LATE SILURIAN SEDIMENTATION, SEDIMENTARY STRUCTURES AND PALEOENVIRONMENTAL SETTINGS WITHIN AN EURYPTERID-BEARING SEQUENCE [SALINA AND BERTIE GROUPS], WESTERN NEW YORK STATE AND SOUTHWESTERN ONTARIO, CANADA

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INTRODUCTION

One of the most fascinating aspects of Late Silurian sedimentation in the Appalachian Basin is the occurrence of thick sequences of evaporites and associated sediments. In western New York and southwestern Ontario, Canada, these sequences comprise the Salina and Bertie Groups and have been, or are economically important sources of both halite and gypsum.

Our particular interest in this evaporite sequence stems from the peculiar occurrence of complex eurypterid assemblages distributed, cyclically, throughout the sequence. If there is any hope of understanding the true habitat of the eurypterids, it will come from a more detailed examination of all lithofacies and contained sedimentary structures. We continue in this paper, and associated field trip, to call attention to the great variety of rock types, sedimentary structures, unusual fossil assemblages, and their stratigraphic and geographic distribution.

In the following text, it will be noted that eurypterids are mentioned throughout. This is not only an attempt to illustrate the importance of the eurypterid faunas found throughout the region, but to show their intimate association with part of the sedimentological record reviewed. Furthermore, because eurypterids are structurally complex; because they molted frequently during their growth; and because they often became disarticulated; eurypterid parts were subjected to fragmentation, redistribution by sorting and orientation, and even comminution as bioclasts. We suggest that these processes are important sedimentological features worthy of observation and study.

Likewise, "algal" stromatolites, those moundlike to laminar structures so often encountered in some of the eurypterid beds, are seen herein not only as important biological structures that affected the local sedimentological regimes, but as contributors to the regional sediments as particles and pieces ripped from the biostromes and redistributed, along with eurypterid debris, into flat-pebble conglomeratic accumulations within, primarily, the waterlimes (e.g. Ellicott Creek Breccia) and the finely-crystalline dolostones (e.g. Victor Dolostone) of the Fiddlers Green Formation (Bertie Group).

STRATIGRAPHY

Late Silurian sedimentation in western New York generated a great variety of interesting litho- and biofacies. Lithofacies consist of redbeds, black shales, green shales and dolomitic mudstone, basinal and marginal evaporites, limestones representing biostromal and biohermal accumulations and their "inter-reef" sediments, and the peculiar *waterlimes* of New York with their contained bizarre arthropods – the eurypterids, pseudoniscids, phyllocarids and scorpions.

We concur with Fisher (1960) and Ciurca (1973; 1978, p. 227) with group status for Salina and Bertie sequences that represent the two important phases of sedimentation that followed deposition of the underlying Lockport Group limestones, dolomitic shales and dolostones. Subsequent to Fisher's Silurian Correlation Chart, Rickard (1975) downgraded the Bertie Group to formation status and included all units in an expanded Salina Group. Ciurca (1990) has further revised and expanded the Bertie Group to include previously unknown, but stratigraphically younger strata (Figure 1).

We interpret the Salina Group to be a sequence consisting primarily of thick redbeds (Vernon-Bloomsburg), evaporites (mostly halite and gypsum or anhydrite), limestones and dolostones (Syracuse Formation), and an upper thick sequence of shale and dolomitic mudstones with evaporites (Camillus Formation). Black-shale units are included primarily within the lowest Salina Group.

In contrast, the Bertie Group, a thinner sequence, consists of massive dolostones with their characteristic intercalated waterlime units; minor shale and mudstone units; and minor evaporites (some gypsum and relict evaporites). The Bertie Group contains the two well-known and important eurypterid assemblages - the *Eurypterus remipes remipes* Fauna (older) and the *Eurypterus remipes lacustris* Fauna (younger). The expanded Bertie Group includes the Moran Corner Waterlime, the youngest *Eurypterus*-bearing formation of the group in western New York.

SALINA GROUP

In western New York, the Salina Group consists of three thick formations. At the base are redbeds and green shales and dolomitic mudstones with intercalated eurypterid-bearing black shales. The black shales are the most studied portions in the area because they contain a rich fauna consisting primarily of eurypterids and other arthropods, bivalves, rare articulate brachiopods, and abundant inarticulates (mostly *Lingula* sp.).

Recent observations (Ciurca, 1990) show a multiplicity of recurrent eurypterid horizons within the lower Vernon Formation. The principal biofacies are the *Eurypterus* Biofacies and the *Hughmilleria* Biofacies. They are overlapping biofacies but certain horizons are completely restricted to one or the other genus.

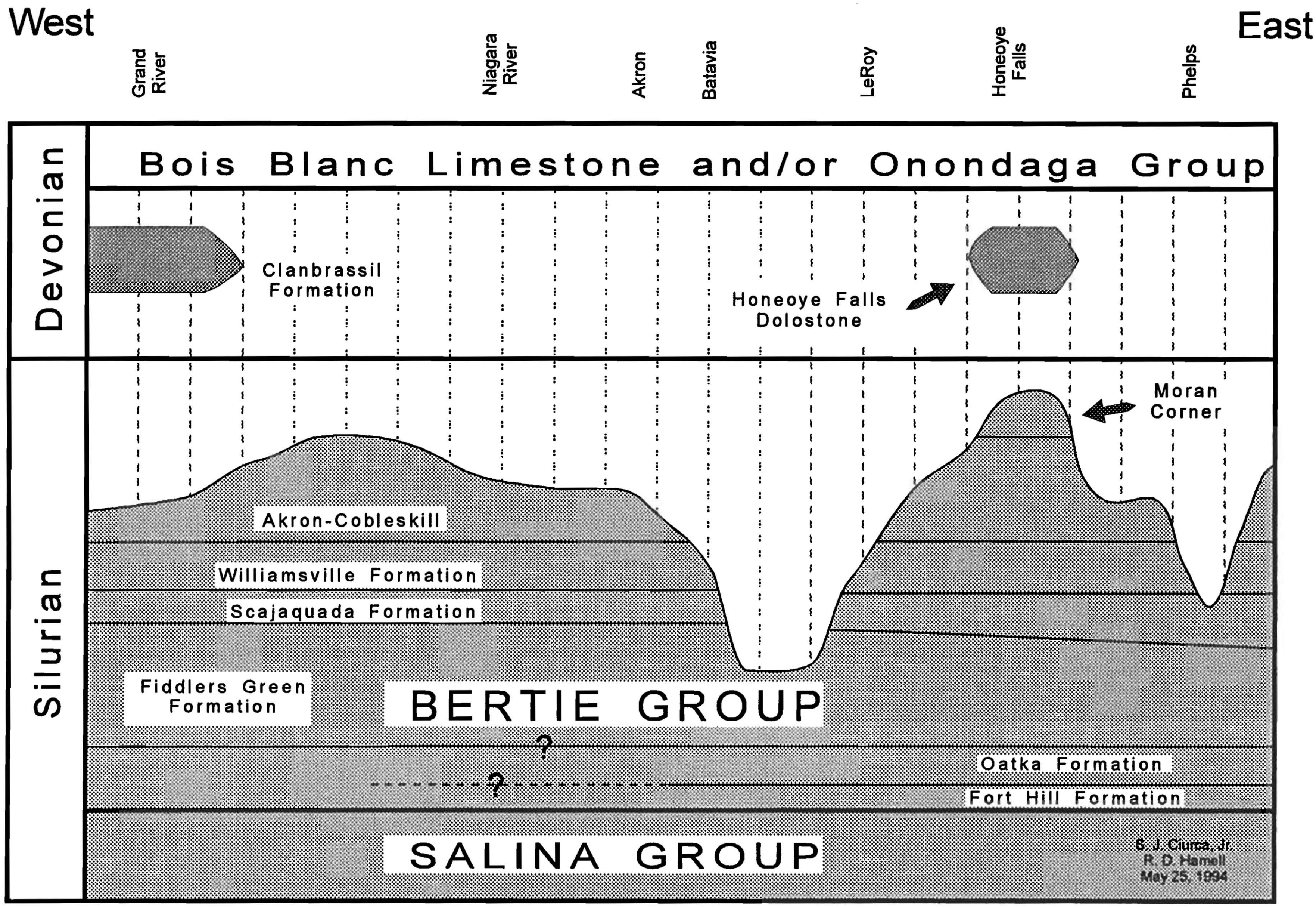

FIGURE 1 Correlation of the Redefined Bertie Group, Western New York and Niagara Peninsula, Ontario, Canada. (Modified from Ciurca, 1990, p. D13; Figure 5).

The middle portion of the Salina Group consists of thin to thick-bedded dolostones and limestones, some argillaceous, usually dolomitic, beds and evaporites that together are referred to as the Syracuse Formation. A transition zone at the base (see Leutze, 1956) bears a significant faunal zone, the *Waeringopterus* Biofacies that has been traced through the region as far west as Batavia and across the border to the Welland Canal in Ontario, Canada (Leutze, 1961, Ciurca, 1990 p. D12). In contrast, the upper portions of the Syracuse Formation contain stromatolitic beds with an *Eurypterus* fauna. Gypsum beds are locally prominent.

The Camillus Formation constitutes uppermost strata of the Salina Group in this part of the state. Shaly dolostone, thin-bedded dolomitic mudstones and evaporites are prevalent. Fossils are exceedingly rare and no important horizons are known in the area.

