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CARBONATE FACIES OF THE ONONDAGA AND BOIS BLANC FORMATIONS NIAGARA PENINSULA, ONTARIO

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INTRODUCTION

Devonian bioherms of the northern Appalachian Basin have been an important source of hydrocarbons since the 1967 discovery of gas from an Onondaga pinnacle reef in Steuben County, New York. Onondaga bioherms are represented in the outcrop belt by small organic buildups which have been studied for at least three-quarters of a century (Grabau, 1903; Stauffer, 1913, 1915). More recent studies of these buildups and their components enable us to better understand the paleogeographic distribution of the buildups, their internal facies structure, and their importance in hydrocarbon exploration.

STRATIGRAPHY

The Onondaga Limestone crops out in a narrow belt across New York (Figure 1) from Albany to Buffalo and continues the length of the Niagara Peninsula of Ontario as far as Hagersville, where it becomes lost beneath glacial drift. South of the outcrop belt the Onondaga is present everywhere in the subsurface.

Within the last 25 years, Onondaga stratigraphy and nomenclature have been modified and refined (Oliver, 1954, 1956a,b, 1966, 1976). Because of their similarity to Onondaga Limestone members

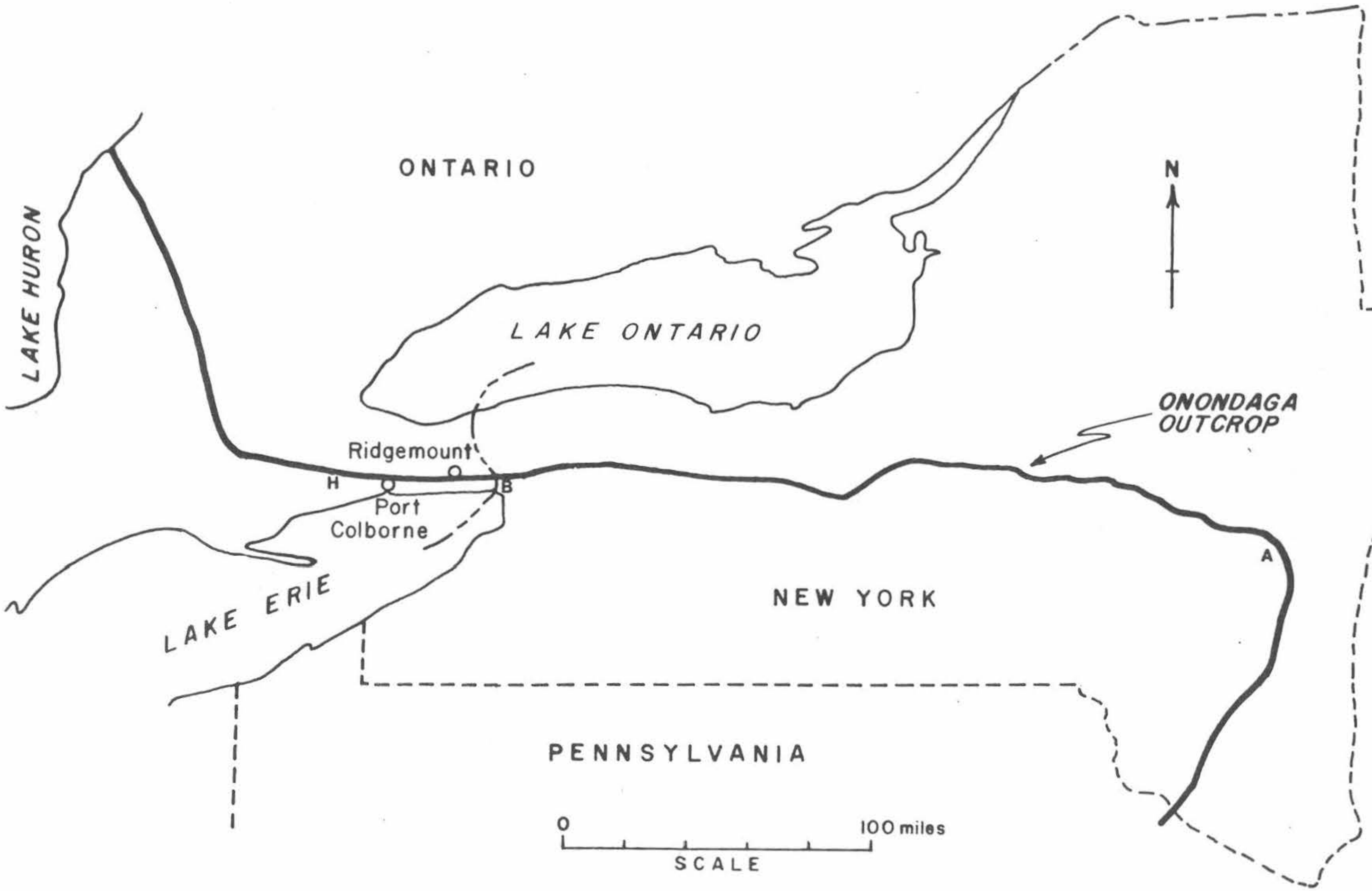

FIGURE 1. Map showing Onondaga outcrop belt and locations of field trip stops. A=Albany; B=Buffalo; H=Hagersville.

of western New York, stratigraphic equivalents on the Niagara Peninsula of Ontario are commonly referred to by New York terminology rather than terminology of central-southwestern Ontario and Michigan. Figure 2 shows approximate relationships between the stratigraphy in southwestern Ontario, New York and Pennsylvania.

Onondaga County, New York, is designated as the type locality for the Onondaga Limestone. The unit consists of four members (in ascending order): Edgecliff, Nedrow, Moorehouse, and Seneca. In western New York, a fifth member, the Clarence, replaces the Nedrow or lies between it and the Edgecliff. In western New York and Ontario, the Onondaga may be underlain by Middle Devonian Bois Blanc Limestone, Lower Devonian Oriskany Sandstone, or Upper Silurian Bertie Dolomite. The Silurian-Devonian unconformity is characterized by a broadly undulatory surface displaying local relief up to 1 m and development of joints and fractures which do not extend into overlying beds (Kobluk and others, 1977). Infilling of some of these solution-widened joints by "Oriskany-type orthoquartzitic sand and conglomerate" indicates post-Oriskany exposure and erosion (Kobluk and others, 1977, p. 1157). In many places, a thin bed of dark green or gray glauconitic, calcareous shale separates the light olive gray, finely crystalline Bertie Dolomite from overlying Bois Blanc or Edgecliff beds.

The Blois Blanc Formation consists of basal Springvale Sandstone and Bois Blanc Limestone. In outcrop, it ranges in thickness from zero at Buffalo to nearly 35 ft at Hagersville. Oliver (1966) discussed the multiple unconformity at the base of the Devonian in New York and on the Niagara Peninsula. In addition to faunal evidence, he described six sequences in which sand may be present or absent at the base of the Onondaga or Bois Blanc formations. The sand is believed to be reworked basal Devonian sandstone and has been designated "Springvale Sandstone," extending the original Ontario usage (Stauffer, 1913) into New york. Because the name applies to two sandy horizons of different ages, this terminology is confusing. In this paper, the original terminology of Stauffer (1913) is adhered to and the term Springvale is applied only to the lower sandstone member of the Bois Blanc Formation.

The Springvale Sandstone and the Bois Blanc Limestone characteristically contain sufficient glauconite to give both units a greenish color. The Springvale also commonly contains phosphate nodules and clasts of Silurian dolomite. The Bois Blanc Limestone is typically medium dark gray, medium-bedded, abundantly cherty skeletal wackestone in which fossils are concentrated in layers. Brachiopods are the dominant constituent, however bryozoans, trilobites and corals are also common. Wispy laminae are characteristic in the Port Colborne area, but at Hagersville, bioturbation has homogenized the clay content of the carbonate. Quartz sand-filled burrows occur in the upper portions of

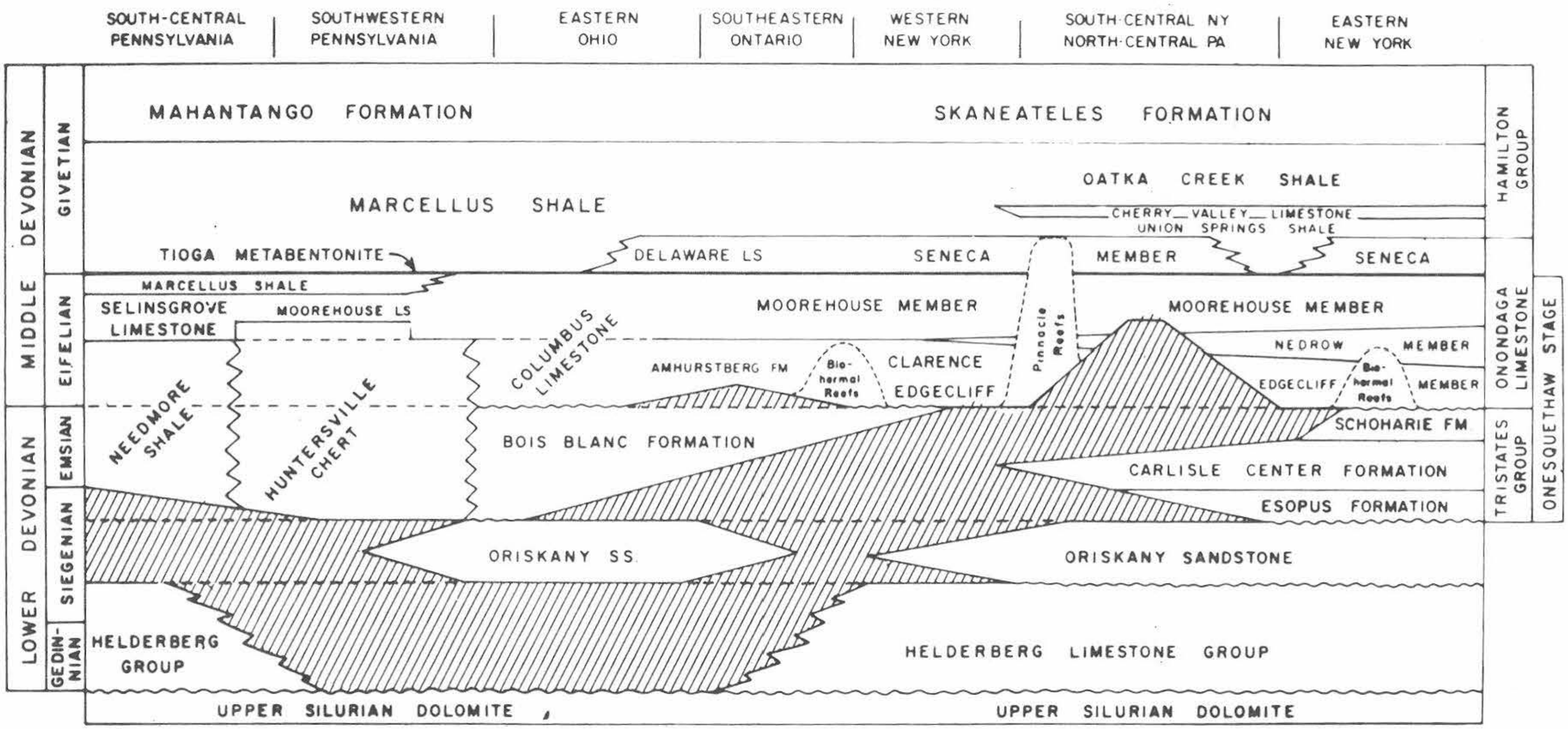

FIGURE 2. Middle and Lower Devonian stratigraphy in the northern Appalachian basin.

some beds. Chert is common in the Bois Blanc in the form of nodules, silicified fossils, and siliceous lime mudstone. Several beds of chert are found at Hagersville. At Port Colborne a bed of dolomitic, glauconitic chert breccia, in which angular chert clasts float in a matrix of siliceous lime mudstone, occurs at the base of the Bois Blanc Limestone.

