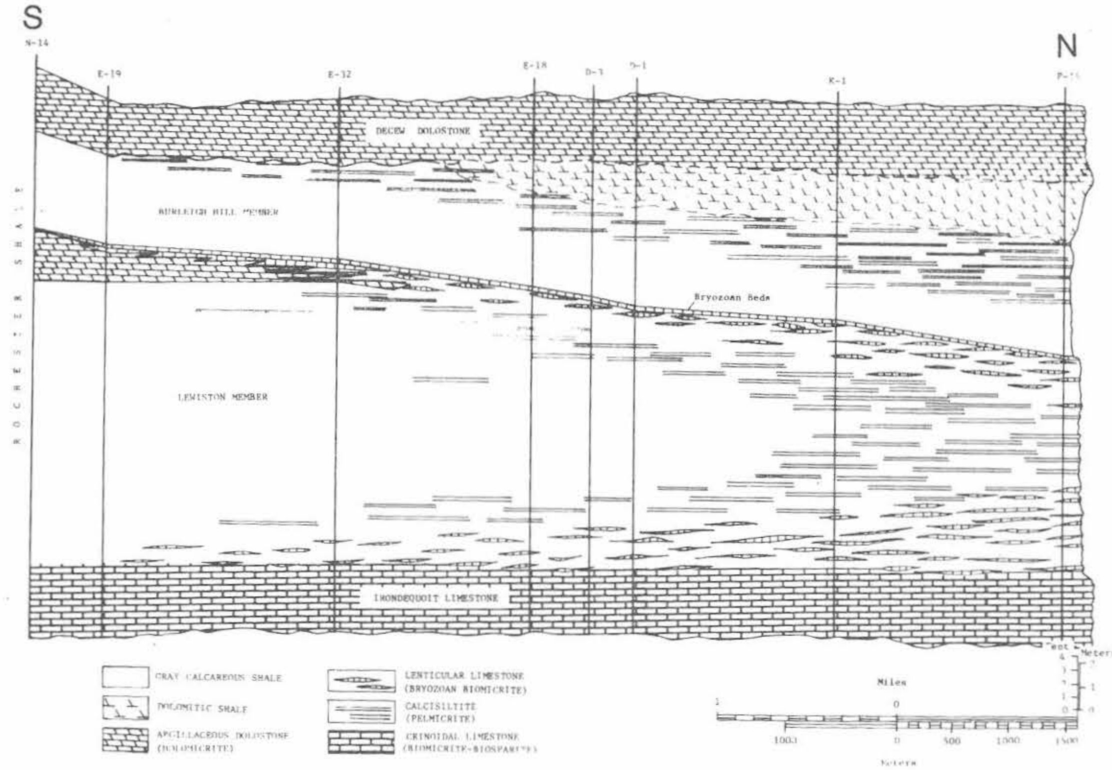

FIG. 4.-- North-south stratigraphic relationships of the Rochester Shale in Niagara Gorge; vertical lines indicate positions of measured sections from drill cores logged by Bolton, (1957; appendix B, p. 107-141); numbers correspond to codes assigned by Bolton to each drill core.

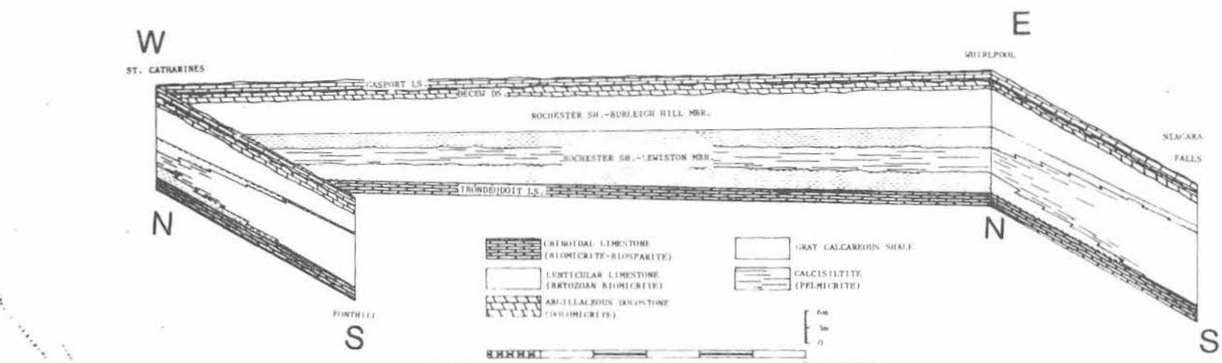

FIG. 5.-- Stratigraphic relationships of the upper Clinton and lower Lockport Groups from Niagara Gorge (east section) to the Fonthill Reentrant (west section). Note consistent north-south facies changes in each area, contrasting with facies continuity in the east-west oriented section.

of five or six 10-30 cm thick bands of barren, laminated dolomitic calcisiltites, closely resembling the higher DeCew Formation. At the site of the old Schoellkopf Hydroelectric Plant in the city of Niagara Falls, the bands merge into a single blocky dolomitic band about a meter thick; this unit persists to the southern end of Niagara Gorge. The only vestige of the highly fossiliferous limestones of unit E remaining at Niagara Falls is a thin (5-10 cm) uppermost bed of biosparite containing abundant crinoid ossicles and scattered brachiopod and bryozoan fragments.

Lithological changes in the upper Burleigh Hill Member in Niagara Gorge are less pronounced than those of the Lewiston. However, there is a general southward loss of calcisiltite beds in the upper portion of the unit. The lower contact remains sharply defined at the top of the upper calcarenite bed of the Lewiston Member. In contrast, the upper contact with the DeCew Dolostone, which is completely gradational at the north end of the Gorge, becomes sharp and undulatory south of the Whirlpool. The DeCew locally contains clasts of Rochester Shale, suggesting erosional rip-up.