While exposures of the Salina Group are few and far apart, the divisions can generally be recognized across the region. Important localities exhibiting various portions of the Salina Group are noted below.

<u>Erie (Barge) Canal at Pittsford and eastward</u>

Vernon Formation (redbeds) can be observed along the canal walls at Pittsford, New York (near Main Street Bridge) when the canal is drained for the winter. No natural outcrops of the important eurypterid-bearing units (Pittsford, Monroeav, Barge Canal Beds) are known, all occurrences being excavations for highways, buildings, and the canal.

The Vernon Formation occurs at Fairport in the Erie Canal and was recently reexacavated on the northeast side of the bridge over the canal in the village. Sporadic exposures of Vernon Fm. can also be observed along the canal banks all the way to Newark, New York.

<u>Oatka Creek at Garbutt and the Oatka Trail, Oatka Valley</u>

The Oatka Valley contains important exposures of the Syracuse Formation (Garbutt) and higher beds including much of the Camillus Formation (Oatka Trail and side roads to NY 19). Gypsum was formerly mined at the Garbutt sites and good exposures of resistant Syracuse limestone and dolostone, underlying the gypsum bed, can be observed in the floor of and along the banks of Oatka Creek both upstream and downstream of the bridge over the creek at Garbutt.

The contact of the Salina Group with the Bertie Group occurs along the NY19 roadcut just north of LeRoy where the Camillus Formation is directly overlain by the type Fort Hill Waterlime, the basal formation of the Bertie Group. This contact is also excellently revealed at nearby Buttermilk Falls.

Black Creek at NY33 east of Batavia, New York

Exposures along the west side of Black Creek contain about 20 feet (7m) of the Syracuse Formation and consist of thin to thick-bedded, fine-grained dolostones within the *Waeringopterus* Zone.

I990 Roadcut north of Buffalo, New York

An excellent portion of the Syracuse Formation (Salina Group) can be observed in the I990 exposures. The section consists of argillaceous dolostone and thin to medium-bedded dolostone with intercalated gypsum.

BERTIE GROUP

Overlying the Salina Group in western New York is an assemblage of litho and biofacies quite distinct from much of the strata below. The resistant beds are ledge-formers and consequently a number of waterfalls in the area are supported by Bertie dolostones. Some of the more important Bertie localities are noted at the end of this section.

The term "Bertie" was originated by Chapman (1864) for a sequence of strata in the Niagara Peninsula of Ontario, not far from the Canada-United States border. Originally a formation, Fisher (1960) wisely regarded the rocks as a group consisting of named formations (Oatka through Williamsville). A selected history of Bertie nomenclature is shown in Figure 2). See also Ciurca, 1982.

Chapman undoubtedly included the Akron Dolostone in his interpretation of the Bertie as he gives a thickness of about fifty feet for the sequence west of the Niagara River. Recent measurements of the type Bertie indicate that 45-50 (15-18m) of strata are present, inclusive of the Akron Dolostone. The Akron Dolostone (Akron-Cobleskill strata) consists of very fine-grained rocks in the Canadian sections and approaches a mottled waterlime in character. Because the rocks are so similar to the typical Bertie strata below, especially to the Victor Dolostone, and because the unit is generally thin (3-5 meters), the Akron-Cobleskill here, as well as the newly discovered and stratigraphically higher waterlime (Moran Corner Waterlime, Ciurca, 1990, p. D17), have been included within the Bertie Group (Figure 1). Inclusion of these units assembles all the recurring eurypterid-bearing waterlimes into a useful package (i.e. Bertie Group), presumably completely of Late Silurian age (essentially the *Eccentricosta jerseyensis* Zone in the Appalachian Basin).

Oaks Corners Quarry southeast of Phelps, New York

Exposures in quarry walls exhibit the very irregular contact of the Middle Devonian Onondaga Limestone with the underlying Late Silurian Akron Dolostone. The Williamsville

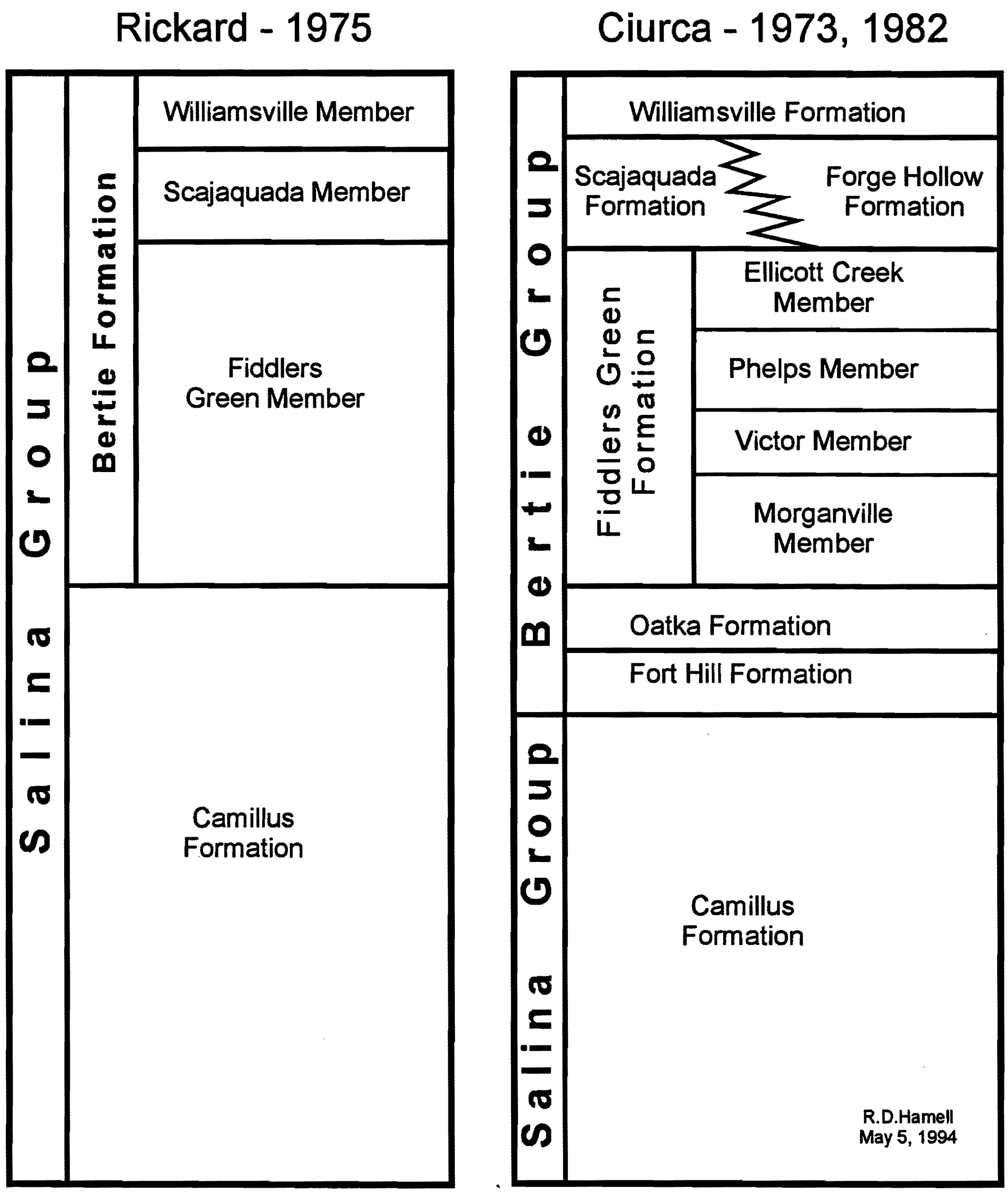

FIGURE 2 Evolution of Stratigraphic terminology for part of the Late Silurian sequence in New York State.

Waterlime is exposed on the quarry floor at the east end with several feet of the underlying Scajaquada Formation usually covered by water at the lowest portion of the quarry.

NYS Thruway and NY88 roadcuts at Phelps, New York

Roadcuts just northwest of Phelps expose Middle Devonian Onondaga Limestone (sandy at base) resting upon only a small portion of the Scajaquada Formation. Most of the Scajaquada Fm., the overlying Williamsville Waterlime and the Akron Dolostone have all been removed by an erosional event prior to the deposition of the Devonian units.

Both roadcuts reveal an almost entire sequence of the Fiddlers Green Formation, including the type Phelps Waterlime Member with a horizon of mudcracks at the top. Underlying units include the Oatka Shaly Dolostone, the Fort Hill Waterlime, and uppermost Camillus Formation (Salina Group). The Silurian-Devonian contact in this region varies considerably in position (See Figure 1).

Mud Creek at East Victor

Just south of NY96, along Mud Creek, is a small waterfall formed of resistant Morganville Waterline (basal Fiddlers Green Formation) with large scale conchoidal fracturing (conchoids) upon weathering. Upstream, the Victor Dolostone (type section) is intermittently exposed and bears a fauna of brachiopods, ostracods and eurypterids.

All higher units, including most or all of the Akron-Cobleskill, are well displayed much farther upstream. Both the *Eurypterus remipes remipes* Fauna and the *Eurypterus remipes lacustris* Fauna are well represented in these exposures

Buttermilk Falls north of LeRoy, New York

A large waterfall, capped by resistant cherty Onondaga Limestone, exposes the entire Fiddlers Green Formation and about 20 feet (7m) of underlying units (Camillus through Oatka Fms.).

