PHYSICAL AND BIO-STRATIGRAPHY OF THE ONONDAGA LIMESTONE IN OTSEGO COUNTY, NEW YORK

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PURPOSE

The purpose of this article is to summarize the work which has been done on the Onondaga Limestone so as to provide a brief introduction, and a fairly comprehensive set of references for those who are curious about the formation. No stratling new discoveries will be revealed. The Onondaga formation has been the subject of study by numerous of the immortals of New York State geology, by three doctoral students and at least five students at the master's level. These studies have provided a wealth of information on the formation which has not previously been compiled into a comprehensive summary other than those which are so concise as to provide nearly no information at all. At present numerous aspects of the formation are being studies at the industrial, governmental, and academic levels. We know of several studies in the academic sector alone which are so near completion as to necessitate the modification of this summary almost before it becomes available. "So it goes." Kurt Vohnegut, Jr. (1970B)

INTRODUCTION

The Onondaga Limestone has long been recognized in New York and is one of the state's most extensively exposed and prominent formations. Its outcrop and characteristic escarpments extend for over 550 km from Buffalo to the Helderbergs and thence southward through Kingstone to Port Jervis (Fig. 1). This outcrop is dotted with hundreds of active and inactive quarries which have produced vast quantities of building stone and aggregate material. Since 1967, when the first large, subsurface, gas-bearing Onondaga "reef" was located, interest in the formation has waxed somewhat. Despite its prominence and economic import there is yet much to be learned about this formation, particularly in its more academic aspects.

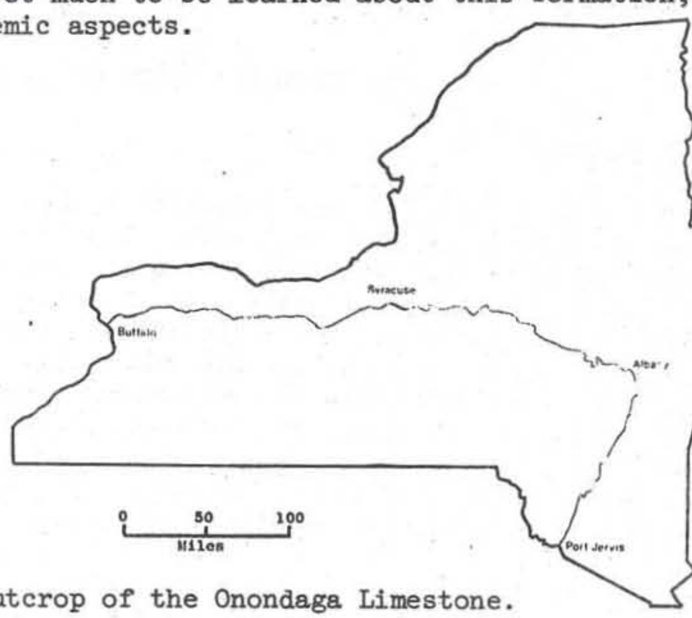

Fig. 1 - Outcrop of the Onondaga Limestone.

The Onondaga Formation is a coarse-to-fine-grained limestone, which ranges in thickness from 21.5 m (70') in central New York to in excess of 49 m (160') in the eastern and western parts of the state (Table 1). A variety of forms and colors of chert are common throughout. The formation was deposited during Eifielian time (lower Middle Devonian) (Rickard, 1975) just prior to and during the first clastic influx from the Acadian Orogeny. The Onondaga represents the last extensive carbonate and reef building phase in the region.

HISTORY OF GEOLOGIC STUDY

The Onondaga Formation figures prominantly in the history of New York State geology and it has a long and diverse history all its own. The first illustration of a fossil from the New York Devonian strata was a gyroconic nautiloid from the Onondaga. It was published in 1807 (Wells, 1963). Prior to the establishment of the New York State Geologic Survey in 1836, mention of those strata now known as the Onondaga Limestone consisted mainly of descriptions of its escarpments, fossils, and resistance to the efforts of the Erie Canal builders. One notable exception is found in the work of Eaton (Wells, 1963) who in his pioneer stratigraphic studies placed the long persistent name of "Cornitiferous Limerock" on the formation and recognized two subdivisions. In 1839, Vanuxum, working in central New York, divided the formation into four subdivisions, which roughly correspond to the present day members. The uppermost of Vanuxum's subdivisions received the name "Seneca Limestone" a label which persists today. In 1841 Hall (p. 156-158) recognized a three-fold division of the formation and introduced the term "Onondaga Limestone" for those beds now known as the Edgecliff Member. Following the time of these early studies the stratigraphy of the formation was in a state of flux for over a century. Oliver (1954, 1956), in a detailed state-wide study of the formation, established the type sections, descriptions, and extents of the Onondaga Formation and four members within it. Ozol (1963), working in western New York, established the presence of a fifth member and brought the stratigraphy of the formation to its present state.