In many places, a Bois Blanc-Onondaga disconformity can be readily observed; in other places, it is not easily detected. Oliver (1960) recognized two distinct coral assemblages at the base of the Onondaga in western New York. He found the lower (Amphigenia) zone to be lithologically and paleontologically distinct from the Edgecliff Member and suggested it represents "the eastern feather edge of the Bois Blanc Formation" (p. B173), separated from the upper assemblage by a disconformity, which does not represent subaerial exposure.

In the type area the Onondaga is approximately 70 ft thick, and its members exhibit greatest differentiation. It thickens westward and eastward in outcrop from the Syracuse area, exhibiting lateral changes in fauna and lithology, which require alternative criteria for differentiating members and the introduction of an additional member in the west.

Along the outcrop belt of New York and the Niagara Peninsula, the Edgecliff Member is a light gray, coarsely crystalline, massive-bedded limestone, dominantly a crinoid packstone or wackestone containing numerous rugose and tabulate corals. Biohermal facies occur locally. Oliver (1954, 1966, 1976) described many of the bioherms of western New York and Ontario in which colonial rugose corals are profuse. The Edgecliff is thinner in the Buffalo region (5 ft or less) than in the type area, but thickens westward to 12 ft at Hagersville. Light gray, nodular chert is common in the Edgecliff, especially in the upper portion.

Overlying the Edgecliff in the type area is the Nedrow Member; an argillaceous, cherty limestone containing a sparse fauna characterized by platycerid gastropods. In the east, the relative increase of terrigenous sediments, represented by the sharp lower contact of the Nedrow, is interpreted as a time plane (Oliver, 1976). To the west, faunal and lithologic characteristics of the unit overlying "typical" Edgecliff strata change sufficiently to warrant designation (Ozol, 1964) of the Clarence Member. The exact relationships between the Clarence, Nedrow and Edgecliff Members are not clear. Oliver (1966) suggested that in western New York and adjacent Ontario "the Clarence is roughly equivalent to the Nedrow Member, but may include some of the lower Moorehouse Member and uppermost Edgecliff as well" (p. 40). According to Ozol (1964), in western New York the Nedrow Member "does not overlie the Edgecliff, but is present higher in the section" (p. 4145). This relationship is diagrammed by Rickard (1964). The Clarence is the least fossiliferous member of the Onondaga Limestone in western New York and Ontario. It is an olive gray, argillaceous mudstone containing a sparse fauna, including corals, brachiopods, and bryozoans. Dark chert nodules are extremely abundant.

The Nedrow (and Clarence ?) grades upward into the Moorehouse Member, a fine-grained, massive-bedded limestone containing diverse fauna and representing a return to more Edgecliff-like conditions. In many places it resembles the Edgecliff in lithology and fauna, but lacks abundant corals and biohermal facies. It consists of interbedded, massive, olive gray and light olive gray crinoidal wackestone, packstone, and grainstone with sparse tabulate and rugose corals and abundant nodular chert.

Above the Moorehouse is a thin clay bed, the Tioga Bentonite, known throughout the Appalachian basin. It forms a prominent break in outcrop, separating the Seneca and Moorehouse Members which are similar in lithology and fauna, although the Seneca is darker and somewhat more argillaceous. In western New York and Ontario, the upper Onondaga is rarely exposed in outcrop, but subsurface data show that it grades upward and southward into dark shales of the Marcellus Formation.

Chert is ubiquitous throughout the Onondaga. In fine-grained facies it occurs most commonly as lumpy, ellipsoidal nodules, their long axes parallel to bedding. In coarser grained facies (for example, in the Edgecliff), nodules are of highly variable shape and dimensions and are sometimes anastomosing. Many chert nodules contain preserved carbonate skeletal material. In addition, secondary carbonate phases also occur in the form of ferroan and nonferroan forms of dolomite and calcite (Pfirman and Seleck, 1977). Biogenic origin for the chert is indicated by the presence of preserved radiolaria tests and sponge spicules within chert nodules. The high concentration of dissolved silica which resulted in the large volume of Onondaga chert is believed to be related to the advanced erosion of the land area to the east, providing a large proportion of dissolved silica relative to terrigenous detritus (Pfirman and Seleck, 1977).

TECTONIC SETTING

Tectonic elements which influenced Devonian sedimentation in the eastern Great Lakes region were dominated by the northeast-trending Appalachian basin, a center of subsidence which accumulated thick sedimentary sequences. Positive, more stable areas (shallow marine areas when not exposed) were the Cincinatti-Algonquin arch system to the west and the Adirondack uplift in northeastern New York (Figure 3). During deposition water depths increased eastward and southward off the platform into the basin.

Onondaga sedimentation began in eastern New York, following Schoharie deposition (Lindholm, 1969). Glauconitic horizons and phosphate nodules found locally above the Schoharie and Carlisle Center formations suggest a depositional hiatus. Post-Bois Blanc sedimentation probably followed a hiatus as well, except on the Niagara Peninsula, where Oliver (1976) suggested that the greenish, argillaceous beds at Port Colborne might fill the time gap between Bois Blanc and Onondaga deposition.

Linear facies belts (Figure 4) indicate that Onondaga sedimentation took place on a carbonate ramp; an inclined platform extending basinward without a pronounced break in slope (Ahr, 1973). Characteristics of this model include concentric arrangement of facies belts about the basin axis and dominance of finer grained facies basinward of coarser, less muddy facies. This model differs from carbonate platform models (for example, Purdy, 1963; Enos, 1977) in the distribution of progressively lower energy facies basinward and the absence of abrupt high-energy basin-margin shoals. In the ramp model the highest energy zone is close to shore, in the platform model, it lies on the shelf margin.

The ramp model is also characterized by the occurrence of patch reefs or bioherms rather than continuous reef trends. Isolated large bioherms developed in south-central New York and north-central Pennsylvania, and the bioherms of the Buffalo-Port Colborne area developed landward in somewhat shallower water. Location of these high-energy areas is probably influenced by subtle irregularities on the seafloor, reflecting relict topography or zones of tectonic adjustment. Currents deflected over and around such irregularities provided necessary circulation and food source for carbonate-producing biota.

ONONDAGA BIOHERMS

Small bioherms are common in the Edgecliff and have been the focus of numerous studies. Grabau (1903) described a bioherm exposed near Williamsville, New York which has since been largely removed by freeway construction. In the early 1950's over 20 bioherms were found in east-central New York (Oliver, 1956a), and in recent years several of these buildups have been studied individually (Mecarini, 1964; Bamford,

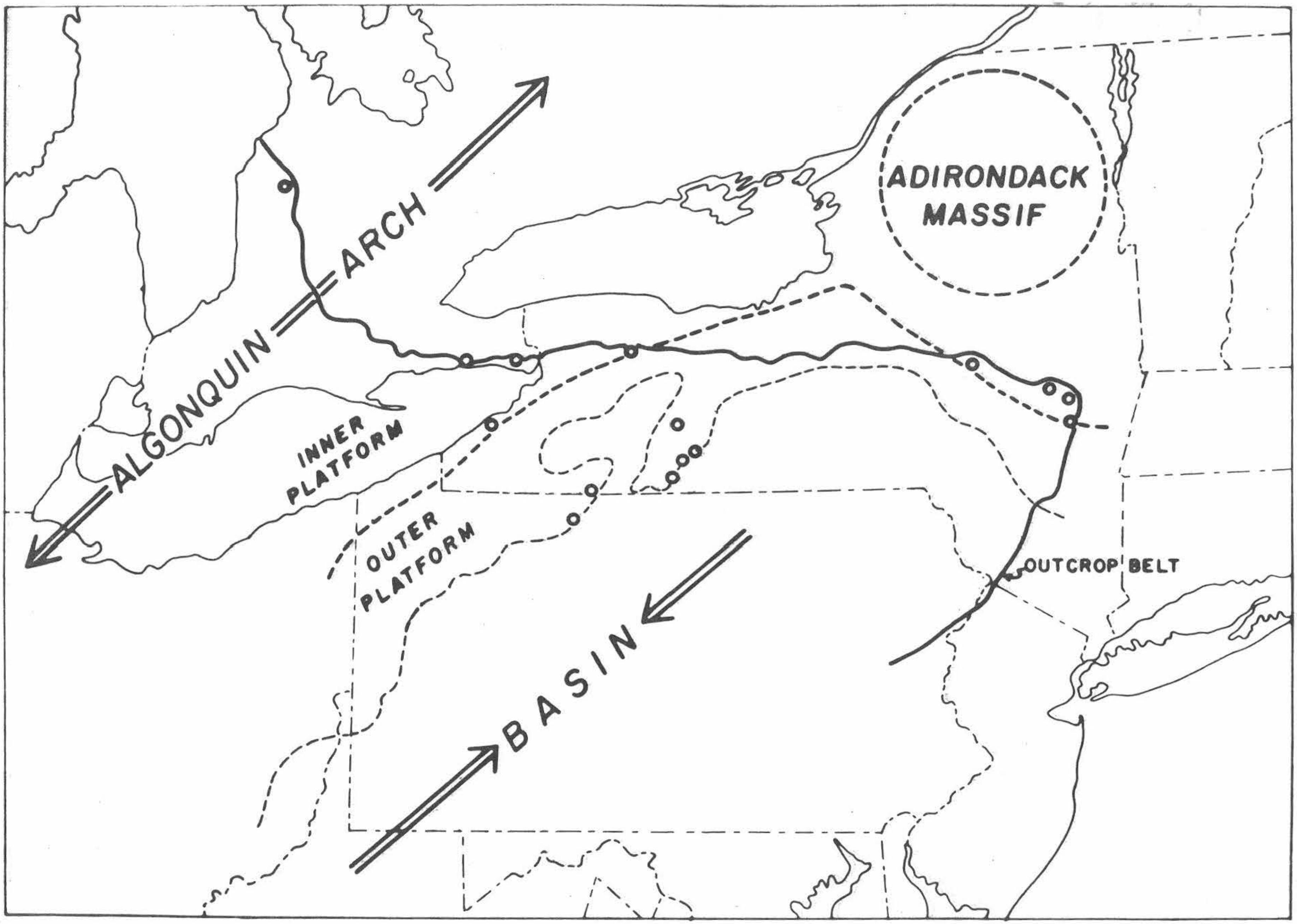

FIGURE 3. Map of tectonic elements which influenced Devonian sedimentation in the northern Appalachian basin, showing position of the platform upon which Onondaga bioherms developed.