The Scajaquada, Williamsville and Akron Formations have all been removed prior to deposition of the overlying Devonian limestones. Nearby, at the Genesee Country Museum Nature Trail, these units reappear beneath the Onondaga Limestone.

Indian Falls west of NY77

A magnificent waterfall, comprised of the very resistant Victor Dolostone (middle Fiddlers Green Fm.) occurs along the creek just west of NY77. These massive beds of Victor Dolostone (fine to medium-grained, finely crystalline dolostone with *Whitfieldella)* occur from the waterfall eastward to the bridge at NY77. Uppermost layers contain salthoppers.

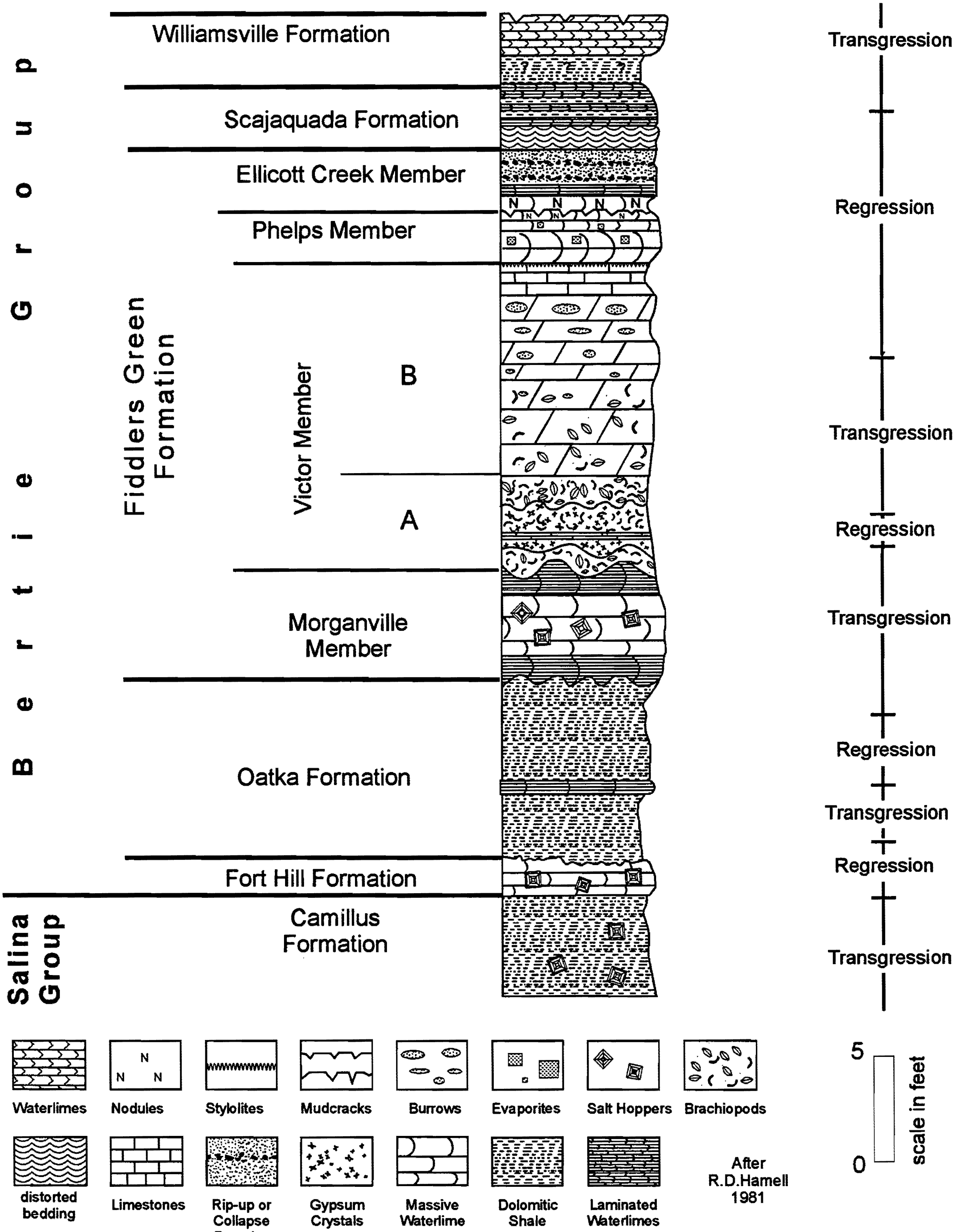

FIGURE 3 Stratigraphic column for part of the Late Silurian sequence in Western New York State. [from Hamell and Ciurca, 1986]

Thick beds of Morganville Waterlime occur in the face of the waterfall and are underlain by the Oatka Fm. followed by the Fort Hill Waterlime. The lowest unit exposed is the Camillus Formation consisting of shaly dolostone and dolomitic mudstone.

POST-SILURIAN SEDIMENTATION

It has been suggested previously (Ciurca, 1982, p. 115, Figure 6) that an unconformity separates Silurian Bertie Group sediments from the subsequent Devonian Manlius Group sediments. This view is reinterpreted in Figure 1 which shows the absence of the Moran Corner Waterlime and part of the Akron-Cobleskill sequence in the Grand River region of the Niagara Peninsula in Ontario.

Biostratigraphically, the hiatus is supported by the abrupt appearance of the genus *Erieopterus* which replaces the "*Eurypterus Beds*" scattered across New York state and the Niagara Peninsula of Ontario. *Eurypterus* is everywhere associated with faunal elements suggestive of a Silurian age (*Cystihalysites, Eccentricosta jerseyensis,* etc.).

The Manlius Group, in contrast, bears *Erieopterus* associated with *Howellella vanuxemi* and grades eastward into a sequence bearing a diverse fauna that is generally interpreted to be Early Devonian in age. Correlatives of the Manlius Group (Honeoye Falls Dolostone, Clanbrassil Formation) are lithologically distinct. The distribution of the Late Silurian and Early Devonian eurypterid-bearing waterlimes of western New York and southwestern Ontario has been illustrated previously (Ciurca, 1990; Figure 5).

SEDIMENTARY STRUCTURES

Many interesting sedimentary structures are preserved throughout the Salina and Bertie Groups. Here we concentrate on those of particular interest in reconstructing the paleoenvironments of the various subdivisions of the Bertie Group. A detailed stratigraphic column indicating the distribution of many kinds of structures is provided in Figure 3. The cyclic nature of the sequence shown is quite evident and has been discussed previously (Ciurca, 1973, 1978; Hamell and Ciurca, 1986).

Salt Crystal Structures

Almost ubiquitous throughout the Salina and Bertie Groups are casts and cavities formed by the dissolution of crystalline halite and other evaporites. Some of the largest relict halite crystals, including salt hoppers, occur within the upper Fiddlers Green Formation of the Bertie Group. Salt hoppers measuring 12 inches (30 cm) on a side are common, particularly along the outcrop belt from Phelps, New York westward to near Buffalo, New York. Though known from the days of the earliest New York geological surveys (see Figure 4), there has been little interest in their distribution geographically and stratigraphically within the evaporite

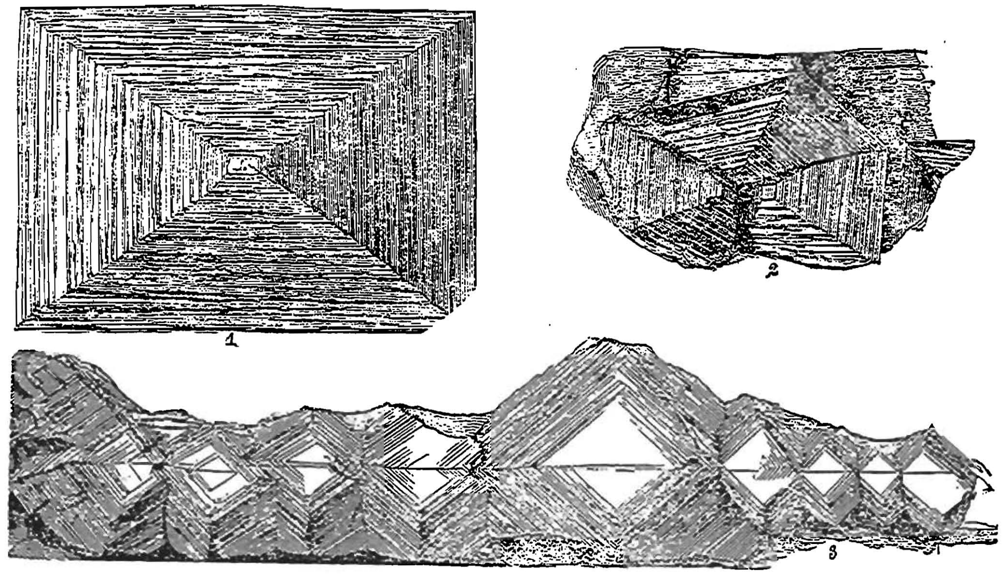

FIGURE 4 "Hopper-shaped crystals from the marl of the Onondaga salt group, town of Lenox, Madison County" (Hall, 1834)

sequence that constitutes much of the Salina and Bertie Groups. Ciurca (1990, p. D6) has recently suggested that hypersaline conditions were actually initiated in upper Lockport Group time within New York State. And just above the Lockport Group, in the basal Vernon Formation, salt hoppers become abundant in association with the eurypterid biofacies distributed in recurrent beds mostly in the Pittsford, New York vicinity (e.g. Barge Canal Bed)..