STRATIGRAPHIC UNITS (Fig. 2)

Edgecliff Member

The type locality of the Edgecliff Member is Edgecliff Park, southwest of Syracuse (Oliver, 1954). The Edgecliff is a light-grey, coarse-grained, crinoidal limestone, with beds ranging in thickness from 15cm-1m. Crinoid columnals with diameters of 2 cm or more are diagnostic of this unit. The Edgecliff is characterized by a rich and abundant fauna of rugose corals and tabulates. Brachiopods, ectoprocts, gastropods, and trilobites are present though not usually common. The typical Edgecliff fauna and lithology can be traced from Buffalo to the Helderbergs. South of the Helderbergs, in the areas of Leeds and Kingston, the Edgecliff swells from its normal thickness of about 9 m to a maximum thickness of 11 m and becomes finer-grained,

LOCATIONS

MEMBERS	Buffalo	Leroy	Syracuse	Richfield Springs	Cherry Valley	Cobles-kill	Helder-bergs	Catskill-Leeds	Saugerties
Seneca	12.3m + 40' +	9.2m 30'	7.8m 25.5'	2.1m 7'	2.1m 7'	- -	- -	- -	- -
Moore-house	17m 55'	17m 55'	7m 23'	22.9m 75'	22.9m 75'	21.3m 70'	21.3m 70'	11.3m + 37' +	30.5m + 100' +
Nedrow	uncer-tain	uncer-tain	4.3m 14'	3.7m 12'	3.7m 12'	4m 13'	4.6m 15'	13.1m 43'	10.4m 34'
Clarence	13.8m 45'	13.8m 45'	- -	- -	- -	- -	- -	- -	- -
Edge-cliff	3.1m 10'	3.1m 10'	6.1m 20'	6.1m 20'	7m 23'	9.1m 30'	9.1m 30'	10.7m 35'	11m 36'
Totals	45.7m + 150' +	42.7m 140'	25m 82'	34.7m 114'	35.7m 117'	34.4m 113'	35m 115'	35m 115'	51.8m + 170' +

Table 1. Average Thicknesses of the Onondaga Limestone throughout N.Y.S.

darker, and less fossiliferous. Further south the member thins to about 4 m at Wawarsing, and, bearing a sparse fauna, can be recognized only by the presence of crinoid columnals.

The Edgecliff has been divided into three faunal zones the elements of which can be found in Oliver (1954, 1956). The zones are described as follows: Zone A is the basal unit at many localities west of Richfield Springs, where the Onondaga ceases to be transitional with the subjacent Schoharie Formation. Zone A is a brachiopod dominated unit with quartz sand and silt scattered about in the limestone. The abundance of quartz grains decreases upwards with the lowermost bed occasionally containing sufficient quartz to be a sandstone. The zone ranges in thickness from less than 2 cm to 1.2 m. Zone B is a discontinuous, coral cominated, limestone which is found only in western New York and Ontario. This zone has been found to represent erosional remnants of the Early Devonian Bois Blanc Formation and has been removed from the Onondaga Formation (Oliver, 1966, 1967). Zone C is the predominant and typical Edgecliff faunal zone. This zone is dominated by rugose corals and tabulates and is the "coral biostrome" of Oliver (1954, p. 635) as well as the "great coral-bearing limestone" of Hall (1879, p. 140). The coral fauna and coarse-grained texture of this zone can be traced from Buffalo to Leeds, a distance of about 490 km. (300 mi.). East of West Winfield Quadrangle two subzones, designated C_1 and C_2, can be recognized. C_1, the lower of the two, is a medium grey, fine-grained, limestone with a non prolific coral (dominant) and brachiopod fauna. Subzone C_2 is the typical and predominant coarse-grained, light-grey, coraliferous Edgecliff Member.

Nedrow Member

The Nedrow Member is typically a thin-bedded, very fine-grained, argillaceous limestone. At its type locality, Indian Reservation Quarry south of Nedrow, N.Y., the unit measures 4.6 m (15') with an abrupt base and a gradational upper contact (Oliver, 1954). The member maintains its typical thickness over most of its recognizable range except in the vicinity of Leeds and Saugerties where it is 13 m (43') and 10.5 m (34') respectively. In eastern and western New York the Nedrow is difficult to recognize due to the absence or scarcity of argillaceous sediment. In westernmost New York Nedrow equivalent beds lie above the Clarence Member rather than the Edgecliff which it normally succeeds (Rickard, 1975). In the eastern part of the state the Nedrow is lithologically very similar to the Edgecliff Member and is recognizable only by its fauna and thin bedding.

The Nedrow bears a distinctive fauna by which it can frequently be identified despite its lithologic variability. The base of the member often consists of a 0.6 m - 1.5 m zone of very thinly bedded argillaceous limestone containing two species of rugose coral <u>Heliophyllum</u> <u>halli</u> and <u>Amplexiphyllum</u> <u>hamiltonae</u>, as well as a diversity of platycerid gastropods and brachiopods. This unit, designated Zone D by Oliver (1954), bears very few corals other than those mentioned above and is quite widespread throughout the state. Zone

E, which succeeds the latter, is thicker bedded, less argillaceous, and bears a low diversity, high density brachiopod fauna to the exclusion of most other taxa.