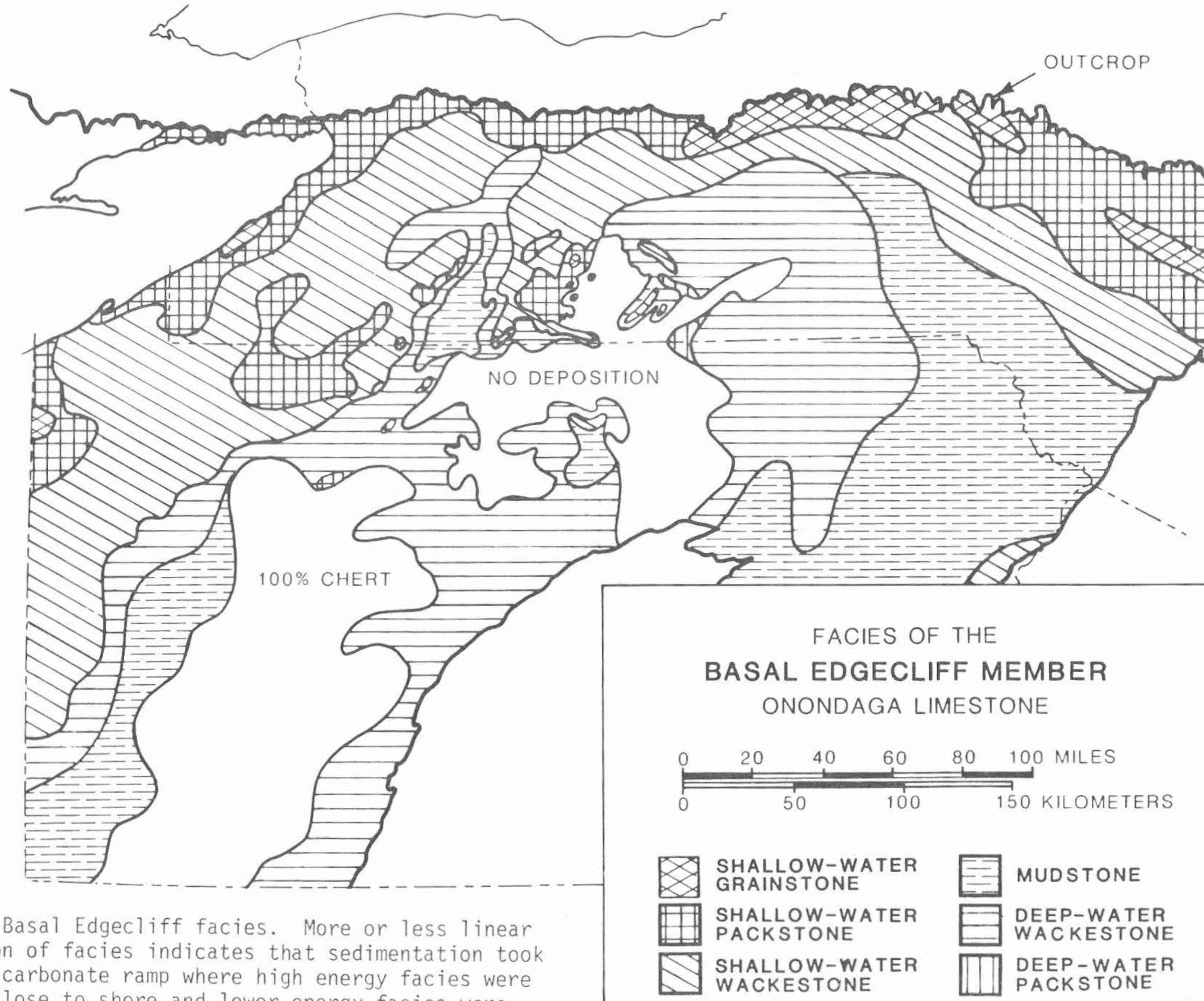

FIGURE 4. Basal Edgecliff facies. More or less linear distribution of facies indicates that sedimentation took place on a carbonate ramp where high energy facies were deposited close to shore and lower energy facies were deposited basinward.

1966; Williams, 1977, 1979; Polasek, 1978). In addition to the eastern buildups, several buildups are known from western New York (Poore, 1969; Crowley and Poore, 1974; Oliver, 1976; Coughlin, 1981), from the Niagara Peninsula of Ontario (Telford and Tarrant, 1975a,b; Oliver, 1976; Cassa, 1979) and from southwestern Ontario (Fagerstrom, 1961; Mayo, 1965). The buildups are stratified and lack a rigid framework. In many cases only slightly dipping marginal beds and prolific coral growth give any clue to the presence of a buildup. In some quarries, massive core rock remains undisturbed because of the difficulty in quarrying rock without well developed bedding and joints. Reconstructed dimensions range up to several hundred feet in diameter and 80 ft in thickness.

In contrast to outcrop bioherms, subsurface "pinnacle reefs" of south-central New York and north-central Pennsylvania (Mesollela and Weaver, 1975; Kissling and Coughlin, 1979; Coughlin, 1981; Kissling, 1980, 1981; Kissling and Moshier, 1981; Kissling and Polasek, 1982) cover several hundred acres and comprise over 200 ft of Onondaga sedimentation. Like their surface counterparts, these bioherms contain an abundant coral fauna. Gamma ray-neutron logs record low radioactivity and extremely high porosity.

Subsurface Facies

The subsurface Onondaga is dominated by moderately deep-water facies which grade southward into the Needmore and Marcellus shales and Huntersville Chert. Facies represent relative bathymetry. Presumably deep-water calcisiltite mudstone, stylioline wackestone, and thin-shelled brachiopod packstone facies delineate the epicratonic Appalachian basin in south-central New York and most of Pennsylvania. Wackestone, packstone, and grainstone facies, dominated by crinoids, bryozoans, and robust brachiopods outline an arcuate platform that bounded the basin on its northern and western sides. Ooliths, peloids, carbonate intraclasts, coated grains, and calcified or stromatolic algae are completely absent, indicating that if shallow, nearshore environments had existed, they once lay north of the present outcrop belt, perhaps marginal to the Algonquin arch and Adirondack massif.

During deposition, water depths increased progressively throughout the basin, as reflected by northward shift of facies comprising successive members, and by northward migration with time of the Marcellus Shale. Basin and platform were joined in south-central New York and northwestern Pennsylvania by a south-sloping ramp dissected by troughs and surmounted by isolated banks. All seven gas-bearing Onondaga bioherms discovered to date were initiated as Edgecliff coral-crinoid mounds on the seaward or southeastern margin of these banks.

Subsurface Stratigraphy

The Onondaga ranges from 8 to 215 ft thick and is readily divisible into the Edgecliff, Nedrow, Moorehouse and Seneca Members. Of these, only the upper part of the Moorehouse Member is present throughout the basin. Other units are absent in places as a result of nondeposition or submarine scour or because of lateral gradation with the Marcellus Shale.

The upper contact of the Onondaga is characterized by an abrupt decrease in radioactivity in gamma-ray profiles (Figure 5). The Tioga Bentonite, separating the Seneca and Moorehouse members, is typically moderately radioactive. Because as many as three bentonites occur in the upper part of the Onondaga, in areas where the Seneca is very thin or absent the others could be misidentified as the Tioga. The Moorehouse displays relatively low radioactivity on gamma ray logs, except for the bentonites. The upper Moorehouse is commonly somewhat more porous than the lower Moorehouse.

The argillaceous Nedrow Member can be identified by a slightly shaly kick in the gamma-ray profile and corresponding moderate neutron count. However, this relationship does not always occur, nor does the Nedrow always appear as shaly as expected.

Both the Clarence and the Edgecliff Members are uniformly low in radioactivity, displaying little character in gamma-ray profiles, and are relatively low in porosity. The contact between the two members appears to be transitional and cannot be accurately placed in many cases. Extrapolation from outcrop has resulted in an estimate of where the contact should be and is the basis on which Edgecliff and Clarence lithofacies have been mapped.

The Bois Blanc generally contains one or more shaly layers and is of high porosity, making it fairly easy to pick with consistency. The basal Devonian unconformity almost always stands out as a thin shaly kick. The Oriskany Sandstone and Bass Islands Group are characteristically of low radioactivity and high porosity.

Subsurface Bioherms

Subsurface Onondaga buildups (Figure 6), popularly known as pinnacle reefs, are similar in fauna and facies to bioherms known in the outcrop belt; however, in contrast to outcrop bioherms, they are separated paleogeographically, are generally far larger (118 to 207 ft in thickness and 3,900 and 10,500 ft in diameter), and continued their growth throughout Onondaga deposition. Like their surface counterparts,