Figure 5A. *Eurypterus remipes remipes* (carapace) with "halo" of micritized brachiopods (*Whitfieldella*) preserved on a conchoid of upper Victor Dolostone (Fiddlers Green Fm.) (X1).

B. Slab of flat-pebble conglomeratic waterlime. Dark clasts (small arrows) are believed to be of "algal" origin, ripped away from nearby biostromes. Note salt hopper on clast marked H near bottom of figure. Eurypterid fragments (large arrow near top of figure) are present including this pretelson probably belonging to *Eurypterus laculatus*. Specimens: Ellicott Creek Breccia (Fiddlers Green Fm.), Ontario, Canada (X0.75).

C, D. Fossil plants. Figure D is *Cooksonia*, believed to be one of the earliest land plant, from the Williamsville Fm., i.e. the *Eurypterus remipes lacustris* Zone of western New York. Note preservation of terminal sporangia and the fragmentary nature of the specimens (C-X1.2, D-X1.25). Specimens: Ciurca Eurypterid Collection.

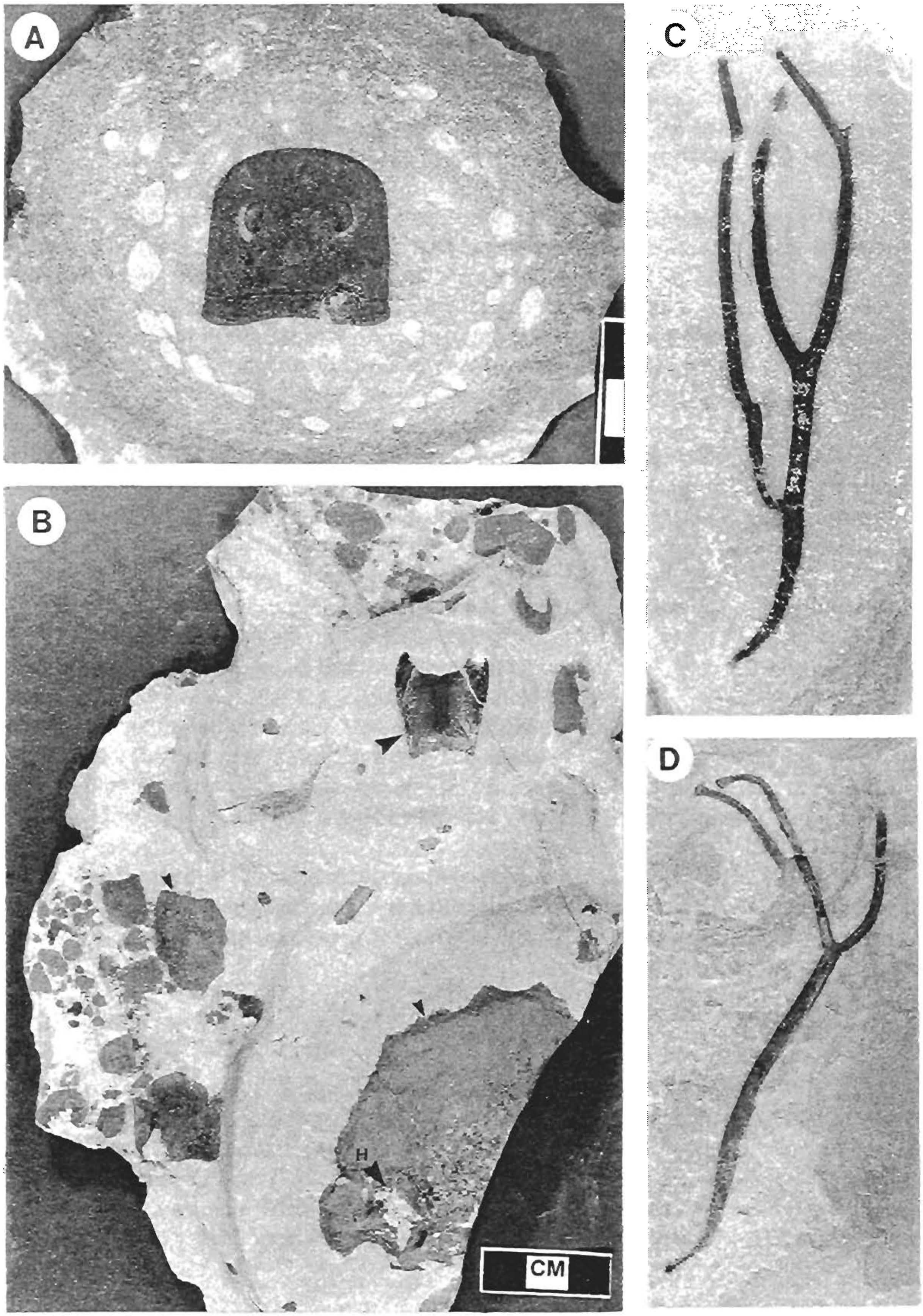

FIGURE 5 Some Fossils and Sedimentary Structures, Bertie Group.

Salt hoppers occur commonly on eurypterid parts, especially carapaces, in the Bertie Group rocks (Ellicott Creek Breccia in Ontario, Canada) and on *Waeringopterus* in the Salina Group rocks. Recently, salt hoppers have also been observed on what are interpreted to be ripped up clasts of algal mats (see Figure 5B).

One of the interesting aspects of the occurrence of salt hoppers throughout the series is replacement mineralization. Pseudomorphs after halite vary considerably. Commonly, dolomitic muds (waterlime) infill the halite crystals or their hopper faces, upon dissolution, and preserve the crystals as molds and casts. Within, particularly, the Ellicott Creek Breccia, the salt hoppers are delineated by red surfaces, presumably an alteration product (hematite or limonite) of iron sulfide. In strata not particularly exposed to weathering, pyrite has been observed to fill in the spaces, especially those along the hopper surfaces.

Crystalline (metallic) hematite replaces the halite within certain zones of the Vernon Formation (Salina Group). White, pearly dolomite replaces halite in the Fiddlers Green Fm. of the Auburn, New York area. And in the Syracuse Fm. at Camillus, New York, halite is replaced by quartz.

Several years ago, we had an opportunity to examine "outcrops" along the new "road" then being constructed at the Retsof Salt Mine (AKZO) from the main level (about 1180 feet beneath the surface) to a lower salt horizon some ninety feet below. In the argillaceous rocks exposed in the “roadcut”, presumably Vernon Fm. (Rickard, 1969), we were able to observe the halite "still in their hopper form". While much of the salt in the mine is of the granular type, clear masses of halite filled the hoppers. When such rocks are exposed at the surface, along the outcrop belt, the halite, of course, is quickly removed by water. Left behind are relict "crystals" or their cavities commonly infilled by various minerals as noted above.

Many of the stromatolites found at various horizons throughout the Salina-Bertie grew in hypersaline environments as indicated by their intimate association with relict halite. Indeed, stromatolites in the Syracuse Fm. (Fayetteville, N.Y.) grew atop salt hoppers, the hoppers having been later replaced by selenite.

Laminations

Some of the waterlimes present very straticulate bedding. The fine laminae are varvelike, and are probably seasonal and intimately associated with "algal" growth in nearby stromatolite tracts. We must be careful, however, in ascribing all finely laminated carbonate rocks to "cryptalgal" activity. In the cases observed (Ciurca, 1982, p. 103) the laminated sediments are generally associated with stromatolite mounds and are "inter-reefal" in nature. They are areally limited due to rapid facies changes. Examples include the upper Victor Member, Fiddlers

Green Fm., exemplified in Bertie Township, Canada. These beds are finely laminated and contain abundant *Eurypterus laculatus* and *Eurypterus remipes remipes* associated, essentially always, with *Whitfieldella* and abundant ostracods ("*Leperditia*"). The laminae grade laterally into well-developed shell beds, the beds becoming coarse-grained dolostone with irregular black, presumably carbonaceous, bedding planes. Figure 5A shows a carapace of *Eurypterus remipes remipes* surrounded by a "halo" of micritized brachiopods (*Whitfieldella*) and is from the upper beds of the Victor Dolostone.

The Ellicott Creek Breccia, especially in its upper portions ("topographic waterlime" beds) is also unusually distinctively straticulate. Close examination, however, showed an intimate association with occasional stromatolitic mounds and, again, eurypterids are found in these intermound strata.

Part of the Williamsville Fm. (Bertie Gp.), with its characteristic *Eurypterus remipes lacustris* Fauna, is also finely straticulate, but no "algal" mounds have yet been identified. On the Niagara Peninsula, a ripplemarked surface at the contact of Williamsville A and B Submembers is interpreted as indicating deposition in very shallow water. Just to the east, at Ellicott Creek and Akron Falls, New York, mudcracks occur in the sequence (Ciurca, 1982, p. 107) and indicate that portions of this waterlime, as in the case of many other cyclically formed waterlimes, were deposited in shallow basins susceptible to subaerial exposure and erosion.

In eurypterid-bearing sequences, laminated strata are typically present, and an excellent example is provided by the well-known Kokomo Formation of Indiana and its equivalent on the Bruce Peninsula of Ontario, Canada ("Eramosa Fm." of authors). These occurrences are all illustrative of a general setting of restrictive marine environments, usually with accompanying preservation of relict evaporite structures and other indicators of shallow-water deposition of the dolomitic lime muds as discussed in previous sections.