The Burleigh Hill thins to the south along Niagara Gorge, as the Lewiston Member thickens, maintaining an approximately uniform thickness of the entire Rochester Shale. This is anomalous with respect to the general southward thickening of the Rochester (see above), and is attributed to two factors. First, the sharp erosional upper contact of the Rochester Shale, south of Whirlpool, suggests truncation of upper Rochester beds (possibly by downslope erosion). Second, south of the Whirlpool, the DeCew Dolostone exhibits a 1-2 m interbed of calcareous shale, closely resembling the Stoney Creek Member. This indicates interfingering of DeCew and upper Rochester facies.

Rapid southward facies change is also corroborated by field data from stream exposures of the Rochester Shale in the Fonthill Reentrant, an 8 km (5 mi) southward embayment in the Niagara Escarpment just west of St. Catharines. Here again, the Lewiston Member thickens and grades southward into a more monotonous, sparsely fossiliferous shale interval. Bryozoan-rich beds of unit E, well represented at DeCew Falls (loc. 19), again diminish and are replaced by calcisiltite beds capped by one or two thin beds of crinoid-brachiopod-rich calcarenite. A three-dimensional fence diagram (Fig. 5) demonstrates consistent southward changes in the Niagara Gorge and Fonthill sections with relatively little facies change along the main (east-west) escarpment outcrop belt.

A third area where abrupt north-south changes are observable in the Rochester Shale is the Burlington Bay Reentrant, at the western end of Lake Ontario. Here the Niagara Escarpment makes an abrupt bend from east-west to north-south; exposures of Rochester Shale occur in both north and south sides of the 8 km (5 mi) wide reentrant (Fig. 1). At Route 403 (loc. 5), on the south side of the reentrant, the Rochester

Shale is 4.3 m (14 ft) thick and is subdivisible into Lewiston and Stoney Creek members; 8 km (5 mi) to the north of this area at Clappison Corners (Rt. 6; loc. 1) the Rochester consists of 0.6 m (2 ft) of intraclastic sandy limestones and calcareous shales. North of this locality, the Rochester is represented by merely a shaley parting or is absent altogether. As noted previously, this rapid northward thinning and pinch-out of the Rochester Shale can be recognized in the subsurface as far west as the Windsor area of Ontario.

The rapid and substantial north-south facies changes of the Rochester Shale across the Burlington and Fonthill Reentrants and in the length of Niagara Gorge contrast with the east-west persistence of facies. This indicates that, in western New York and adjacent Ontario, Rochester facies belts are elongate east to west, parallel to a northern paleoshoreline and subparallel to the modern Niagara Escarpment. The rare north-south outcrop sections are approximately perpendicular to the strike of facies belts and thus show rapid internal changes. Finally, the stratigraphic cross sections of Niagara Gorge and the Fonthill Reentrant closely resemble hypothetical transgressive regressive cycles (cf. Raup and Stanley, 1978, p. 215).

DISCUSSION

The general depositional environment of the Rochester Shale in Ontario and western New York is envisaged as a shallow (less than 50 m) gently south-eastward sloping, muddy shelf (Fig. 6). This region was bordered on the southeast by a sandy shoreline and on the northwest by carbonate shoals. A hypothetical northwest to southeast transect would include the following facies: A) crinoidal bank-biohermal facies (Wiarton), coinciding with the Algonquin axis; B) either i, an argillaceous-carbonate facies reflecting mixed terrigenous and detrital carbonate sedimentation (Stoney Creek and upper Burleigh Hill-Gates Members), or ii, a bryozoan belt facies consisting of abundant patches of ramose bryozoan, and associated diverse brachiopods, echinoderms and other fossils, formed during times of low sedimentation rates (Lewiston B, D, and E); C) a calcisiltite facies comprising mudstone and interbedded barren, carbonate, storm-silt layers (Lewiston C, lower Burleigh Hill); D) a sparsely fossiliferous mudstone facies (undifferentiated lower Rochester Shale, lower Burleigh Hill in part).

Vertical facies changes in the Rochester Shale at a given section are attributed to lateral (north or south) shifts of environmental (facies) belts due to migration of a northern paleoshoreline. The Irondequoit to Gasport sequence constitutes a major transgressive-regressive cycle (Dennison, 1970; Dennison and Head, 1975), with two superimposed subcycles in the Rochester Shale.

As noted earlier, the Irondequoit and Gasport limestones appear in north-south cross sections as two basinward extensions of the Wiarton crinoid bank facies. From the preceding discussion, it is evident that these