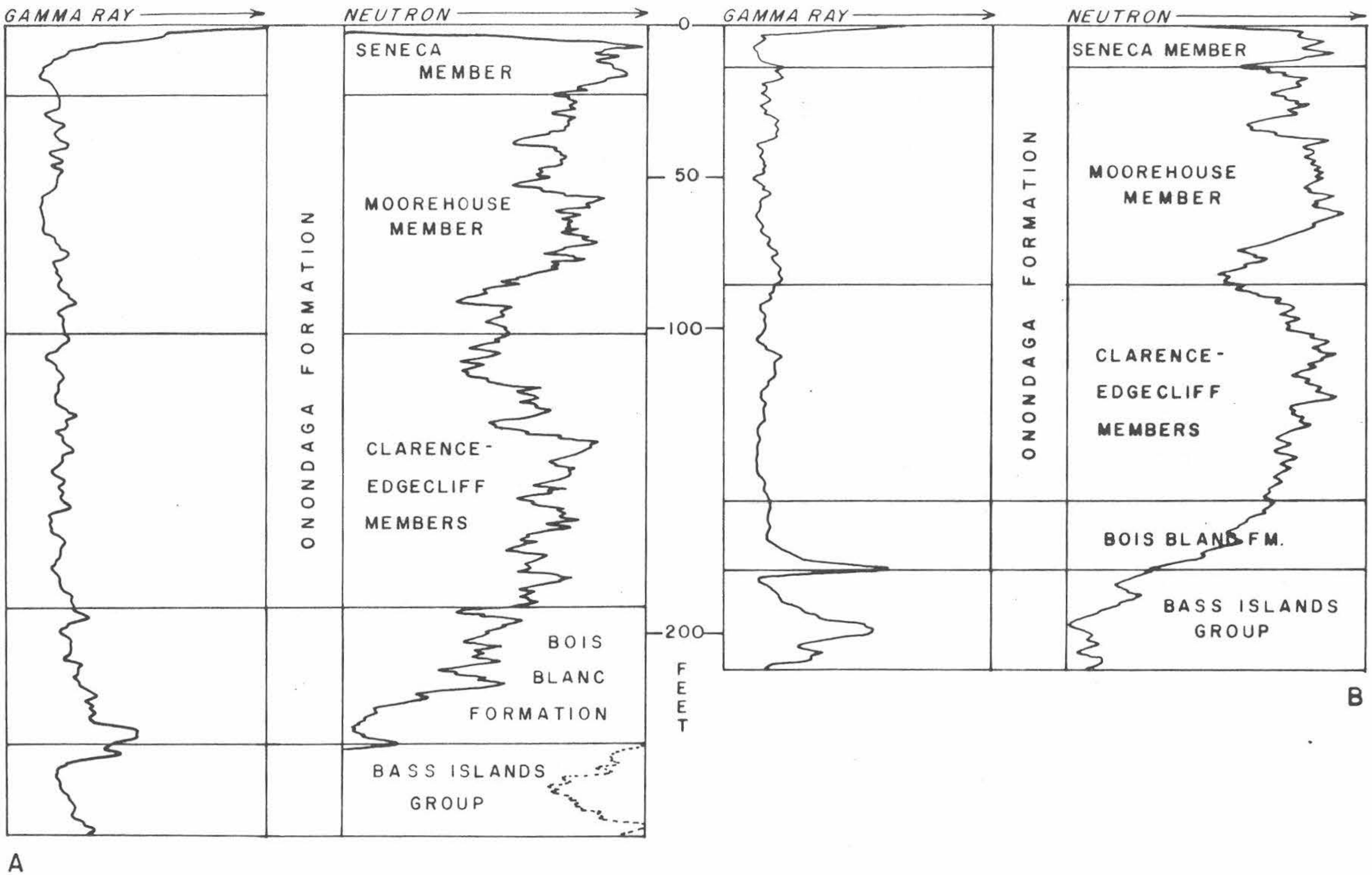

FIGURE 5. Gamma ray-neutron logs of the Onondaga Limestone. A. Apache Corp.-Hica Corp. H. Carnahan No. 1, Chautauqua County, New York. B. New York State Natural Gas Co. Jones No. 1, Erie County, New York.

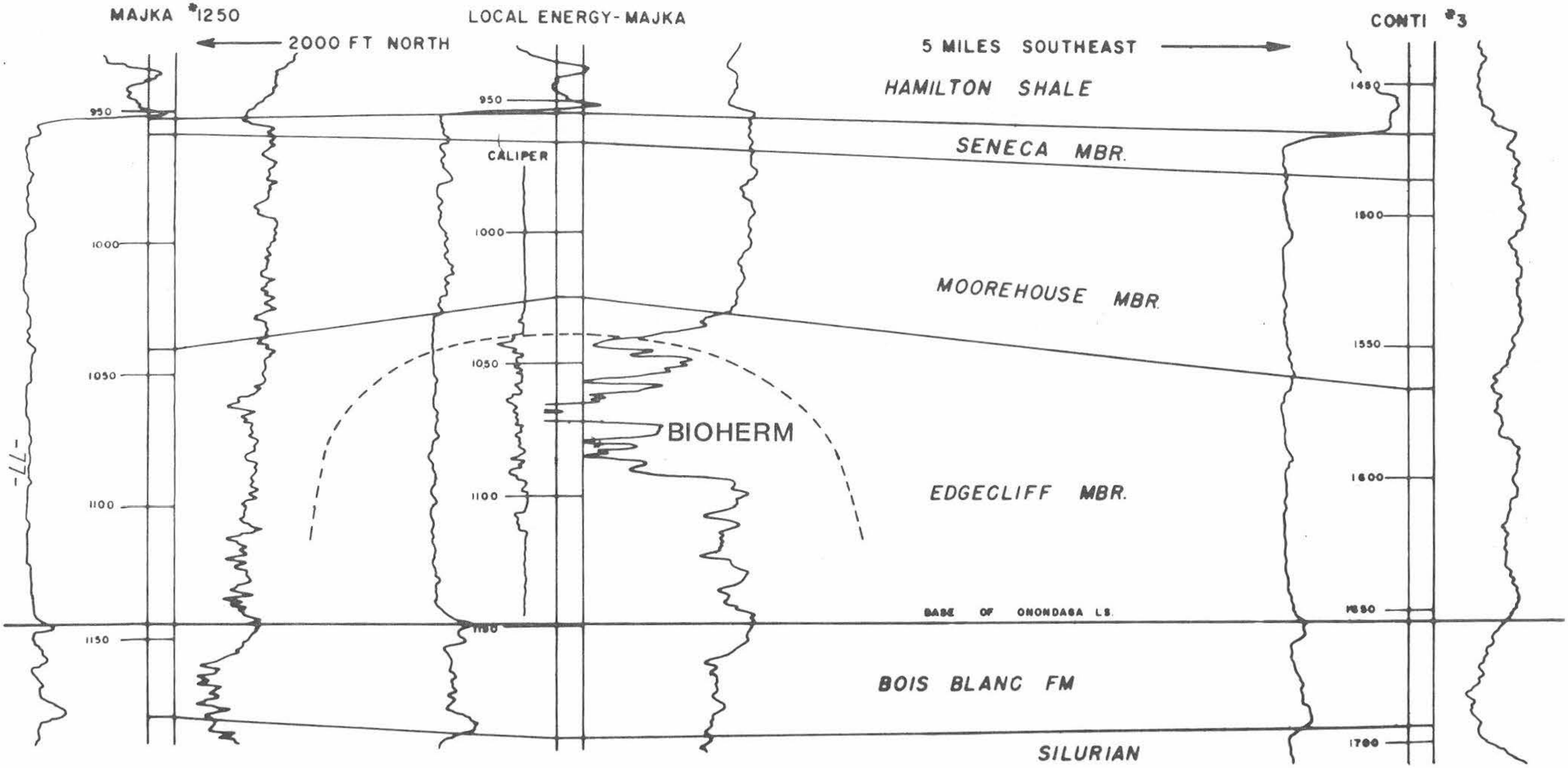

FIGURE 6. Gamma ray-neutron logs showing biohermal (center) and nonbiohermal characteristics of the Onondaga Limestone in Erie County, New York.

subsurface bioherms exhibit broadly domed structures that consist of coral bafflestone in crinoid-coral fragment packstone matrix. Initial Acinophyllum-Cladopora coral thickets were succeeded by alternating thickets of Cylindrophyllum and Acinophyllum-Cladopora, and were capped by bryzoan-Cladopora wackestone. Proximal bioherm flanks consist of branching coral mudstone in crinoid packstone and grainstone; distal flanks are coral floatstone rich in favositid tabulates. Although surrounded by deep-water Moorehouse and Seneca facies upon subsidence of the supporting banks, these bioherms continued vertical and lateral growth until terminated by anoxic waters accompanying northward-encroaching euxinic Marcellus deposition. Neither outcrop nor subsurface bioherms were wave-resistant reefs. They formed at considerable depths, probably below effective photic zone. Calcified algae and stromatoporoids, primary components of Devonian reefs elsewhere, are virtually absent, despite the equatorial paleolatitude of the northern Appalachian Basin. Extinct buildups remained as submarine knolls for millenia until onlapped by the Marcellus and Skaneateles Shales.

Most existing porosity consists of primary intraskeletal, intergranular, and growth-framework voids. Effective pore-reducing processes, which characterized the early diagenetic history, included internal sedimentation, aragonite-to-calcite inversion, pressure-solution, and associated calcite cementation and neomorphism. Subsequent development of fractures and microfractures furnished permeability needed for migration of liquid hydrocarbons into the reservoirs, and led to significant hydrocarbon-induced leaching. Late diagenetic events such as stylolitization, pore plugging by bitumen residue, and silica replacement further reduced bioherm porosity to the present average of 4 to 5%. Primary intercoralline and intraskeletal voids are the most common pore types observed from core slabs and thin sections. Many intercoralline voids apparently represent original sheltered cavities. Solution-enlarged fractures constitute the major pore-communication system in Onondaga reservoirs. To date, six gas-producing and one shut-in Onondaga bioherm fields are known from New York and Pennsylvania. As of January, 1981, nine wells have produced more than 18 bcfg.

COMPARISON WITH OTHER DEVONIAN BUILDUPS

Devonian bioherms have nearly worldwide distribution and, as a group, are perhaps best known among Paleozoic carbonate buildups. Despite their widespread occurrence they are remarkably similar in many respects, including facies types, faunal components and development.

The most striking difference between Onondaga bioherms and Devonian bioherms elsewhere is the role of stromatoporoids as frame builders and constructors. Generally, the stromatoporoid-dominated community so characteristic of most Devonian bioherms represents a highly specialized community which may have been particularly sensitive to changes in the environment. Stromatoporoids, however, are not a appreciable component of Onondaga fauna. They are virtually absent in bioherms of eastern New York, but thin, laminar forms become relatively common in biohermal and non-biohermal facies of western New York and the Niagara Peninsula. Formosa bioherm, 90 mi northwest of Hagersville, is composed primarily of tabular stromatoporoids and rugose corals, which suggests it developed under more turbulent and perhaps somewhat shallower conditions than had existed to the east.

A second important difference between Onondaga bioherms and most other Devonian buildups is the conspicuous absence of calcified algae. In most Devonian reefs algae play an important role as binders and encrusters, as well as contributing clay-sized sediment in the manner of modern codiaceans. However, depositional features of Onondaga sediments suggest that sedimentation took place in water sufficiently deep to inhibit the growth of green algae.

Thus, despite many similar characteristics, Onondaga bioherms do not seem to fit the mold of other Devonian buildups. Upper Middle Frasnian bioherms of the Dinant basin (Lecompte, 1959) exhibit stratified, nonrigid structures similar to those of Onondaga buildups and lack signs of subaerial exposure. Flank beds of reef-derived talus and indications of wind and current influence such as elongation or asymmetry are also lacking. Like many Onondaga bioherms, the initial phase of bioherm development is represented by impure, argillaceous limestone. However, instead of fasciculate corals characteristic of Onondaga bioherms, lamellar forms such as Alveolites dominate initial assemblages in Dinant basin bioherms. Stromatoporoid reefs were superimposed on the small, stratified Dinant basin mounds when they grew into the zone of turbulence, illustrating an environmental potential different from that of the lamellar corals.

Embry and Klovan (1972) analyzed facies relationships of an Upper Devonian buildup in the Canadian Arctic and established absolute water depths based on paleoecological zones. They determined that locally prolific coral growth in relatively deep, quiet water resulted in a small biogenic bank. As the bank grew up toward wave base, tabular stromatoporoids became the dominant fauna. In many cases, this pattern resulted in development of extensive reef tracts analogous to modern examples such as the Great Barrier Reef of Australia and reefs of the Yucatan and Belize shelves (Klovan, 1974). The latter stages of this pattern, however, are not represented in Onondaga bioherms.