Ripplemarks

Ripplemarks appear to be a rarely preserved structure within the Salina-Bertie rocks. There are important horizons in the Victor Dolostone near Jerusalem Hill and in the massive Victor dolostone as displayed in Black Creek, Morganville, New York. At the latter site, the Devonian Onondaga Group rests unconformably upon the Victor Dolostone, all overlying Bertie Group units having been eroded from the site before Middle Devonian sedimentation commenced.

Recent studies at sites within the type area of the Bertie in Ontario, Canada (Ciurca, in progress) have shown the presence of ripplemarks within the Williamsville Waterlime at or just above the top of Williamsville A Submember, the important eurypterid-bearing unit of the Williamsville Formation in the region.

The position of known ripplemark horizons, in association with many other sedimentary structures present in these rocks, especially well-developed mudcracks (suncracks of many authors), establishes the shallow-water nature of most of these sediments (see the following section on paleoenvironmental settings).

The extensive fossil windrows, i.e. widespread current-generated accumulations of plants and animals (see Ciurca, 1978, p. 226), are a peculiar type of ripplemark intimately associated with the eurypterid-bearing waterlimes of the Salina-Bertie sequence.

In addition to the "algal" bioclasts, dislodged and transported into the accumulating lime muds of the quieter interbiostromal regions, and represented by the recurrent waterlime beds of the Bertie Group sequence, a few typically marine forms were introduced. They are generally found in clusters (e.g. small high-spiraled gastropods) or in linear clusters, i.e. windrows (e.g. various cephalopods including *Hexameroceras*). Also obviously introduced were fragments of plants including algae of various kinds, and some of the early "land plants". Recently discovered plants (Ciurca, in preparation), found in the Williamsville Waterlime, and illustrated in Figure 5C and Figure 5D, show the fragmentary nature of the specimens preserved. *Cooksonia*, generally regarded as an early "land plant" bears terminal sporangia (Figure 5D).

Chert Nodules

Small, very round chert nodules are characteristic of the Scajaquada Fm. (Bertie Gp.) from at least Victor, N.Y., westward into Bertie Township on the Niagara Peninsula, Ontario, Canada. Within this formation, and in transitional beds of the Ellicott Creek Breccia, are horizons of an oolitic texture, perhaps silicified oolites (i.e. chert; Hamell, 1981). Petrographic evidence for this type of replacement (gypsum-anhydrite) is the length-slow nature of the chalcedony (Friedman, 1964; West, 1964, 1973; Folk and Pittman; 1971). In the Bertie Gp. occurrences, sphalerite is sometimes associated with the chert replacement.

Evaporite structures (halite) occur in the Scajaquada Fm. at Phelps, N.Y. and the gypsum beds of the Forge Hollow Fm. appear just to the east (Cayuga Lake, Auburn areas). These observations support the interpretation above, that the chert is likely pseudomorphic after gypsum, being intimately associated with an evaporite sequence that divides the Bertie Group (redefined) into two parts of about equal thickness.

Chert beds constitute much of the Cobleskill Fm. in the Marcellus Falls, New York area, but these beds are not believed to be associated with gypsum deposition. They occur, rather, in a more normal marine sequence adjacent to possible Cobleskill "reefs" of corals and stromatoporoids (somewhat analogous to sections of the Lockport Group).

Soft Sediment Deformation And Other Structures

Cross-bedding is generally so fine that it escapes notice. However, many of the eurypterid-bearing waterlimes, especially those that exhibit straticulate bedding, show evidence of cross-bedding, scouring, slumping, reworking of sediments including rip-up clasts and redistribution of sediment. Included within the sedimentation processes are the eurypterid remains which were wrinkled and otherwise distorted as they were transported to the accumulating carbonate muds.

Extensive windrows of oriented fossils in the waterlimes are due to currents that accumulated the hard parts (i.e. exoskeletons) and disarticulated structures into arrays of clustered debris (see Ciurca, 1978, Figure 1, p. 226). Microfaulting is commonly observed (e.g. Phelps Waterlime at Sphon Hill sites east of Cedarville, New York) where dolomitic muds were disturbed by current activity and subjected to subaerial exposure. Sometimes the integument of eurypterid parts are offset by microfaulting. During subaerial exposure, disarticulated eurypterid parts were washed into opened cracks before being sealed by lime muds (Ciurca, in progress).

Brecciation is particularly well-developed in the Ellicott Creek Breccia and was generated by rip-up currents associated with stromatolite "reefs" and their intermound channels. The laterally extensive zone of waterlime breccia (over 100 miles) may represent a seismite deposit. While strong currents undoubtedly ripped-up clasts, both dolomitic mud and "algal mats", from the "algal reef" tract, it may have been a particularly extensive phenomena (e.g. earthquake, tsunami) that dislodged and carried lithoclasts and bioclasts shoreward to form part of the Ellicott Creek Breccia. No other waterlime unit exhibits such a degree of brecciation. As previously noted (Ciurca, 1982, p. 103), the Ellicott Creek Breccia is a tripartite unit with stromatolite mounds particularly important in the middle and brecciated waterlimes particularly evident in upper and lower portions, when present.

Stromatolites

Stromatolitic and thrombolitic structures are among the most important elements distributed through the eurypterid-bearing sequences in New York and these structures continue into the Niagara Peninsula of Ontario (see discussion in Ciurca, 1990). These structures, forming extensive biostromes and bioherms, were initiated upon deposition of much of the Lockport Group (Zenger, 1965; Ciurca and Domagala, 1988).

Within the Salina Group, stromatolite distribution has been little studied. Stromatolites are important within certain zones, most notably the *Waeringopterus* Zone near the base of the Syracuse Formation (Ciurca, 1990, p. 82, p. 111). Within this zone, the stromatolites extend from at least Syracuse westward to the Welland Canal in Ontario, Canada. At the latter site, a bed of gypsum occurs just below the horizon. At Garbutt, New York, stromatolites occur along Oatka Creek in upper beds of the Syracuse Formation. Little is known, however, of the associated fauna in this area.

The recent discovery of *Eurypterus pittsfordensis* near the Niagara Gorge (Ciurca, 1993) was made in a sequence of large-scale stromatolitic mounds in the upper Lockport Group (see Zenger, 1965, p.114, Figure 22). The thin-bedded micritic beds found adjacent to the stromatolites are similar in many ways to the eurypterid-bearing waterlimes of the Salina and Bertie Groups. Ciurca (1990, p. D6) noted distinct stromatolite mounds in a transitional interval at the North Chili site where *Eurypterus pittsfordensis* is particularly abundant in a "*Chondrites* facies." See Figure 6.

Stromatolites are also widely distributed within the Bertie Group from the Sphon Hill area near Cedarville, New York westward throughout the state and into the Niagara Peninsula of Ontario. Particularly noteworthy are the occurrences at the Neid Road Quarry (north of LeRoy, NY) where eurypterids are found in the waterlimes surrounding the stromatolites (presumably Ellicott Creek Breccia). The same observations have been made at the Ridgemount Quarry near Fort Erie, Ontario, Canada within the Ellicott Creek Breccia (uppermost Fiddlers Green Fm.). The *Eurypterus remipes remipes* Fauna is abundantly represented at this site and the remains are mostly concentrated in the dolomicrite (waterlimes) that underlie, overly or surround the stromatolites.

Thrombolites (see Cys and Mazzullo, 1978) are peculiar "algal" mounds, resembling outwardly the shapes of many types of stromatolites, but having a clotted structure rather than a laminated appearance. Impressive thrombolitic biostromes also occur within the Victor Dolostone at the Ridgemount Quarry Site (see Figure 7) and again well-preserved eurypterid remains are often encountered in the interbeds, in this case the *Whitfieldella* beds which dominate much of the Victor Member throughout it extent. One of the most characteristic eurypterids of the Victor Dolostone is *Eurypterus laculatus* (Figure 8). Note although widely misidentified, particularly by Copeland and Bolton (1985), *Eurypterus laculatus* is part of a group termed the "Ontario eurypterids" by Ciurca (1990) because of their widespread occurrence in a belt paralleling Lake Ontario and that continues into the province of Ontario, Canada. *E. laculatus* is intimately associated with the thrombolites in Ontario and is also unusually abundant at Morganville, New York (Victor Dolostone) and also occurs in the Neid Road Quarry associated with stromatolites and other eurypterids. It is also notably a common form in the Victor and Ellicott Creek Members of the Fiddlers Green Formation of southwestern Ontario, Canada (Ciurca, in preparation)

An example of Devonian eurypterid/stromatolite association was given for the Thacher Limestone at Clockville previously (Ciurca, 1978, p. 24). The eurypterid is *Erieopterus* and the stromatolite horizon was illustrated by Rickard (1962, p. 5, Figure 12). *Erieopterus* was also shown "swimming" in a *Howellella* maze among thrombolites (Chrysler Formation, H Member). See Ciurca, 1978, p. D24, Figure 6.

Recent examples of stromatolitic structures, and their modification of the local environment, are rare. For an unusually impressive seascape showing rippled sands flowing between stromatolite mounds in the shallow waters of the eastern Bahamas. See the article by Gore (1989, p. 674-675).