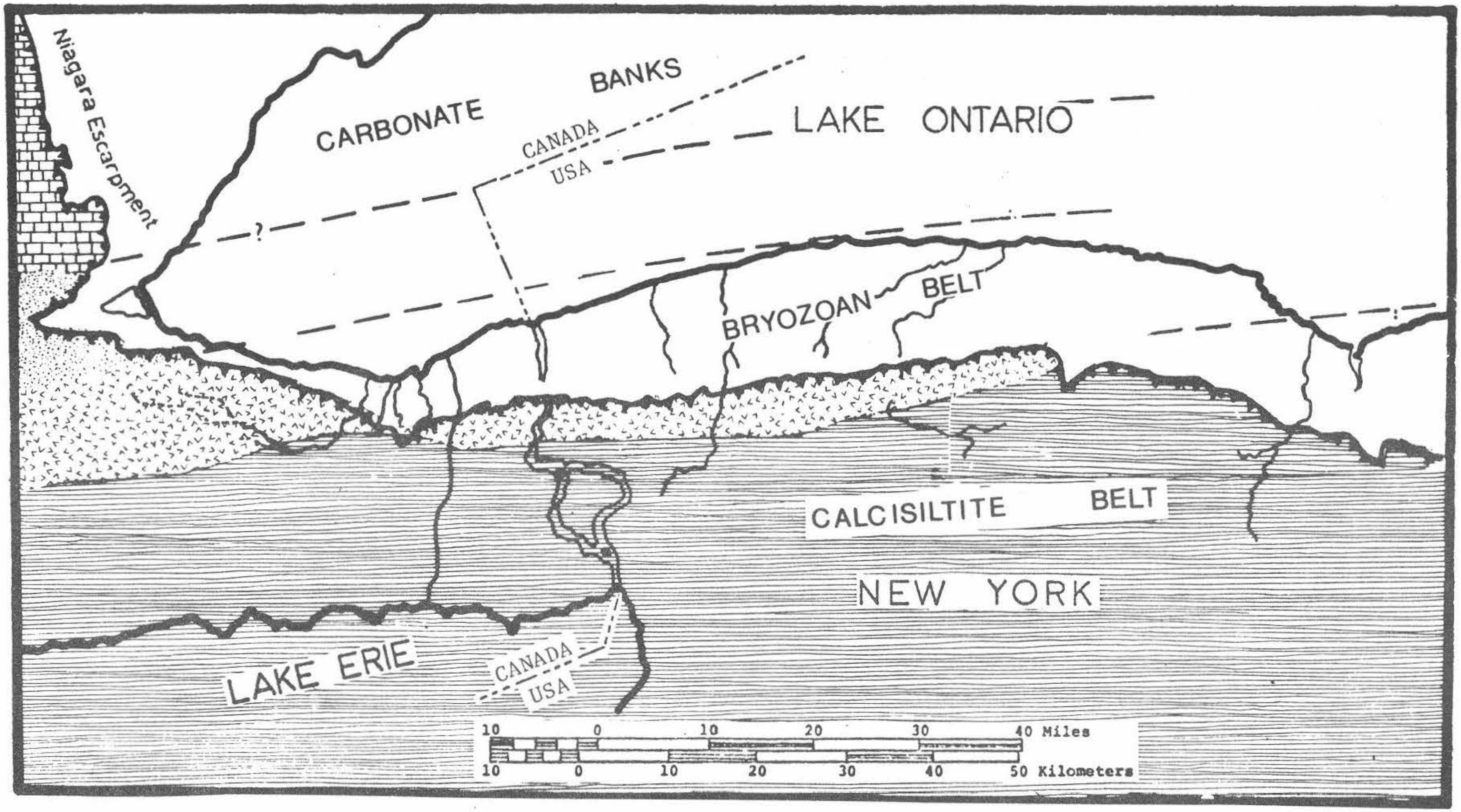

FIG. 6.--Facies map for Rochester Shale in Ontario and western New York State. Reconstruction shows approximate geographic position of facies belts during deposition of the upper portion of the Lewiston Member (submember E). Note parallelism between facies belts and modern Niagara Escarpment.

tongues define a large-scale transgressive-regressive cycle comprising Irondequoit-Rochester-DeCew-Gasport. Previous authors (Dennison and Head, 1979) suggested that the Rochester Shale was deposited during a single rise of sea level. However, the preceding discussion indicates that this is not entirely correct. Detailed stratigraphy of the Rochester reveals evidence for a minor regressive event of lesser magnitude than that which produced the Irondequoit or Gasport limestones during the middle of Rochester Shale deposition.

The Lewiston Member records a subsymmetrical cycle of deepening (units submembers A-C) and shallowing (submembers C-E). In contrast the upper unit (Burleigh Hill or Stoney Creek member) reflects aspects of an asymmetrical shallowing-upward hemicycle. The transgressive portion of this sequence is poorly preserved or absent and is usually represented by a slight disconformity: the contact between calcarenites of Lewiston E submember and upper barren shales. Greatly increased detrital carbonate sedimentation during deposition of the upper Burleigh Hill-DeCew interval inhibited the growth of bryozoans in shallow water and prevented the development of bryozoan facies analogous to those observed in the Lewiston Member. Predictably, in outcrops toward the center of the basin, e.g., in the Genesee River Gorge, these smaller scale cycles are less obvious, and the entire section takes on a more monotonous, homogeneous aspect.

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ROAD LOG FOR SILURIAN ROCHESTER SHALE FACIES IN WESTERN NEW YORK

CUMULATIVE MILES	MILES FROM LAST POINT	ROUTE DESCRIPTION
	0.0	Begin trip at Buffalo Marriott Inn. At entrance turn left and proceed north on Millersport Highway (Route 263).
0.9	0.9	Coventry entrance to SUNY at Buffalo Amherst Campus.
1.8	0.9	Junction North Forest Road.
2.5	0.7	Junction Campbell Blvd. (270). Turn left (north) on Route 270.
		Junction Route 356.
3.3	0.8	Junction French Road.
5.7	2.4	Bridge over Tonawanda Creek. Enter Niagara County.
7.5	1.8	Junction Bear Ridge Road.
8.7	1.2	Junction Fiegel Road.
10.5	1.8	Junction Lockport Road.

11.7	1.2	Junction Saunders Settlement Road (Route 31).
13.2	1.5	Junction Upper Mountain Road. Route 270 ends, proceed across Upper Mountain Road onto Lockport Junction Road (Route 93 North).
13.5	0.3	Begin road cut in Lockport and Rochester formations.
13.6	0.1	Exposure of upper Rochester/DeCew Dolostone contact. Pull vehicles off in parking area on left side of road.