MODERN ANALOGUES

No direct analogues for Onondaga buildups can be found today, however, several partial analogues may be of help in establishing parameters for the Onondaga depositional environments. Cold- and deep-water coral banks and patches composed primarily of ahermatypic corals together with a diverse invertebrate assemblage exist in water 600 to 900 ft deep off the coast of Norway and elsewhere in the Atlantic Ocean (Teichert, 1958). They show no evidence of erosion, however, flanking debris may be composed of organically fragmented skeletal material. Because the environment of these banks is generally deep, calcareous algae are absent.

Several submerged reef banks are found on the Campeche shelf off Mexico, a modern carbonate ramp (Logan and others, 1969). They are oval to round in outline and show little indication of influence by action of wind or waves, although situated in only 30 ft of water. They do, however, possess flanks composed of algal nodules or encrusting coralline algae.

Boo Bee patch reef, on the Belize shelf (Halley and others, 1977) is one of many flat-topped lagoonal mounds founded on relict Pleistocene topographic highs. Unlike Onondaga buildups, these mounds developed behind a protective barrier reef. Resemblance to Onondaga bioherms is found in the occurrence of lime silt and mud at the base and coralline lime sand and rubble which comprise the major portion of the mound. Like Onondaga buildups, Boo Bee patch reef lacks internal structure and lithologic or faunal zonation. It represents a local proliferation of coral growth which was protected from wave destruction and kept pace with rising sea level. Relatively sudden deepening of the water could result in cessation of coral growth by relative increase in fine-grained terrigenous and carbonate sedimentation associated with decreased rate of carbonate production. Such sediments would closely resemble the Clarence Member which overlies Onodaga bioherms.

Rodriguez Bank (Turmel and Swanson, 1976) on the Florida reef tract near Key Largo is a Holocene mudbank having sedimentological characteristics similar to those of Onondaga buildups. Absence of rigid coral-algal framework and abundance of lime mud are indicative of calm-water development. Mud, which probably was produced in place by disintegration of green algae and other skeletal material, was trapped and stabilized by marine grasses and small branching corals, perhaps similar to the initial Acinophyllum beds of Onondaga buildups. With sea level rise and wider inundation, the quiet-water environment of early bank development changed to more open-water circulation favorable for skeletal sand and gravel production, indicated by vertical increase in average grain size. Packstone and grainstone beds in the Onondaga buildups may be similarly interpreted.

ACKNOWLEDGEMENTS

Much of the information contained in this article is from M. R. Cassa's master's degree work at SUNY-Binghamton. Other information is drawn from theses by R. M. Coughlin and J. F. Polasek. Consolidated Gas Supply Corporation and the American Chemical Society provided funds for these investigations. Gulf Research and Development Company provided funds for reconnaissance and preparation of the field trip guide. Michelle Mracna typed the manuscript; Vince Flotta drafted Figure 4 from an original by D.L. Kissling. The assistance of Helen Delano is greatly appreciated.

REFERENCES CITED

Ahr, W.M., 1973, The carbonate ramp; an alternative to the shelf model: Trans. Gulf Coast Assoc. Geol. Soc., v. 23, p. 221-225.

Bamford, R., 1966, Paleoecology of the Albrights Reef, Onondaga Limestone (Devonian), eastern New York: M.S. Thesis, Univ. Nebraska.

Cassa, M.R., 1979, A Middle Devonian bioherm, Niagara Peninsula, Ontario (abs.): Northeastern Section Geol. Soc. America, 14th Ann. Mtg. Abstracts with Programs, p. 7.

Coughlin, R.M., 1981, Reefs and normal facies of the Onondaga Limestone (Eifelian) in west-central New York: M. A. Thesis, State Univ. New York, Binghamton.

Crowley, D., and Poore, R.Z., 1974, Lockport (Middle Silurian) and Onondaga (Middle Devonian) patch reefs in western New York: N.Y. State Geol. Assoc. 46th Ann. Mtg., Guidebook, p. A1-A41.

Embry, A.F., III, and Klovan, J.E., 1971, A Late Devonian reef tract on northwestern Banks Island, N.W.T.: Bull. Can. Petroleum Geol., v. 19, p. 730-781.

Enos, P., 1977, Holocene sediment accumulations of the south Florida shelf margin, <u>in</u> Enos, P., and Perkins, R.D., Quaternary sedimentation in south Florida: Geol. Soc. America Mem. 147, p. 1-130.

Fagerstrom, J.A., 1961, The fauna of the Middle Devonian Formosa Reef Limestone of southwestern Ontario: Jour. Paleo., v. 35, p. 1-48.

Grabau, A.W., 1903, Paleozoic coral reefs: Geol. Soc. America Bull., v. 14, p. 337-352.

Halley, R.B., Shinn, E.A., Hudson, J.H., and Lidz, B., 1977, Recent and relict topography of Boo Bee patch reef, Belize: Third Int'l. Coral Reef Symposium Proc., v. 2, p. 29-35.

Kissling, D.L., 1980, Onondaga pinnacle reefs; their facies and paleogeography: 11th Ann. Appalachian Petroleum Geol. Symposium, Morgantown, West Virginia.

__________, 1981, Subsurface Onondaga biohermal banks; paleogeography, facies, and reservoir characteristics: New York State Geol. Assoc., 53rd Ann. Mtg., Guidebook, p. 231-232.

Kissling, D.L. and Coughlin, R.M., 1979, Succession of faunas and frameworks in Middle Devonian Pinnacle reefs of south-central New York (abs.): Northeastern Section Geol. Soc. America, 14th Ann. Mtg., Abstracts with Programs, p. 19.

Kissling, D.L. and Moshier, S.M., 1981, The subsurface Onondaga Limestone; stratigraphy, facies and paleogeography: New York State Geol. Assoc., 53rd Ann. Mtg., Guidebook, p. 229-230.

Kissling, D.L. and Polasek, J.F., 1982, Exploration and reservoir characteristics of Onondaga bioherms: 13th Ann. Appalachian Petroleum Geol. Symposium, Morgantown, West Virginia.

Klovan, J.E., 1974, Development of western Canadian Devonian reefs and comparison with Holocene analogues: Amer. Assoc. Petroleum Geol., v. 58, p. 787-799.

Kobluk, D.R., Pemberton, S.G., Karolyi, M., and Risk, M.J., 1977, The Silurian-Devonian disconformity in southern Ontario: Bull. Can. Petroleum Geol., v. 25, . 1157-1186.

LeCompte, M., 1959, Certain data on the genesis and ecological character of Frasnian reefs of the Ardennes (Moore, Trans.,): Int'l. Geol. Rev., v. 1, p. 1-23.

Lindholm, 1969, Carbonate petrology of the Onondaga Limestone (Middle Devonian), New York; a case for calcisiltite: Jour. Sed. Petrol., v. 39, p. 268-275.

Logan, B.W., Harding, J.L., Ahr, W.M., Williams, J.D. and Snead, R.G., 1969, Carbonate sediments and reefs, Yucatan Shelf, Mexico: Am. Assoc, Petroleum Geol. Mem. 11, 196 p.

Mayo, C.R., 1965, Petrography of a Middle Devonian bioherm, southwestern Ontario, Canada: The Compass, Sigma Gamma Epsilon, v. 42, p. 88-100.

Mecarini, G., 1964, Ecological succession in a Middle Devonian bioherm: M. S. Thesis, Brown Univ., 35 p.

Mesolella, K.J. and Weaver, O.D., 1975, What is the overall significance of Appalachia's Devonian pinnacle reefs? Oil and Gas Jour., v. 73, no. 8, p. 98-103.

Oliver, W.A., Jr., 1954, Stratigraphy of the Onondaga Limestone (Devonian) in central New York: Geol. Soc. America Bull., v. 65, p. 621-652.

_________, 1956a, Stratigraphy of the Onondaga Limestone in eastern New York, Geol. Soc. America Bull., v. 67, p. 1441-1474.

_________, 1956b, Biostromes and bioherms of the Onondaga Limestone in eastern New York: N.Y., State Mus. Cir. 45, 23 p.

_________, 1960, Coral faunas in the Onondaga Limestone of New York: U.S. Geol. Surv. Prof. Paper 400-B, p. 172-174.

_________, 1962, The Onondaga Limestone in southeastern New York, in Guidebook to field trips: N.Y. State Geol. Assoc., 34th Ann. Mtg., Port Jervis, N.Y., p. A2-A6, A16-A19.

_________, 1966, Bois Blanc and Onondaga Formations in western New York and adjacent Ontario: New York State Geol. Assoc. Guidebook, 38th Ann. Mtg., p. 32-43.

_________, 1976, Noncystimorph colonial rugose corals of the Onesquethaw and Lower Cazenovia Stages (Lower and Middle Devonian) in New York and adjacent areas: U.S. Geol. Surv. Prof. Paper 869, 156 p.

Ozol, M.A., 1964, Alkali reactivity of cherts and stratigraphy and petrology of cherts and associated limestones of the Onondaga Formation of central and western New York: Dissertation Abs., Ann. Arbor, v. 24, no. 10, p. 4144-4145.

Pfirman, S., and Selleck, B.W., 1977, Origin and possible tectonic significance of chert in the Onondaga Limestone: Northeastern Section Geol. Soc. America, 12th Ann. Mtg., Abstracts with Programs, p. 308-309.

Polasek, J.F., 1978, Onondaga Limestone facies and reef trends in eastern New York State: Unpubl. Master's project, State Univ. New York, Binghamton, 79 p.

Poore, R.Z., 1969, The Leroy Bioherm; Onondaga Limestone (Middle Devonian), western New York: M. S. Thesis, Brown Univ., 69 p.

Port Colborne Chamber of Commerce.

Purdy, E.G., 1963, Recent calcium carbonate facies of the Great Bahama Bank; 2. Sedimentary facies: Jour. Geol., v. 71, p. 472-497.

Rickard, L.V., 1964, Correlation of the Devonian Rocks in New York State: N.Y. State Geol. Surv. Map and Chart Series 4.

Stauffer, C.R., 1913, Geology of the region around Hagarsville, Ontario: Int'l. Geol. Cong., XII, Toronto, Canada, Guidebook 4, p. 82-99.

Stauffer, C.R., 1915, The Devonian of southwestern Ontario: Can. Geol. Surv. Mem. 34, 341 p.

Teichert, C., 1958, Cold- and deep-water coral banks: Amer. Assoc. Petroleum Geol. Bull., v. 42, p. 1064-1082.

Telford, P.G. and Tarrant, G.A., 1975a, Paleozoic geology of the Dunnville area, southern Ontario: Ontario Div. Mines, Prelim. Map P-988, Geol Series.

Telford, P.B. and Tarrant, G.A., 1975b, Paleozoic geology of the Welland-Fort Erie area, southern Ontario: Ontario Div. Mines, Prelim. Map P-989, Geol. Series.

Turmel, R., and Swanson, R.G., 1976, The development of Rodriquez Bank, A Holocene mudbank in the Florida reef tract: Jour. Sed. Petrol., v. 46, p. 497-517.

Williams, L.A., 1977, Successional patterns in a Middle Devonian patch reef: Northeastern Section Geol Soc. America, 12th Ann. Mtg., Abstracts with Programs, p. 330-331.