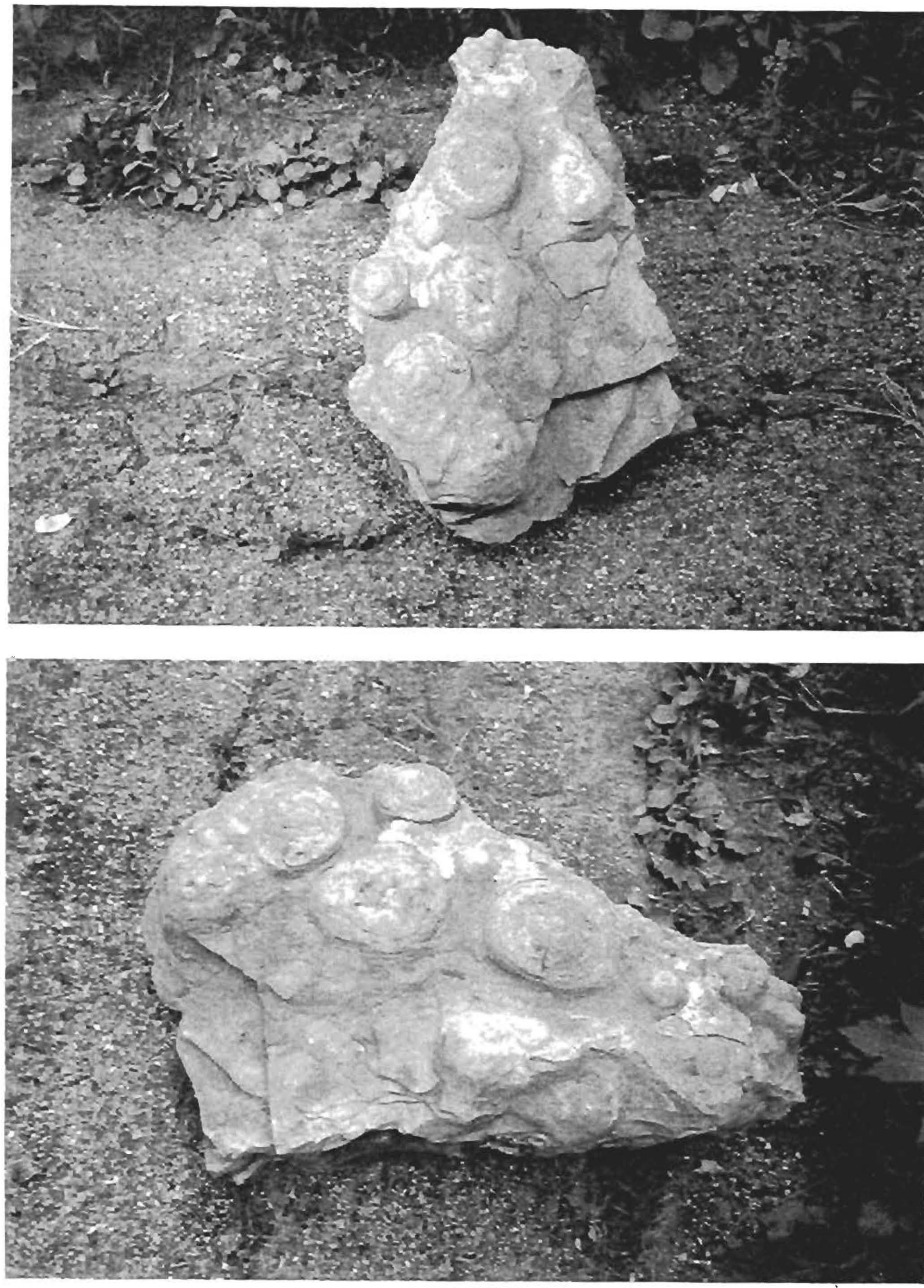

FIGURE 6 Massive stromatolite complex presumably constructed by cyanobacteria ("algal" mound) recovered from ~20 feet below the surface in transitional Lockport/Salina Groups. Irregular top portion was covered by black shaly partings. Sequence is within *Eurypterus pittsfordensis* Zone. NY 33 at North Chili, New York. Stromatolite block is 64 cm along the long axis. Specimen from the Ciurca Eurypterid Collection.

FIGURE 7 Large thrombolite in a block of Victor Dolostone, Fiddlers Green Formation. Note irregular contact of the mound with the overlying waterlime (lighter color) "fused" to its surface. The waterlimes contain the eurypterid fauna. Interthrombolite sediments contain abundant brachiopods, e.g. *Whitfieldella* sp., Ridgemount Quarry, Bertie Township, Ontario, Canada.

FIGURE 8 *Eurypterus laculatus*. Specimen is one inch in length and is from the Ellicott Creek Breccia, Fiddlers Green Formation, Bertie Group, Ridgemount Quarry, Ontario, Canada.

FIGURE 9 Examples of "Boomerangs", peculiar sedimentary structures recently exposed on quarry floor at contact of Williamsville A Submember with Williamsville B Submember, Bertie Group, Ridgemount Quarry, Ontario, Canada. Pointer in photo is 0.5 meters and points north.

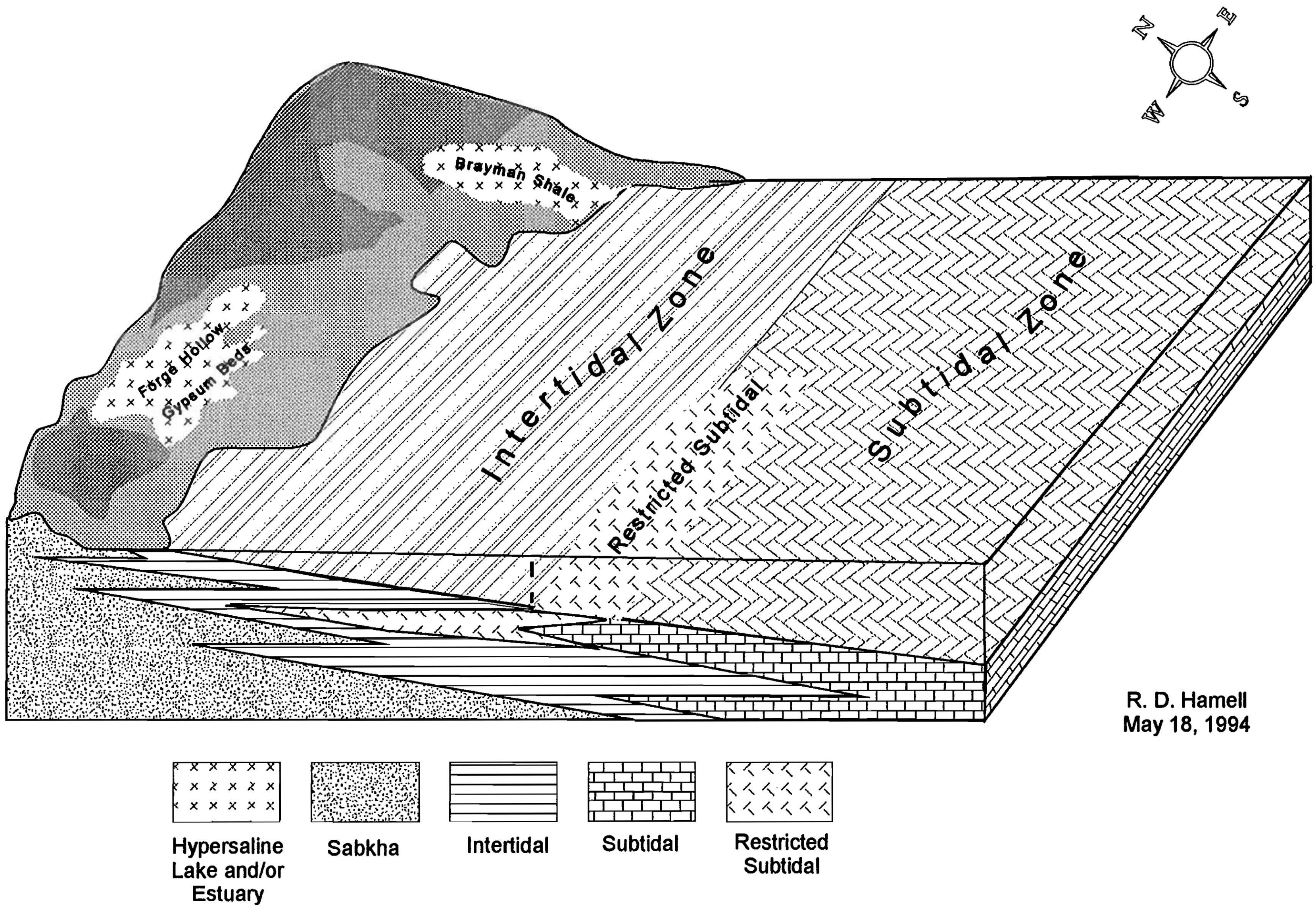

FIGURE 10 Schematic reconstruction of the paleoenvironmental setting during the deposition of the Bertie Group lithologies.
[After Hamell, 1981]

Trace Fossils

Trace fossils are relatively rare in the waterlimes of the Bertie Group. Some very peculiar and large structures, about the size and shape of a boomerang, were observed by Ciurca (and recently witnessed by C. Brett) in the Spring 1994. The "boomerangs" were observed on the quarry floor at the Ridgemount Site and occur at or just above the contact of Williamsville A and B Submembers. Samples (or casts) of these unusual structures are currently under study. These structures (Figure 9) may actually prove to be due to some kind of extraordinary current activity.