STOP 1. LOCKPORT JUNCTION ROADCUT. The first two stops of this trip provide an overview of the Rochester Shale in eastern Niagara County, for comparison with Niagara Gorge sections farther west. This exposure illustrates the gradational upper contact of the Rochester Shale with the overlying DeCew Dolostone. The upper 3-4 m of the Burleigh Hill Member of the Rochester Shale are exposed at the base of this cut. Nearly barren, friable, calcareous shale grades upward into a 1-2 m interval of interbedded dolomitic shale and buff weathering, burrow-mottled layers of argillaceous laminated calcisiltite. These beds appear to be gradational into the overlying DeCew Dolostone. This transitional upper Rochester unit thickens eastward to form the Gates Member which is recognized near the type section at Rochester, New York. The upper portion of the roadcut exposes an excellent section of the Gasport Formation (Lockport Group) and the sharp contact between the DeCew Dolostone and the cross-bedded, crinoidal biosparites of the Gasport.

The uppermost Rochester and DeCew are interpreted as rapidly-deposited carbonate silt and clay sediments, winnowed from Gasport crinoidal shoals which lay nearby to the northwest. Cross lamination and abundant soft sediment deformation in the DeCew suggest rapid influx of sediment followed by dewatering. Body fossils are exceedingly rare in the upper Rochester and the DeCew, but burrows, including Chondrites, Planolites and Teichichnus are abundant. This may, again, reflect high turbidity.

13.6		Return to vehicles and reverse directions, proceeding south on Lockport Junction Road.
14.0	0.4	Junction of Upper Mountain Road. Turn right (west).
14.7	0.7	Junction Thrall Road on right. Turn right (northwest).
15.1	0.4	Small exposure of Gasport Limestone.

16.1	1.0	High cutbank in Rochester Shale and Lockport Group, in pasture along south side of Thrall Road. Park vehicles on right hand side of road in front of driveway to farm.

STOP 2. THRALL ROADCUT, CAMBRIA, NEW YORK. Although somewhat weathered, this exposure provides a good reference section for the middle Rochester Shale in eastern Niagara County. Here the upper 4 or 5 m of the Lewiston Member, and its sharp contact with the overlying Burleigh Hill are exposed. Although largely covered by slumped talus, limestone ledges of Lewiston submember E ("bryozoa beds" of Grabau, 1901) protrude from the bank in several locations. This is an excellent locality for collecting the diverse fauna of middle Rochester beds. Weathered talus at the base of the slope has yielded over 20 species of brachiopods, corals, gastropods and complete thecae and crowns of Stephanocrinus, Caryocrinites, and various crinoids. Weathered slabs of limestone replete with ramose and fenestrate bryozoans are abundant here. Note the sharp contrast with the overlying barren mudstone of the Burleigh Hill Member. Thin calcisiltites comprise the only interbeds in this upper portion of the Rochester. Weathered slabs from the upper bank have yielded abundant trilobite remains (Dalmanites, Trimerus), ostracodes, Tentaculites and crinoid columnals. However, the bulk of the interbedded shale is very sparsely fossiliferous, in marked contrast to the underlying Lewiston beds. The top of this section is again capped by buff weathering DeCew Dolostone and Gasport Limestone.

16.1		Return to vehicles and proceed northwest along Thrall Road.
16.7	0.6	Junction Blackman Road.
16.8	0.1	Y-junction of Thrall Road onto Lower Mountain Road. Bear left (west) onto Lower Mountain Road.
17.6	0.8	Junction Cambria Road.
29.8	12.2	Junction Route 425 on right.
29.9	0.1	Junction Shawnee Road. We are now riding along the base of Niagara Escarpment.
30.6	0.7	Junction Baer Road. Turn left (south) and proceed up low ridge formed by lower platform of Niagara Escarpment on Irondequoit Limestone.
30.72	0.12	Roadcut in Rockway and Irondequoit Limestones. Park near south end of cut.

STOP 3. BAER ROADCUT. There are very few outcrops in Niagara County where the basal beds of the Rochester Shale can be examined. This will be a brief stop to observe the uppermost Irondequoit Limestone which immediately underlies the Lewiston Member. Here the Irondequoit is a crinoidal biosparite, similar to the Gasport Limestone. Well-preserved fossils occur sparingly in the upper Irondequoit, including thecae of *Stephanocrinus*, *Caryocrinites* and other echinoderms. Small, white-weathering bioherms composed of fistuliporoid bryozoans and bound biomicrite occur near the top of this exposure. Such small bioherms occasionally protrude upward into the basal beds of the Rochester Shale.

30.72		Continue southward along Baer Road crossing the small plateau on Irondequoit Limestone and then up the main Niagara Escarpment.
31.4	0.7	Small exposure of Gasport Limestone at turn in road.
31.9	0.5	Intersection Upper Mountain Road. Turn right (west).
32.0	0.1	Overpass over Route 429. The classic Pekin roadcut through a Gasport bioherm is exposed along 429 immediately below Upper Mountain Road at this locality.
32.2	0.2	Access road to Route 429 (Grove Street).
32.7	0.5	Junction Bridgeman Road.
33.1	0.4	Meyers Hill Road.
33.6	0.5	Excellent view off Niagara Escarpment onto Ontario Lowlands Plain. On clear days this affords a view of Lake Ontario.
34.7	1.1	Junction Black Nose Spring Road.
35.3	0.6	Junction Walmore Road.
37.5	2.2	Y-intersection with Model City Road. Bear left staying on Upper Mountain Road. View to right out to Ontario Lowlands Plain and Lake Ontario.
38.1	0.6	Western boundary of Tuscarora Indian Reservation.

38.4	0.3	Reservoir for Robert Moses Hydroelectric Plant appears as bank on left.
39.1	1.7	Junction of Upper Mountain Road and Military Road at stop light. Proceed straight across intersection onto access road for Robert Moses Parkway, Route I-190, and Route 104.
39.15	0.05	Exit for Route I-190 north onto Lewiston-Queenston International Bridge.
39.35	0.2	Exit for Route I-190 south.
39.55	0.2	Junction Route 104 east (north) to Lewiston.
39.7	0.15	Junction Route 104 west (south) to Niagara Falls.
39.9	0.2	At Y-intersection merge with southbound lane of Robert Moses Parkway and cautiously cross to right hand lane.
40.0	0.15	Pull off on broad shoulder of Robert Moses Parkway and park at 55 mph sign. Passengers will disembark here, proceed over guard rail and down a slope, bearing to the right or north to cliffs along Niagara Gorge (see Fig. 7 point A).