_________, 1979, Physical and biotic controls in Thompsons Lake Reef (Middle Devonian, New York State) and their relevance to community succession models: Northeastern Section Geol. Soc. America, 14th Ann. Mtg., Abstracts with Programs, p. 59-60.

_________, 1980, Community succession in a Devonian patch reef (Onondaga Formation, New York) - physical and biotic controls: Jour. Sed. Petrol., v. 50, p. 1169-1186.

ROAD LOG AND STOP DESCRIPTIONS FOR CARBONATE FACIES OF THE BOIS BLANC AND ONONDAGA FORMATIONS, NIAGARA PENINSULA, ONTARIO

[Routes and locations of stops are shown in Figures 7 and 8.] Passports are not required of U.S. citizens to enter Canada or return to the United States. However, proof of citizenship must be carried - birth or baptismal certificate, voter registration card. Naturalized citizens should carry naturalization papers. U.S. resident aliens must have an Alien Registration Receipt Card. Citizens of countries other than the U.S. or Canada must have a valid passport and visa.

Road log starts from from Marriott inn.

Cumulative Mileage	Miles from last point	Route and Stop Description
0.0	0.0	Leave Marriott Inn and turn right onto Millersport Highway (NY 263).
0.2	0.2	Pass under railroad tracks and bear right onto Interstate 290 west.
6.7	6.5	Keep left and continue south on Interstate 190.
8.8	2.1	Tonowanda Channel of Niagara River on right. Grand Island is visible across the river, behind us. At the south end of Grand Island, the Tonowanda and Chippewa Channels join and Fort Erie, Ontario can be seen across the river.
11.2	2.4	Buffalo District, U.S. Army Corps of Engineers on right.
12.0	0.8	Schaefer Brewery on left.
12.2	0.2	Toll booth.
12.4	0.2	Lock in Black Rock Canal on right.
13.0	0.6	Pass under Peace Bridge.
13.1	0.1	Bear right onto Porter Avenue exit ramp.

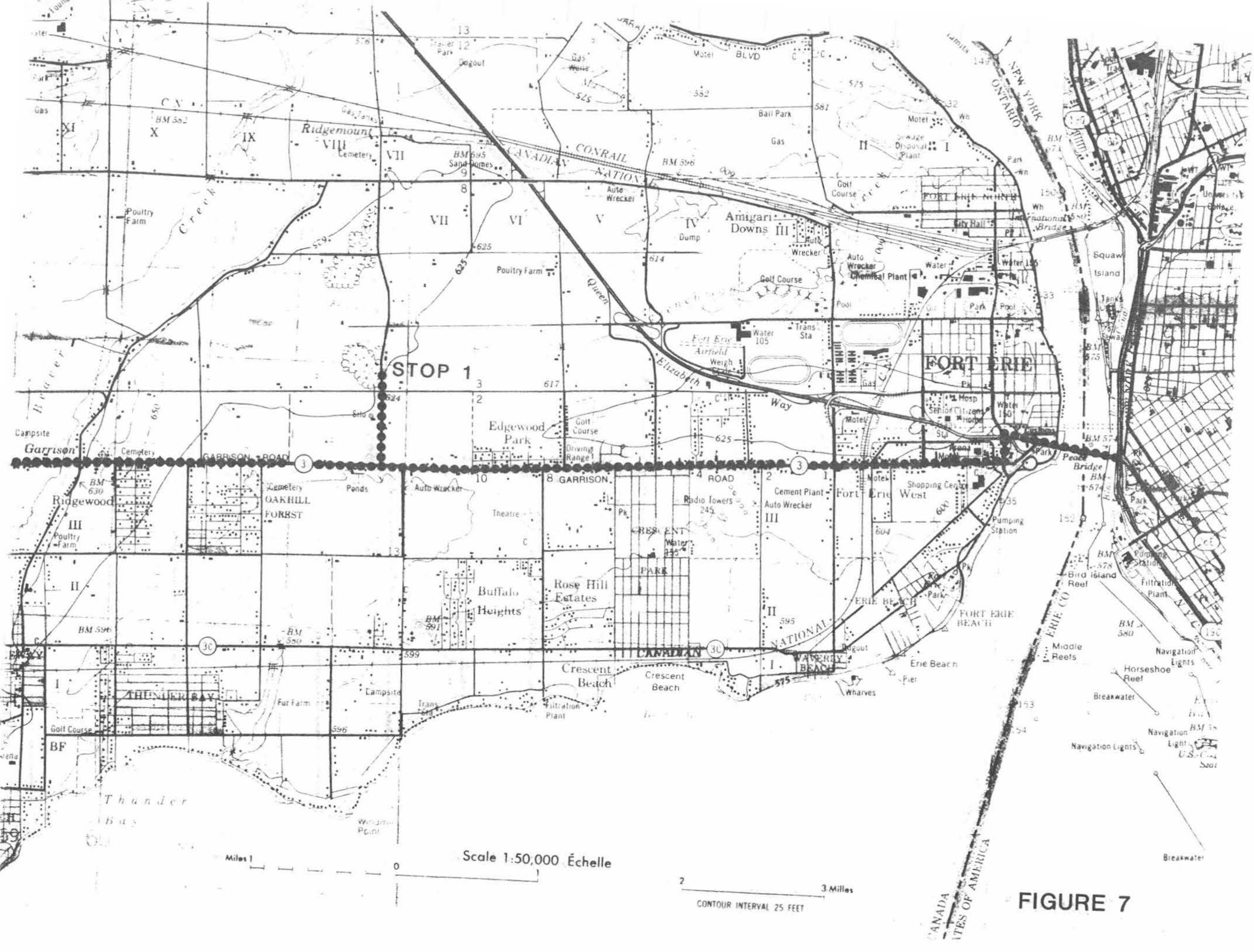
STOP 1
FORT ERIE
Fort Erie North
Fort Erie West
Garrison Road
Ridgewood
Ridgemount
Edgewood Park
Buffalo Heights
Rose Hill Estates
Crescent Park
Crescent Beach
Thunder Bay
Erie Beach
Fort Erie Beach
Waverly Beach
Amigari Downs
Squaw Island
Peace Bridge
Bird Island Reef
Middle Reefs
Horseshoe Reef
Queen Elizabeth Way
Canadian National
Conrail
New York
Ontario
Canada
States of America
Scale 1:50,000 Échelle
Contour Interval 25 Feet

FIGURE 7

13.6	0.5	Stop. Turn left onto Porter Avenue.
13.8	0.2	Turn left at traffic light, following signs to Peace Bridge.
14.1	0.3	Toll booth - Peace Bridge.
15.0	0.9	Customs.
15.1	0.1	Bear right at exit to Ontario Highway 3, toward Windsor and Crystal Beach.
15.5	0.4	Turn right at traffic light onto Ontario Highway 3 west (Garrison Road).
19.6	4.1	Stonemill Road on left.
19.8	0.2	Turn right onto Ridgemount Road (Regional Road 120).
20.5	0.7	Turn left into driveway of Ridgemount Quarries, Ltd.

STOP 1. RIDGEMOUNT QUARRY

Hard hats must be worn. Please exercise caution near quarry walls; watch for overhangs and loose rock.

An excellent exposure of the Silurian-Devonian unconformity is found in the north wall of this quarry. Several small bioherms are exposed in the northern part of the quarry and in an "embayment" a few hundred feet west of the entrance. The mounds are characterized by abrupt thickening of lower Edgecliff strata which contain abundant solitary and colonial rugose corals, tabulate corals, and crinoid material (Figure 9). Dominant coral genera include *Acinophyllum*, *Cladopora*, *Heliophyllum*, *Cystiphylloides*, *Syringopora*, and *Emmonsia*. Internal structure is stratified; facies are represented as successive layers which pinch out laterally and drape over one another to give the characteristic mounded appearance. Stratified structure and absence of rigid framework indicate that turbulence was low during deposition. Biohermal strata contrast markedly with laterally equivalent and onlapping crinoidal packstone and wackestone beds of non-biohermal Edgecliff.

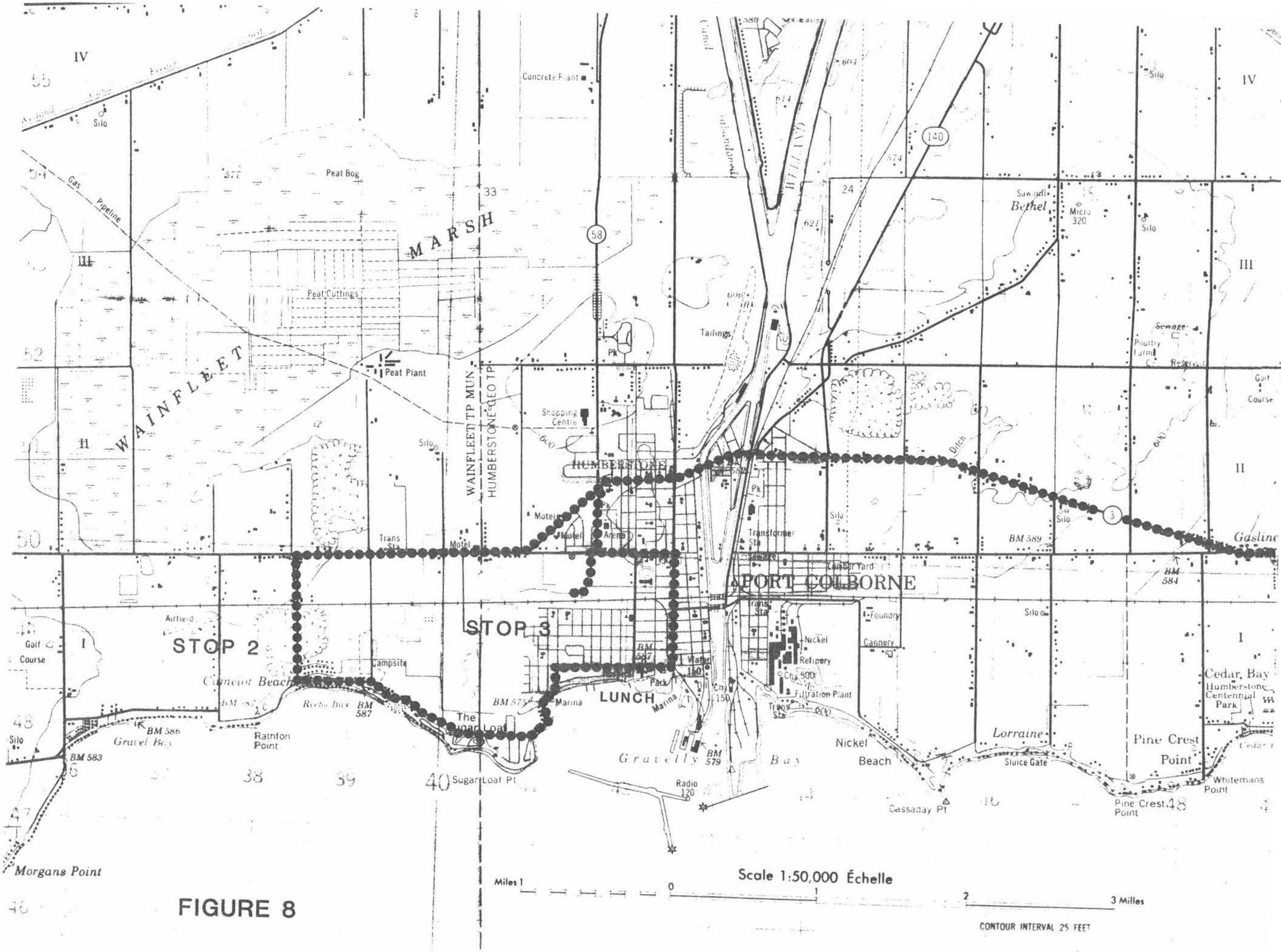
STOP 2
STOP 3
LUNCH
PORT COLBORNE
HUMBERSTONE
WAINFLEET
MARSH
WAINFLEET TP MUN
HUMBERSTONE GEO TP
Peat Bog
Peat Cuttings
Peat Plant
Gas Pipeline
Shopping Centre
Concrete Plant
Tailings
Nickel Refinery
Filtration Plant
Foundry
Cannery
Lumber Yard
Transformer Sta
Camelot Beach
Reebs Bay
The Sugar Loaf
Sugar Loaf Pt
Rathfon Point
Gravel Bay
Gravelly Bay
Nickel Beach
Lorraine
Sluice Gate
Pine Crest Point
Whitemans Point
Cedar Bay
Humberstone Centennial Park
Cassaday Pt
Morgans Point
Bethel
Airfield
Golf Course
Campsite
Marina
Arena
Motel
Silo
Scale 1:50,000 Échelle
Miles 1
0
1
2
3 Milles
CONTOUR INTERVAL 25 FEET