Exceedingly abundant trace fossils occur within the Victor Dolostone and the Akron-Cobleskill. Undoubtedly the mottling, so characteristic of both units, is due to extensive bioturbation and this in turn appears to have controlled dolomitization of these units. Bedding planes are profusely covered by rodlike structures presumably made by unknown burrowers. Bedding planes in these units are generally irregular and covered by black (carbonaceous) shaly material. Only ostracods and a limited variety of brachiopods are present. Note: Eastward (and southward) the Akron-Cobleskill becomes progressively more fossiliferous. Biostromes with stromatoporoids and corals are encountered, and the brachiopods become more diversified. For a description of Cobleskill Formation stromatoporoids, see Stock (1979); and for brachiopods, see Berdan (1972).

PALEOENVIRONMENTAL SETTINGS

Eight different paleoenvironments are recognized in the Bertie Group (Hamell, 1985). From onshore to offshore they are: 1) sabkha, 2) hypersaline lake, 3) lower supratidal, 4) upper intertidal to lower intertidal, 5) lower intertidal, 6) restricted subtidal, 7) non-restricted subtidal, and 8) semi-restricted lagoon-estuary. A schematic reconstruction of the paleoenvironmental settings during deposition of the Bertie Group is shown in Figure 10. Further details can be found in Hamell and Ciurca, 1986).

Sabkha

Sabkhal sedimentation is characterized by relatively barren dolomitic muds. Carbonate based shells (i.e. brachiopod-*Whitfieldella*) were leached out during periodic flooding. Evaporites are common such as gypsum-anhydrite nodules and halite (casts). This depositional setting is reflected in the sediments of the Camillus Formation (Salina Group) and the Oatka and Scajaquada Formations of the Bertie Group.

Hypersaline Lakes - Estuaries

The gypsum deposits of the Forge Hollow Formation in central New York are considered to be analogous to the present day sedimentation of gypsum reported by Lucia (1968) as occurring in shallow hypersaline lakes on Northern Antilles island of Bonaire. These restricted sabkhal-hypersaline lake deposits are separated from the sea by a barrier composed of permeable sabkhal sediments. The permeability of these sediments permits the influx of sea water to the hypersaline lakes so as to replace water lost to evaporation. Seasonal changes in recharge and evaporation rates result in the laminated bedding of these barren and thick gypsum beds.

Supratidal

Sediments in lower sabkhal to upper supratidal environments are indicated by collapse and rip-up breccias of the Ellicott Creek Member of the Fiddlers Green Formation. Deposition (rip-up breccias) is the result of high spring tides and major storm surges. In the interim, during prolonged subaerial exposure, evaporites form. Periodic influx of water in the sediment, from precipitation and/or flooding, dissolves the evaporites causing the subsequent collapse breccias.

Intertidal

Discussion of the Brayman Shale of eastern New York is important in presenting a complete interpretation of Bertie environmental facies. Past studies by Belak (1980) and Treesh (1972) have inferred that the Brayman Shale and the Phelps and Williamsville Waterlimes were deposited in an intertidal environment. Fisher and Rickard (1953) noted that the dissimilarity of the Brayman and the Forge Hollow Fms. was most likely the result of slight facies changes. The high content of pyrite and black shales in the Brayman suggests a restricted estuarine environment where sulfate-reducing bacteria inhibited the accumulation of gypsum which is found in the Forge Hollow. Morris and Dickey (1957) described a similar depositional environment in Peru.

Intertidal deposition of waterlimes is represented by portions of the Fort Hill Formation, Morganville and Phelps Members of the Fiddlers Green Formation and the Williamsville Formation. Lowermost sabkhal to uppermost intertidal zones are characterized by mudcracks and laminated bedding. Subaerial exposure and evaporation resulted in the generation of hypersaline water in these sediments and subsequent deposition of salt hoppers, reticulate halite structures. Fossils are sparse, cryptalgal structures and an eurypterid fauna being the most common. Ghost structures of cephalopods and gastropods have also been found. Their poor preservation is the product of leaching (dissolving) of calcium carbonate based shells, whereas chitinous exoskeletons of eurypterids and phyllocarids are relatively unaffected. Such selectivity of preservation has been documented in modern sediments of intertidal marsh environments.

Subtidal

The Victor A Submember is a lithographic limestone that contains the small brachiopod *Whitfieldella*. The central portion of this unit contains a one-foot thick layer of tightly packed gypsum crystals. The upper 2.5 feet of the Victor B Submember has a similar deposit of gypsum. These units represent conditions of hypersalinity in a restricted upper subtidal environment.

The rock units of the lower Victor B Submember range from having an undulating (wavy) laminated bedding to mottled and thick-bedded dolostones. When freshly broken the rocks emit a strong petroliferous odor. The mottling of this facies is due to bioturbation and is typical of modern shallow intertidal environments (unrestricted). Complete specimens of the brachiopod *Whitfieldella* and the common ostracod *Leperditia* are a common constituent of this zone.

The Victor B Submember, a dark, slightly argillaceous dolostone with brachiopods horizontal burrows, indicates a deeper subtidal facies. Although this environment represents a more seaward setting, the small size of *Whitfiedella*, along with a low faunal diversity and absence of typical marine organisms, indicate a depositional environment under hypersaline conditions.

SUMMARY

The Bertie Group is a carbonate sequence that accumulated during multiple oscillations (e.g. sabkhal-intertidal-sabkhal; Camillus-Fort Hill-Oatka Formations, see Figure 3) of the Late Cayugan Sea. Numerous waterlimes, noted for the eurypterid assemblages they contain, occur cyclically in this sequence and are associated with numerous structures indicating a shallow-water origin for much of the Bertie Group.

The Fiddlers Green Formation records the major transgressive-regressive cycle within the lower Bertie Group. Farthest offshore facies are represented by the Victor B Submember, a fine-grained fossiliferous limestone that contains well-developed horizontal burrows and mottling due to extensive bioturbation.

The waterlime breccias of the Ellicott Creek Member indicate supratidal conditions. Intraclasts formed from lime muds and ripped-up algal mats characterize the unit from the Niagara Peninsula, Ontario, Canada, eastward to at least Phelps, New York. Supratidal to intertidal sedimentation is displayed by the Morganville and Phelps Waterlime Members, as well as other waterlime units. Key indicators include mudcracks, cryptalgal structures, and laminated sediments.

Subtidal deposition, under conditions approaching near-normal salinity, are recorded in the thickest and most fossiliferous member of the Fiddlers Green Formation, i.e. the Victor Dolostone, and also the Akron-Cobleskill of the region. Restricted subtidal deposition of bladed gypsum crystals is represented in the Victor B Submember.

ACKNOWLEDGMENTS

S. J. Ciurca, Jr. wishes to thank Marilar Maher and Steve Jarose for supporting some of the field work. Photographic assistance was provided by Steve Pavelsky and John Honan. Photographs of the fossils for Figure 5 were kindly provided by Wendy L. Taylor (University of Rochester). Gary Rakes produced the fine enlargement of *Eurypterus laculatus*. I am grateful to Ridgemount Quarries Ltd. for allowing unlimited access to their quarries to retrieve sedimentological structures, fossil specimens, and data before they were transformed to crushed stone.

We wish to thank AKZO for the access to the Retsof Salt Mine so that we could examine the primary salt bed and the "roadway" to the lower salt bed. We extend our gratitute to Linda Hefron for her support in developing the roadlog. Carlton Brett read the manuscript and we are grateful for his comments.

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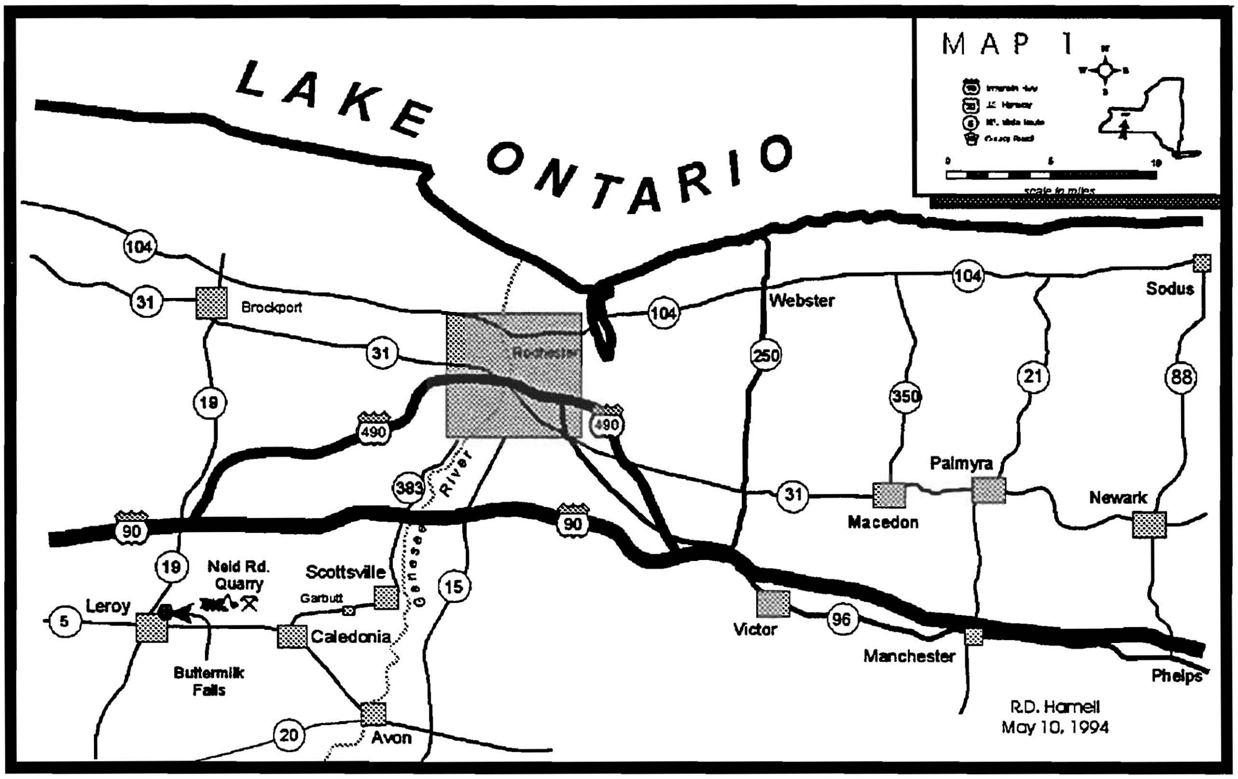


FIGURE 11 Field Trip Map. Follow NY383 South to Garbutt, formerly the site of a gypsum mining industry.