STOP 4. NORTH END, NIAGARA GORGE NEAR LEWISTON, NEW YORK. Cliffs along the east face of Niagara Gorge between Lewiston Queenston Bridge and the Robert Moses Power Plant provide an excellent section of the entire Irondequoit, Rochester, and lower Lockport units. Here the Rochester Shale is approximately 17 m thick; the lower half comprises the Lewiston Member which consists of about 8.7 m (28.6 ft) of medium to brownish gray calcareous shaley mudstone with interbedded thin carbonates. The member exhibits a gradational lower contact with Irondequoit Limestone, but is sharply differentiated from the overlying Burleigh Hill Member at the top of a 1-2 m interval of bryozoan rich limestones (unit E). As at most localities in western New York and adjacent Ontario the Lewiston Member can be subdivided into six informal units or submembers designated by letters A-E. All of these beds are readily accessible in this cliff section and will be described as follows:

A) The basal transition zone of the Lewiston is up to 1 m thick and consists of dark-brownish to ashy-gray, silty, very calcareous and fossiliferous mudstone with interbeds of argillaceous limestone (biomicrite and/or biosparite). Brachiopods are very abundant and may be packed into layers; characteristic species include: Atrypa reticularis,

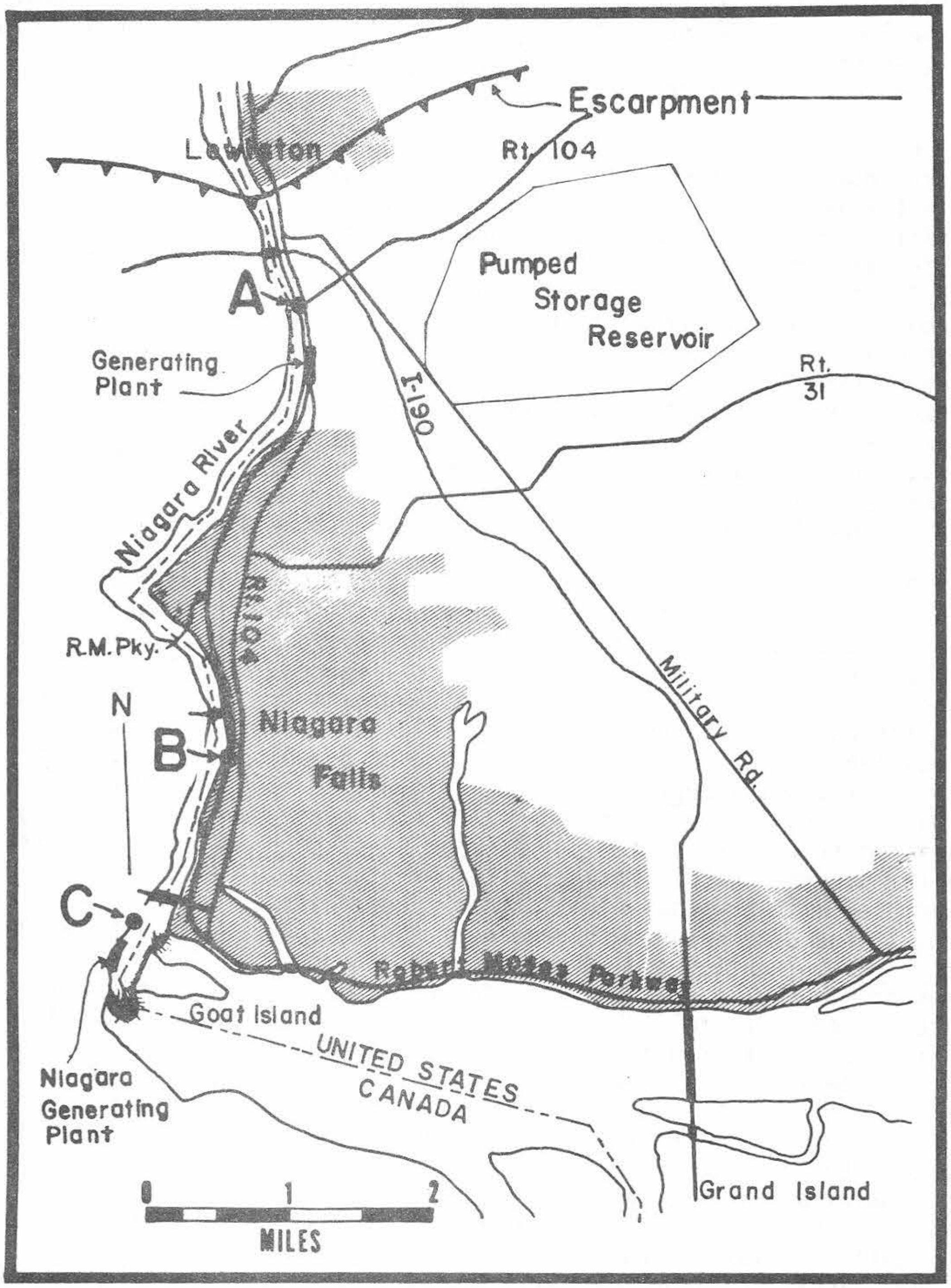

FIG. 7.-- Location map for fieldtrip stops along Niagara Gorge. Locations include: A) Stop 4, Cliffs along east side of Niagara Gorge south of Lewiston-Queenston bridge; B) Stop 5, exposures at Niagara sewage pumping station, Niagara Falls, New York; C) Stop 6, exposures along access road for Ontario Hydro Niagara Generating Plant, Niagara Falls, Ontario.

large Leptaena rhomboidalis, Whitfieldella oblata and Plectodonta transversalis. Bryozoans are less common than in overlying beds, but laminar fistuliporoids are not uncommon. Echinoderm debris is abundant in the lower shales and unit A has yielded certain unique forms including a high, narrow morph of Stephanocrinus angulatus, large Eucalyptocrinites, and the very rare crinoid Paracolocrinus (Brett, 1978).