FIGURE 8

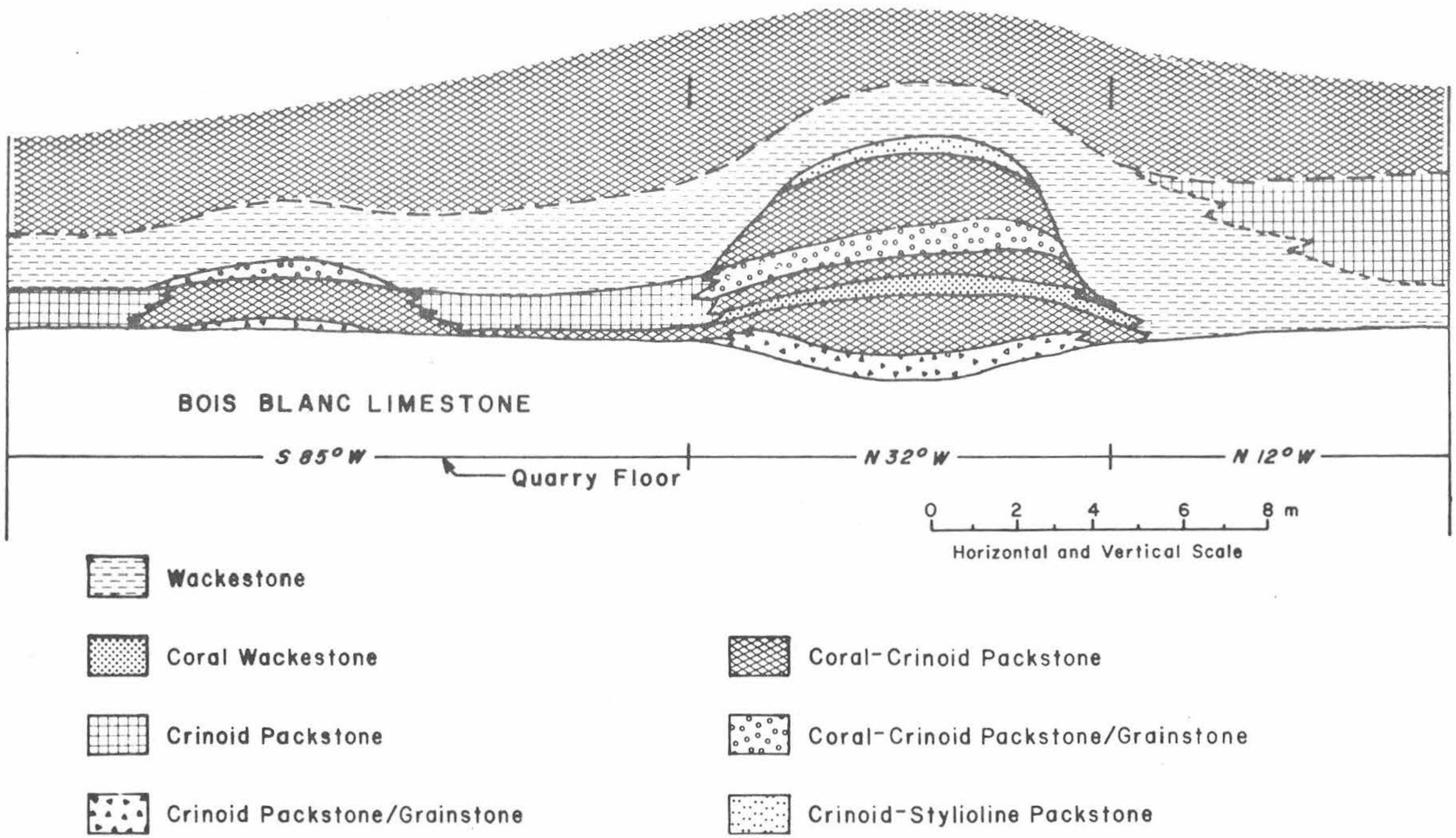

FIGURE 9. Edgecliff facies profile, Ridgemount bioherm.

Sub-biohermal Strata

Mottled olive-gray Bertie Dolomite is unconformably overlain by 0.4 m of yellowish-gray conglomeratic Springvale Sandstone, containing large, flat dolomite clasts. The Bois Blanc consists of 3.2 m of light olive-gray, cherty, fine-grained limestone, containing trilobites, bryozoans, and abundant brachiopods. The mounds are separated from the Bois Blanc Limestone by a thin, shaly zone.

Biohermal Strata

The base of the larger mound sags markedly into underlying strata. Basal beds of the two mounds are similar, consisting of 0.2 to 0.5 m of yellowish-gray, crinoid packstone. Abundant in-place *Syringopora* and other corals are found in the basal beds of the smaller mound.

The overlying facies, 1.0 to 1.5 m of crystalline coral-crinoid packstone, can be traced between mounds. It contains *Acinophyllum*, *Syringopora*, *Cladopora*, *Heliophyllum*, and *Cystiphylloides*, as well as large crinoids whose columnals measure up to 2 cm in diameter. The smaller mound is capped by coral-crinoid packstone-grainstone, containing abundant *Acinophyllum*, common *Heliophyllum*, and sparse *Cystiphylloides*.

In the larger mound, the coral-crinoid packstone is overlain by 0.5 m of coral-dominated wackestone, which, in turn, is overlain by 0.5 m of packstone containing *Acinophyllum* and branching tabulate corals, *Cladopora* and *Aulopora*. Above that, *Acinophyllum*, *Heliophyllum*, and *Cystiphylloides* are found in coral-crinoid grainstone or packstone matrix. This facies is porous, with bitumen-lined interparticle and intraskeletal pores. The mound is capped by up to 0.5 m of crinoid-stylioline wackestone-packstone, containing few corals. Rare chert nodules in biohermal beds are light-colored and highly irregular in shape. Overlying the mounds are olive-gray, argillaceous crinoid-stylioline wackestone and mudstone, containing abundant dark chert nodules and many rugose and tabulate corals.

Non-Biohermal Strata

The overthickened, richly fossiliferous strata of the bioherms grade laterally into somewhat thinner, non-biohermal beds of the lower Edgecliff which consist of medium-grained crinoid grainstone and packstone containing few corals. This facies, approximately 0.8 m thick, is overlain by 7.6 m of crinoid packstone and grainstone which contain many Heliophyllum and Acinophyllum colonies. In his description of this locality, Oliver (1976) assigned these beds to the Clarence Member, perhaps based on the presence of chert nodules or on the darker, more argillaceous nature of laterally equivalent beds which overlie the mounds. Although the exposure could represent a local, fossiliferous facies of the Clarence, Oliver's (1976) suggestion that the Edgecliff and Clarence interfinger may be borne out here in the occurrence of light gray biostromal beds characteristics of the Edgecliff in association with darker olive gray, argillaceous beds containing fewer corals.

Leave quarry and return to Ontario Highway 3.

21.2	0.7	Turn right.
23.1	1.9	Battlefield and museum on right. Plaque on museum building reads: "This house stood on the battlefield during the Fenian raid June 2, 1866. John Teal's family cared for the wounded soldier shot near the front verandah." Monument is memorial to "Queen's Own Rifles, 13th Hamilton Battalian Caledonian and York Rifle Companies of Haldimand in defense (sic) of country June 2, 1866."
27.1	4.0	Port Colborne town line.
29.8	2.7	Village of Gasline.
31.3	1.5	Humberstone International Speedway on right.
33.3	2.0	Port Colborne Quarries, Ltd. to the north. These quarries are floored in the Silurain Bertie Dolomite.
33.5	0.2	Junction, Ontario Highway 140. Robin Hood Flour mill is visible to the northwest. Port Colborne is the second largest flour milling city in Canada.
34.1	0.6	Cross Welland Canal - Lock No. 8. The Welland Canal connects Lake Ontario (St. Catherines) with Lake Erie, an elevation difference of 99.5 m (326.5 ft). It was built in the early 1800's and had to be widened, straightened, and deepened several times as ships increased

		in size and traffic volume grew. This lock, the guard lock, was the longest in the world when it was built in 1933.
34.4	0.3	Cross abandoned canal channel.
34.6	0.2	Sunbeam shoe factory on left. Sunbeam is the largest manufacturer of bowling shoes in Canada.
35.1	0.5	Junction, Ontario Highway 58, McDonalds on NW corner.
36.0	0.9	Wainfleet town line.
37.0	1.0	R.E. Law Crushed Stone Quarry on right.
37.3	0.3	Turn left onto Quarry Road.
37.6	0.3	Cross Canadian National Railroad tracks. Pull off and park immediately south of the tracks.

STOP 2. PORT COLBORNE WEST QUARRY

Hard hats are optional. Please exercise caution near quarry walls, both from below and from above.

A portion of a broad biohermal bank is particularly well exposed in the east wall of this quarry (Figure 10). Original reconnaissance and detailed study were carried out here and in the R. E. Law quarry, approximately one mile north. The Law quarry is floored in Silurian dolomite and exposes Springvale and Bois Blanc strata, including greenish, Acinophyllum-rich beds of the upper Bois Blanc and lower Edgecliff, which represent initial stages of bioherm development. This southern quarry is floored in the upper Bois Blanc (Oliver, 1976). Lower Edgecliff strata are characterized by a coral assemblage which includes Cystiphylloides, Cylindrophyllum, and Heliophyllum. The tabular "core" facies contains a variety of colonial rugose corals and replaces bioclastic beds which are more characteristic of the Edgecliff. Massive favositid tabulate corals are more abundant in the upper, less argillaceous beds.