ROADLOG

CUMM. MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
		Depart University of Rochester Campus at Wilson Blvd.
0.00	0.00	Roadlog begins at the intersection of Wilson Blvd. and Elmwood Ave. TURN RIGHT.
0.40	0.40	Genesee River on right. BEAR LEFT. Go south on NY383.
2.60	2.20	Jct. 252A. Continue south on NY383.
3.90	1.70	Jct. NY252 (Jefferson Road).
8.50	4.60	NYS Thruway (I-90) overpass.
9.80	1.30	Village of Scottsville. Continue south on NY383.

11.00	1.20	Jct. NY386.
12.80	0.10	TURN LEFT on Union Street. Cross railroad tracks. Turn RIGHT into the parking lot of Oatka Creek Park.

STOP 1 - OATKA CREEK AT GARBUTT

Excellent exposures of the Syracuse Fm. (Salina Gp.) occur along Oatka Creek both upstream and downstream of the Union Street Bridge over the creek. Over 50 feet of strata have been measured along the south side of the creek and the entire section appears to represent the Upper Syracuse Formation. Included are argillaceous, thin-bedded (flaggy) dolostones, massive limestones and dolostones (particularly along the banks of the creek), thin waterlime units and evaporites. The site was extensively mined for gypsum and the ruins of some of the buildings that were constructed are still visible on the north side of the creek just upstream from the bridge. Note the buildings were constructed with glacial erratics and slabs of Syracuse Formation. An account of the gypsum mining activity here, and in nearby areas, can be found in Newland (1929).

Very few fossils have been described from the Syracuse Fm. of the region. The eurypterid *Waeringopterus* was traced into western New York but has not been found along the Oatka Creek Valley (Ciurca, 1990, p. D10). *Eurypterus* has been found in a waterlime bed immediately upstream from the bridge. The exposures in the wall on the south side of Oatka Creek have yielded cephalopods and *Medusaegraptus*. An algal stromatolite horizon occurs near the top of the section.

13.00	0.10	Leave parking lot. TURN LEFT (north) on Union. Proceed (back) to NY383.
13.20	0.20	Jct. NY383. TURN LEFT.
17.10	3.90	Jct. NY 36 TURN LEFT (south) to Mumford.
17.50	0.40	Flint Hill Road. TURN RIGHT.
18.90	1.40	Genesee Country Museum on left.
20.20	1.30	Entering Genesee County.
21.10	0.90	Jct. Neid Road. TURN RIGHT.
21.30	0.20	Park along roadside adjacent to large boulders.

STOP 2 - VICTOR DOLOSTONE ERRATICS

Massive Victor Dolostone (middle member of the Fiddlers Green Fm.) can be observed in the waterfall at nearby Buttermilk Falls. The large erratics at the driveway exhibit the finely crystalline character typical of the Victor Dolostone. Bedding planes are often covered with the small brachiopod, *Whitfieldella.*

Continue north on Neid Road.

21.50	0.20	Jct. road to the Town of LeRoy Refuse Area. TURN LEFT.

STOP 3 - THE NEID ROAD QUARRY

This quarry exposes a fine section of the Late Silurian Bertie Group overlain by massive beds of the cherty Onondaga Group. The erosional Silurian-Devonian unconformity is well-displayed here. The quarry floor is comprised of the upper waterlimes of the Fiddlers Green Fm. and includes an eurypterid fauna consisting of *Eurypterus* and *Dolichopteris*. The irregularity of portions of the floor is due to algal stromatolite mounds. Salt hoppers and associated relict halite structures are common at this level.

Brecciated waterlimes (Ellicott Creek Breccia) are present just above the quarry floor, particularly at the north wall of the quarry. Immediately overlying this is 5-8 feet of the Scajaquada Formation, an argillaceous, mostly thin-bedded dolostone containing several chert nodule horizons.

The Williamsville Formation, here a particularly drab gray to cream colored dolostone, is exposed along the north wall of the quarry. Fossils are exceedingly rare in this unit. Only phyllocarid telsal spines and a few articulate brachiopods have been found here.

The Akron-Cobleskill is nearly missing from the section. At nearby Buttermilk Falls, the Scajaquada, Williamsville and Akron Fms. are all missing, the Onondaga Limestone rests directly upon the Fiddlers Green Formation.

Return to Neid Road Jct. with Flint Hill Road. TURN RIGHT.

22.30	1..50	Park along the roadside.

STOP 4 - STEAM LOCOMOTIVE AND SHOVEL

Turn-of-the-century (1902) steam shovel used quarrying on right.

23.20	0.90	Jct. of Circular Hill Road. TURN RIGHT
25.00	1.80	Jct. with Oatka Trail. TURN LEFT.

25.80	0.80	Jct. Parmelee Road. TURN LEFT.
26.10	0.30	Jct. of NY19. TURN LEFT (south). Park along shoulder.

STOP 5 - FORT HILL WATERLIME

Uppermost Camillus Fm. is well-displayed in the roadcuts along both sides of NY19. At the top is a thin waterlime unit, the Fort Hill Waterlime. The overlying Oatka Formation is concealed by overburden. The Fort Hill Waterlime is considered the base of the Bertie Group and bears an *Eurypterus* Fauna (Ciurca, 1973, p. D3). It is also accessible near the base of nearby Buttermilk Falls.

		Continue south on NY19.
26.70	0.60	Railroad overpass (abandoned)
26.80	0.10	Jct. North Street. TURN LEFT.
27.00	0.20	Park on right shoulder before the bridge over Oatka Creek.

STOP 6 - BUTTERMILK FALLS

Follow the abandoned railroad east to Oatka Creek. A trail to the base of Buttermilk Falls is located on the west side of the valley, north of the railroad bridge over the creek. **Note: walls of the gorge are steep**. The safest trail to the bottom enters the gorge about 1/4 mile north of the falls.

Buttermilk Falls is capped by resistant Onondaga cherty limestone. The underlying Bertie Group forms the reentrant at the unconformable contact with the Onondaga Group.

At creek level is uppermost Camillus Formation (Salina Group). The Bertie Group here starts with the Fort Hill Waterlime, a complete section of the Oatka Formation, and most of the Fiddlers Green Formation. The Scajaquada, Williamsville and Akron Formations are missing due to erosion prior to the deposition of the Middle Devonian Onondaga Limestone.

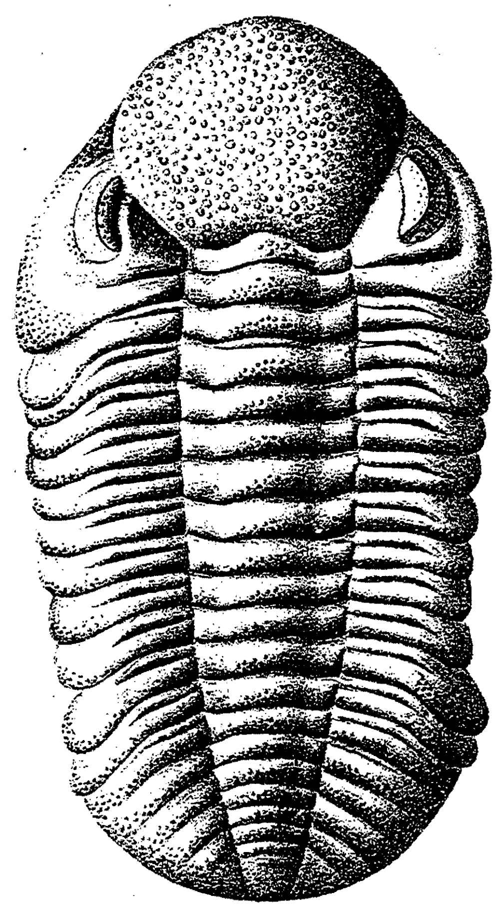
		Proceed on North Street into the Village of LeRoy.
29.00	2.00	Jct. with NY5. TURN RIGHT (west).
		Village of LeRoy, renowned for the creation of **J-E-L-L-O**
29.10	0.10	Bridge over Oatka Creek

STOP 7 - McDONALD'S (on left)

Note: To return to Rochester take NY19 (just west of McDonald's) north to the NYS Thruway (I90) or to I490.

END OF ROADLOG

Late Silurian Estuarine Landscape, Western New York. [Pen and ink drawing by Kay O'Connell, 1980 under the direction of R. Hamell]



Phacops rana

[From Hall, 1888, Natural History of New York: Palaeontology, Vol. VII, Plate I, Figure 10]