Locally, small bioherms 1-5 m across and up to 2 m high protrude upward from the Irondequoit Limestone into the base of the Rochester Shale (Sarle, 1901). These mounds are composed of whitish to massive micritic limestone with abundant laminar fistuliporoid bryozoans. A particularly good example of one of these mounds, now inaccessible, but readily visible, occurs along the high wall of Irondequoit Limestone immediately south of this Rochester Shale outcrop. This mound appears to interfinger laterally with shales of unit A; however, it also contains pockets filled with a greenish clay shale, unlike the basal Rochester. Bioherms such as this have yielded a number of unique fossils not seen elsewhere in the Rochester Shale. Large Bumastus and Calymene trilobites, sometimes as coquinites of cephalic and pygidial shields occur in shaley pockets within the bioherms. Unit A clearly exhibits features transitional between typical Irondequoit Limestone and Rochester Shale.

B) The lower beds of the Rochester Shale grade upward into a 2.5-3 m interval of softer, less calcareous, medium to brownish-gray mudstone with numerous lenticular beds of bryozoan-rich biomicrites. As a whole, this interval is richly fossiliferous, although some mudstone beds are nearly barren. Ramose bryozoans are particularly characteristic and they frequently occur in clusters packed in a mudstone matrix. Associated with these clusters are abundant brachiopods such as Atrypa reticularis, small Leptaena, and Whitfieldella. This interval is particularly notable for the abundance of echinoderm remains including thecae of the blastoid-like pelmatozoan Stephanocrinus angulatus, and the rhombiferan cystoid Caryocrinites ornatus, both of which are typically associated with bryozoan-rich patches. Holdfasts of Caryocrinites are commonly found cemented to bryozoans. Gastropods, the trilobites Bumastus, Arctinurus, Dalmanites and others are also abundant in these beds. Certain limestone lenses in unit B appear to represent starved ripples of storm-concentrated, skeletal debris. Rotated geopetal structures and infillings of brachiopod shells with matrix identical to that of the underlying beds suggest derivation of these fossils by reworking during storms.

C) Near the north end of Niagara Gorge the middle interval of the Lewiston Member consists of about 3-4 m of sparsely fossiliferous gray shales and interbedded dark-gray, burrowed, laminated calcisiltites (pelmicrites). Bryozoan clusters and biomicritic limestones are absent from this interval. These shales exhibit a low diversity fauna dominated by the brachiopods Striispirifer, Strophonella and Parmorthis and the trilobites Dalmanites, Trimerus and Arctinurus near the base of unit C occur thin horizons which locally contain exceptionally well-preserved fossils. These layers, in all about 10-20 cm thick, were designated the Homocrinus band at Lockport, New York (Ringueberg, 1888); they contain the characteristic minute inadunate crinoid Homocrinus parvus, as well as completely articulated specimens of Asaphocrinus and Macrostylocrinus, the cystoid Caryocrinites, edrioasteroids and rare starfish. These fossils are associated with dense bedding plane assemblages of Striispirifer and other brachiopods. Such assemblages suggest rapid smothering of the sea floor by muds, producing catastrophic (live) burial of benthic communities by storm-generated mud layers (Brett, 1978; 1980)

Homocrinus-bearing layers have been recognized at Niagara Gorge about 4.6 m (15 ft) above the base of the Lewiston Member. However, no large assemblages have as yet been obtained from this locality. Calcisiltites of Lewiston C also appear to record a type of storm-generated layer. These units form thin (1-2 cm) persistent bands. Weathered surfaces reveal fine, planar- and hummocky- cross lamination, often in alternating sets. Their upper surfaces may be rippled and basal contacts are invariably sharp. The undersurfaces of some calcisiltites yield abundant sole marks including flute and groove molds which suggest current scouring of cohesive muds; occasionally, well-preserved fossils may also occur on the undersides of these beds. Most calcisiltites are barren of body fossils, but they contain abundant trace fossils including large vertical shafts - possibly escape burrows - and post-depositional mining structures such as Chondrites and Planolites.

Rochester calcisiltites closely resemble storm silt layers described by Reineck and Singh (1972), from the modern North Sea and by Kreisa (1981) from the Ordovician Martinsburg Formation. They are interpreted as deposits from storm-generated density currents which transported carbonate silts from shallow platform areas into the Rochester depositional basin.

D) Overlying unit C is an interval, up to 2 m thick, of fossiliferous mudstone with biomicrites which closely resembles unit B, both in lithology and fauna. Again, clusters of ramose bryozoan are abundant and exhibit virtually all of the associated fauna found within the lower unit B. These beds, again, yield abundant atrypids and Whitfieldella, Striispirifer, Leptaena, Bumastus trilobites, dendroid graptolites and the pelmatozoans Stephanocrinus angulatus and Caryocrinites. Lenticular calcarenites resembling those in unit B become increasingly abundant upward in unit D whereas barren calcisiltites are less frequent than in unit C.