Glacially scoured surfaces are exposed around the perimeter of the quarry, particularly at the south end. The smoothed surfaces reveal glacial striations and offer spectacular plan-view exposures of the fossil bioherm community.

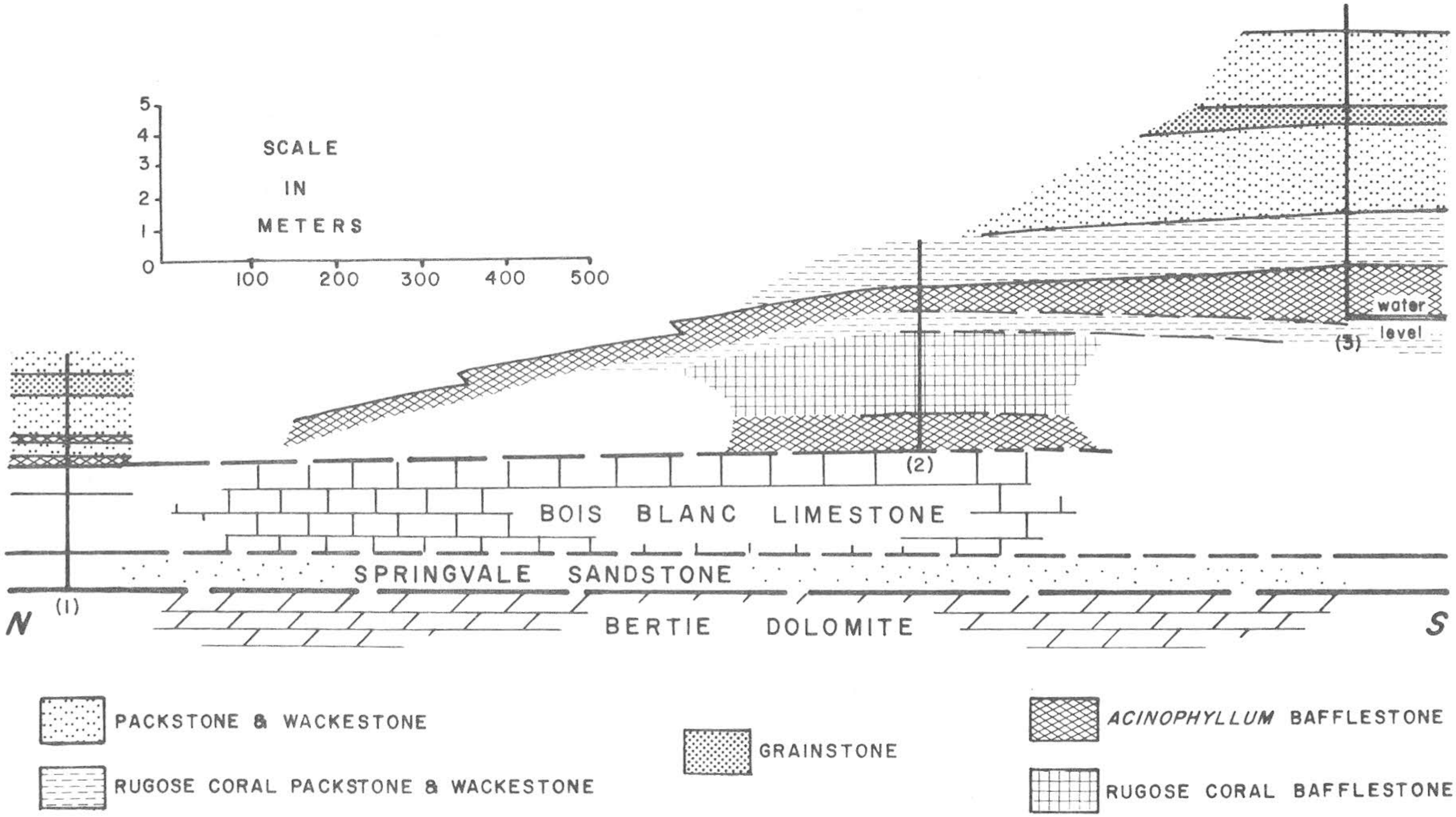

FIGURE 10. Edgecliff facies, Port Colborne bioherm. Three sections, measured in 1978, are represented: (1) R. E. Law quarry; (2) "Port Colborne west" quarry, north face; (3) "Port Colborne west" quarry, southeast corner.

Sub-Biohermal and Bioherm-Equivalent Strata

Calcareous sandstone and sandy limestone and chert of the Springvale Member unconformably overlie the Bertie Dolomite (exposed in the Law quarry). Glauconite gives the Springvale its characteristic greenish color. Cherty, fossiliferous, fine-grained limestone makes up most of the remaining Bois Blanc, which is characterized by the brachiopod Amphigenia elongate (Telford and Tarrant, 1975; Oliver, 1976), in addition to rugose and tabulate corals, trilobites and bryozoans. The upper part of the Bois Blanc differs in consisting of greenish, shaly limestone which grades upward into overlying Edgecliff beds. Oliver (1976) drew the boundary between the formations based on occurrence of Acinophyllum species. Beds which contain A. stokesi and A. simcoensis are considered Bois Blanc; those containing A. segregatum are Edgecliff. He suggests that these units may represent the missing time interval between Bois Blanc and Edgecliff deposition elsewhere. The lithologic transition suggests that similar depositional conditions prevailed throughout late Bois Blanc and early Edgecliff sedimentation. Acinophyllum biostromes which developed under these conditions represent incipient stages of bioherm development.

Biohermal Strata

Two thin (20 cm) beds of Acinophyllum bafflestone mark the earliest phases of Edgecliff bioherm development. These beds and argillaceous limestone containing diverse coral fauna, including rugose corals, Cystiphylloides, Cylindrophyllum, Heliophyllum, and the tabulate favositid coral Pleurodictyum, are exposed in Law quarry and in the northern part of the inactive (southern) quarry. Total thickness is 4.2 m. Overlying are 0.8 to nearly 2.0 m of massive, light-colored limestone dominated by Acinophyllum in association with rugose corals, Cystiphylloides and Heliophyllum, tabulate corals, Favosites and Emmonsia, and sparse stromatoporoids. Intraskeletal porosity is well-developed; black bitumen stains are common. Matrix consists of crinoid grainstone and packstone and contrasts markedly with that of the underlying, more argillaceous Cystiphylloides and Acinophyllum beds.

The massive-bedded Acinophyllum facies is overlain by 7.6 m of medium-bedded packstone, wackestone and grainstone which contains a varied and abundant fauna, including colonial rugose corals, Acinophyllum and Heliophyllum; solitary rugose corals, Cystiphylloides and Siphonophrentis; massive tabulate corals, Favosites, Lecfedites, and Emmonsia; branching tabulates, Cladopora, Thamnopora, Syringopora, and Aulopora; and laminar stromatoporoids. Crinoid debris is abundant; brachiopods are sparse. Thin sections from the upper 4 m of the buildup reveal abundant fenestrate and encrusting bryozoans, the latter occurring in association with crinoid holdfasts. Chert is common throughout the section, but is absent from the *Acinophyllum* and *Cystiphylloides* beds. The buildup is overlain by argillaceous, sparsely fossiliferous mudstone of the Clarence Member, characterized by abundant dark chert nodules.

Vertical extent of the buildup cannot be determined exactly, but a thickness of about 10 m is estimated. Estimating lateral extent is even more difficult, due mainly to the tabular nature and lack of "typical" biohermal zonation and distinct flank facies. Although the position of the exposure in relation to the buildup as a whole is unknown, absence of bioherm facies in the Law quarry suggests the buildup is on the order of 1 km broad.

Leave Stop 2 and continue south toward Lake Erie.

38.0	0.4	Turn left onto Lakeshore Road.
38.3	0.3	Large, stabilized sand dunes on right.
38.7	0.4	Dunes migrating over road surface.
39.3	0.6	Sugarloaf Hill on right. This dune rises more than 100 ft above lake level and has been a landmark to Lake Erie travellers since the days of the earliest explorers.
40.0	0.7	Bridge over drainage canal.
40.1	0.1	Curve left; Lakeshore Road becomes Rosemount Avenue.
40.3	0.2	Stop. Turn right onto Sugarloaf Street.
40.8	0.5	Turn right into park.

LUNCH STOP.

The park offers a view of Port Colborne's harbor and the Welland Canal's port of entry. Over 6,600 ships and nearly 800 pleasure craft passed through the canal in 1980. Inco Metals Company nickel refinery is Port Colborne's largest employer. Canadian nickel, in Inco-developed alloys, was used in the main engines and other components of the space shuttle *Columbia*.

Leave park.

41.4	0.1	Cross Sugarloaf Street and proceed north on Elm Street.
41.5	0.4	Cross railroad tracks.
41.8	0.3	Turn left at traffic light onto Killaly Street (Regional Road 5).
42.3	0.5	Junction, Regional Road 64 (Ontario Highway 58) on right.
42.4	0.1	Turn left.
42.5	0.1	Cross railroad tracks.
42.7	0.2	Rubble pile on right. Park on concrete pad just beyond. Walk SW into abandoned quarry complex.

STOP 3. PORT COLBORNE EAST QUARRY

No detailed studies of this quarry complex have been published since the days of Stauffer (1915). It was once operated by the Canadian Portland Cement Company and included a large plant, of which only the foundations remain. The quarries were developed on a low, ENE-trending anticline. Telford and Tarrant (1975) mapped only Edgecliff at this locality, however, in places, strata have a distinctively Clarence character - argillaceous, fine-grained, abundant chert - particularly in the north and west walls. This is probably another manifestation of the interfingering nature of Edgecliff and Clarence facies as described at the Ridgemount quarry. Beds at water level are packstone or grainstone; skeletal material decreases and mud increases upward. The "island" in the southern end of the quarry is a bioherm. Large blocks of light-colored Acinophyllum bafflestone are piled to the east of the island, along the roadway which leads southward into the quarry. Near the island, a railroad trestle crosses a cut which connects the northern quarry with a smaller one south of the tracks. In this area are exposed approximately 4 m of massive bedded, light gray, crinoid grainstone and packstone containing abundant large favositids, common Cystiphylloides, and fewer Thamnopora and Syringopora. These strata have all the aspects of proximal flanks observed in the subsurface bioherms.

This stop offers excellent fossil-collecting, either from the rubble piled east of the quarry, or from around the quarry itself. As at the western quarry, glacially-smoothed surfaces provide two-dimensional exposures of the fossil bioherm community.

Leave stop 3 and return to Killaly Street.

43.0	0.3	Turn right.
43.1	0.1	Turn left onto Regional Road 64/Ontario Highway 58.
43.5	0.4	Turn right onto Ontario Highway 3/Regional Road 3.
44.5	1.0	Cross main channel, Welland Canal.
61.5	17.0	Peace Bridge. Return to Marriott Inn by best route.

WPC(#1348)