E) "Bryozoa beds." The top of the Lewiston Member is marked by a series of thin lenticular limestones (biomicrites and biosparites) interbedded with soft, gray, fossiliferous shale. Grabau (1901) termed this unit the "bryozoa beds," because of the great abundance of ramose and fenestrate bryozoans which constitute a bulk of the thin limestones. Brachiopods and echinoderms are also abundant in these beds although typically disarticulated and fragmented. Notable is the reappearance of a large, slender morphotype of Stephanocrinus seen also in unit A at the base of the Rochester Shale.

The uppermost bed of unit E is generally somewhat thicker and more continuous than the underlying layers and may be richer in brachiopod valves and crinoidal debris, resembling the uppermost layers of the Irondequoit Limestone. This unit marks the top of the Lewiston Member in nearly all localities. Locally, this topmost limestone bed is glauconitic and contains shale intraclasts, evidently derived by erosion from the underlying beds.

At this locality, as in most areas of western New York, the Lewiston Member is abruptly overlain by medium to dark gray platey and calcareous shale of the Burleigh Hill Member, named for exposures along Burleigh Hill Drive in St. Catharines, Ontario (Brett, in press). In the north end of Niagara Gorge the Burleigh Hill is about 10 m thick. However, as will be noted, this unit thins rapidly southward along Niagara Gorge. The basal 4-5 m of the member are sparsely fossiliferous to nearly barren, laminated and platey shales which weather into elongate slabs. Lithologically and faunally this portion of the Burleigh Hill Member most closely resembles unit C of the Lewiston Member, and, as with the latter unit, these shales contain occasional thin, laminated calcisiltites which increase in frequency upward. No bryozoan biomicrites have been observed in the Burleigh Hill Member at any locality in western New York and bryozoans are generally absent. Near the base of the Burleigh Hill are a few thin shell layers composed chiefly of the brachiopods Fardenia, Parmorthis, and Strophonella as well as trilobite fragments.

The upper half of the Burleigh Hill Member is gradational into the overlying DeCew Dolostone. Bands of calcisiltite become more closely spaced and eventually merge into a silty dolomitic shale near the top. A few thin layers near the top of the Burleigh Hill have yielded local patches of well-preserved crinoids including Dimerocrinites and Dendrocrinus as well as brachiopods and other fossils. Burleigh Hill dolomitic shales appear to pass upward gradationally into the overlying DeCew Dolostone Formation. Unlike the Lewiston Member, which appears to represent a subsymmetrical cycle, Burleigh Hill reflects a shallowing-upward hemicycle.

40.05		Return to vehicle and proceed southward along Robert Moses Parkway.
40.15	0.1	Beginning of penstocks for Robert Moses Power Plant.
40.45	0.3	Overpass of walkway to Robert Moses Power Vista.
41.05	0.6	Pass access road for Adam Beck Plant on Canadian side of Gorge. View of South Haul Road for Robert Moses Power Plant on U.S. side.

41.65	0.6	Devils Hole pulloff.
43.0	1.35	Entrance for Whirlpool State Park.
43.15	0.15	Exit on left for reversing directions on Robert Moses Parkway. Continue south on Robert Moses Parkway.
43.0	0.35	Exit on right for Whirlpool Street and bridge to Canada. Bear right onto exit.
43.75	0.25	Junction Whirlpool Street. Turn right.
43.85	0.1	Underpass for Whirlpool bridge to Canada.
43.9	0.05	Underpass for railroad bridge to Canada.
44.05	0.15	Junction Route 182. Keep right on Whirlpool Street.
44.13	0.8	Fork of Second and Third Streets at the end of Whirlpool Street. Bear right onto Second Street
44.23	0.1	Niagara Aquarium on left.
44.33	0.1	Junction of access road for Niagara sewage pumping station. Make sharp right turn onto dead end access road, and bear right under overpass to Schoellkopf Museum (on left).
44.53-44.63	0.2-0.3	Small exposures of Goat Island Dolostone of the Lockport Group in the roadcut.
44.58-44.68	0.05	Underpass of access road beneath Robert Moses Parkway. Proceed beneath underpass.
44.73-44.83	0.15	Pull off on left and park. Proceed on foot down old access road to Niagara sewage pumping station in the Gorge. Note well-exposed bioherm in the Gasport Limestone along roadcut.

STOP 5. NIAGARA SEWAGE PUMPING STATION. This stop illustrates the contrast between northern and southern sections of Rochester Shale in the Niagara Gorge. A large artificial cut behind the new sewage pumping building exposes the upper portion of the Lewiston and the entire Burleigh Hill Members of the Rochester Shale. At this location in the gorge the Lewiston Member is approximately 12.5 m (41 ft) thick; the majority of this thickness consists of unfossiliferous shales of a greatly thickened submember C, here about 11 m (36 ft) thick in contrast to 3.6 to 4 m (11-14 ft) at Stop 4. The upper portion of this unit, visible at the base of the cut, consists of nearly barren, silty shale with one or two thin calcisiltite bands. The fossil-rich submember D is not recognizable at this locality; its position appears to be occupied by a section of interbedded shales and thin (5-10 cm) calcisiltite bands. Four or five prominent ledge-forming dolomitic calcisiltites occur near the center of the outcrop, apparently representing the lateral equivalent of "bryozoa beds" (submember E). These bands exhibit sedimentary structures including hummocky cross lamination, rippled upper surfaces, and sharp, scoured basal surfaces, suggestive of current deposition of fine carbonate silt. The beds are interpreted as layers derived from winnowing of bryozoan-crinoid shoals which existed to the north (e.g. at the northern of Niagara Gorge). Ripple- and cross-bed orientation suggest southerly current transport of sediments.

Immediately overlying the highest dolomitic band are 1 or 2 thin layers of coarse, rusty weathering biosparite containing an abundance of brachiopods, pelmatozoans and some bryozoan debris, interbedded with slightly fossiliferous shales. These are essentially the only fossil-rich beds in the entire outcrop and they appear to represent a southern vestige of the topmost bed of unit E in the north. Two km to the north the Whirlpool State Park these bands thicken into a 10-20 cm thick interval of fossil debris and the underlying dolomitic calcisiltites interfinger with typical bryozoan-bearing beds indicating a clearcut transition from typical biosparites of unit E, to the dolostones seen at this locality. The upper bed of fossil debris is followed abruptly by barren shales of the Burleigh Hill Member, which closely resemble those of unit C. The Burleigh Hill is about 6m thick and displays a sharp, probably erosional, upper contact with the DeCew Dolostone.

This sparsely fossiliferous section stands in striking contrast to sections just a few miles north. It suggests the presence of a fairly abrupt, southward dipping paleoslope.

44.83		Return to vehicles and reverse route to Second Street.
45.13	0.3	Junction Second Street. Turn right (south).
45.28	0.15	Junction Main Street (Route 104). Turn right (southwest) and proceed straight ahead to entrance for Rainbow International Bridge.

45.53	0.25	U.S. Toll Booth of Rainbow Bridge.
45.83	0.3	Canadian Customs Booth. Those requiring passports should have these ready at this time.
45.88	0.05	Bear right from exit of Customs Booth onto street toward Falls.
45.98	0.1	Turn right onto Hiram Street. Junction River Road. Turn right (south) and proceed toward Falls.
46.28	0.3	Pass circle at Maid of the Mist information building. Pull off bus along the river road here and park. Proceed on foot to access road for Ontario Hydro Niagara Plant, and Maid of the Mist launch area. Note excellent exposures of Lockport Group beginning at the top of the roadcut with Eramosa Dolostone, followed below by the vuggy stromatolitic and stromatoporoid-bearing Goat Island Dolostone and the dolomitic crinoidal limestone of the Gasport Formation; this unit, in turn, is underlain by buff-weathering, sugary-textured, DeCew Dolostone, exhibiting prominent soft sediment deformation ("enterolithic structure"). The access road forks into two branches, one leading to the straight ahead to the Ontario Hydro Plant, and the other, left hand fork leads to the Maid of the Mist launch area. Near the fork are exposures of the upper part of the Rochester Shale.

STOP 6. ONTARIO HYDRO ACCESS ROAD CUT. This roadcut provides one of the southernmost exposures of the Rochester Shale in New York State. Here the upper contact of the formation is well exposed, just north of the fork in the road. The buff-weathering enterolithic DeCew Dolostone rests with sharp, wavy, and apparently channeled contact on the barren shales of the middle Burleigh Hill Member. No transitional interval is observed at this locality and the Burleigh Hill is only about 4.7 m thick. This situation contrasts with the gradational upper contact of the Rochester Shale observed in most western New York localities. It suggests that the upper Burleigh Hill beds have been removed, possibly by downslope erosional truncation, prior to DeCew carbonate silt deposition. The prominent enterolithic structure of the DeCew Dolostone has long been noted and may have resulted from downslope slumping of rapidly deposited carbonate sediments.

The Lewiston Member is exposed to the south of the road fork, and exhibits an upper blocky band of dolomitic mudstone. Note the contrast to the several rippled bands seen at Stop 5. This unit exhibits many features in common with the DeCew Dolostone, including soft sediment deformation structure. Presumably both units record rapid deposition, dewatering and possible slumping of winnowed carbonate silts. The central block (Schoellkopf bed) is followed by interbedded calcareous shale and dolomitic limestones, including one laminated calcisiltite band about 10 cm thick. The uppermost beds include crumbly calcareous shales and lenticular dolomitic limestone, bearing scattered brachiopods and bryozoans, virtually the only fossils found in this outcrop. Again, these beds are thought to represent a remnant of unit E seen farther north. If time and conditions permit we may continue on foot down to exposures in cuts behind the Ontario Hydro Plant. A thick section of nearly barren dolomitic shales with relatively few limestone bands comprises the bulk of the Lewiston Member. Slightly more fossiliferous beds near the base of this section may reflect a southern equivalent of unit B; the basal contact with the underlying Irondequoit Limestone cannot be observed here. The blocky upper beds of the Lewiston Member appear to phase southward into dolomitic shales. Thus, the distinction between Lewiston and Burleigh Hill Members is becoming vague and blurred. Extrapolating trends seen in this outcrop, one might predict that the entire Rochester Formation becomes nearly uniform, calcareous and sparsely fossiliferous shales only a few km to the south.

46.28		Return on foot to vehicles and retrace to Rainbow Bridge.
46.58	0.3	Pay toll at Canadian booth.
46.88	0.3	U.S. Customs. Proceed straight from Customs following signs for Robert Moses Parkway south and Route I-190.
47.08	0.2	Junction Route 384. Turn right (south).
47.18	0.1	Junction of entrance road to Robert Moses Parkway, near old Nabisco Shredded Wheat building. Turn right (south) and continue onto entrance ramp for Robert Moses Parkway southbound, to Route I-190.
48.98	1.8	Intake gates for Niagara Power Project.
50.28	1.3	Exit for Route I-190 south. Bear left onto exit lane and merge onto I-190 southbound lane.

50.7-51.2	0.5-1.0	North Grand Island Bridge over Niagara River just east of the junction of east and west branches of Niagara River around Grand Island. Toll Booth is on Buckhorn Island, a small subsidiary island on the north end of Grand Island. Proceed straight on I-190 southeastward across Grand Island.
56.7-58.8	6.0-7.6	South Grand Island Bridge across east fork of Niagara River.
58.0-60.1	1.3	Junction I-290 (Youngmann Highway). Take exit for I-290 east.
66.5-68.6	8.5	Exit for Millersport Highway (Route 263) northbound. Take exit and proceed north on Millersport Highway.
66.8-68.9	0.3	Entrance to Marriott Inn. End of field trip.