Clarence Member

Ozol (1963) designated that portion of the formation in western New York which overlies the Edgecliff Member and is 40-75% chert as the Clarence Member. The Clarence roughly corresponds to the corniferous limestone of Hall (1841) and the Nedrow black chert facies of Oliver (1954). The member is a medium to dark grey, non-argillaceous, fine-grained, limestone with such an abundance of chert that the limestone is often found only as small "islands" floating in the chert. Fossils are usually absent or very rare though occasionally the lower beds bear a fauna similar to that of the underlying Edgecliff Member. The Clarence is approximately 13.8 m (45') thick over most of its extent and can be traced from Buffalo, through its type locality in Clarence, New York to Avon, New York. East of Avon it apparently pinches out.

Moorehouse Member

The type locality of the Moorehouse is the Onondaga County Prison Quarry at Jamesville, New York (Oliver, 1954). Here the unit is a medium-grey, very fine-grained limestone with numerous shaly partings forming beds of 0.6-1.5 m in thickness. Chert is found throughout but is most abundant in the upper half of the member. The Moorehouse increases in thickness both westward and eastward from central New York where it is 6.3-7.7 m. In western New York it is about 20 m (65') thick, and near Saugerties over 31 m (100').

In central New York two faunal zones can be recognized in the Moorehouse (Oliver, 1954). Zone F is a sparsely fossiliferous unit with a low diversity, brachiopod dominated fauna. Zone G, which is gradational with the subjacent zone F, has the richest fauna of any unit in the formation. A diversity of brachiopods, gastropods, cephalopods, and trilobites is present and often quite abundant. Several mollusc species are characteristic of this zone.

Neither the typical Moorehouse lithology nor the two faunal zones are continuous across the state. West of Geneva the faunal zones are indistinguishable and are replaced by a fairly evenly distributed brachiopod fauna. Gastropods are nearly absent. In westernmost New York the "brachiopod facies" gives way to a "coral facies" which is coarser grained and contains several species of solitary rugose corals in addition to a well developed brachiopod fauna. In eastern New York the Moorehouse has an Edgecliff-like lithology with a diverse brachiopod, gastropod, cephalopod, trilobite, and coral fauna. Cephalopod species characteristic of central New York are absent. Several of the coral species are characteristic of Edgecliff faunas (Oliver, 1963). Between the Helderbergs and Kingston to the south, the Moorehouse is divisible into a lower non-cherty unit, a middle with dark grey to black chert, and an upper non-cherty unit (Oliver, 1956). To date the complex variations in fauna and lithology contained within the Moorehouse Member have not been documented in sufficient detail to display any pattern.

Seneca Member

The Seneca was first described by Vanuxum (1839) from several exposures in Seneca County. Oliver (1954) established the type section at Union Springs, in Cayuga County, where the member is fully exposed and measures 7.8 m (25.5'). It is a fine-grained limestone which becomes darker and less fossiliferous upwards as it grades from a Moorehouse-like lithology below to a shale above. The Seneca and Moorehouse Members are separated by the Tioga Bentonite.

Oliver (1954, 1956) identified five zones within the Seneca Member. Zone H is believed to have resulted from a volcanic ash fall. Though there are several bentonites within the Onondaga (Rickard, 1976) this particular one can be traced across the state with a good degree of certainty. Zone I is a medium-dark grey limestone with a lithology similar to that of the upper Moorehouse Member but characterized by an abundance of Chonetes lineatus. Zone J, also called the "Pink Chonetes zone", is a very thinly bedded limestone. It is packed with Chonetes many of which are pink in color. Zone K is a dark grey limestone which rapidly darkens upward. It is characterized by Chonostrophia reversa with other species being rare and all fossils becoming scarcer toward the top. At its type area, the base of this zone is marked by a concentration of Heterophrentis. Zone L is a very dark grey limestone which is interbedded and intergraded with the overlying Marcellus Shale. This uppermost zone of the formation bears a low density, low diversity brachiopod fauna.

Despite rather poor and intermittent exposure the Seneca Member can be seen to exist in a gradational facies relationship with the overlying Marcellus Shale. The Seneca thins from over 12.3 m (40') at Buffalo to 2.1 m (7') at Cherry Valley. The eastward thinning is matched 30.5 cm for 30.5 cm (foot for foot) by the eastward thickening shale (Oliver, 1956). As the Seneca thins eastward from its type section in central New York, the upper zones are progressively lost. At Stockbridge Falls Zone L is absent and at Cherry Valley only the bentonite and Zone I are present. The member does not exist east of Cherry Valley and presumably the bentonite is enclosed within the Marcellus Shale. Though no exposures of this shale-bentonite relationship are reported from New York, a shale enclosed bentonite believed to be equivalent to the Tioga of central New York is known from eastern Pennsylvania (W.D. Sevon, pers. com.).

FORMATIONAL CONTACTS

Basal Contact

A slightly diachronous relationship is indicated by the contact of the Onondaga Limestone and its subjacent formations. Throughout eastern and southeastern New York a gradational contact exists between the Onondaga Formation and the calcareous mudstones of the Schoharie

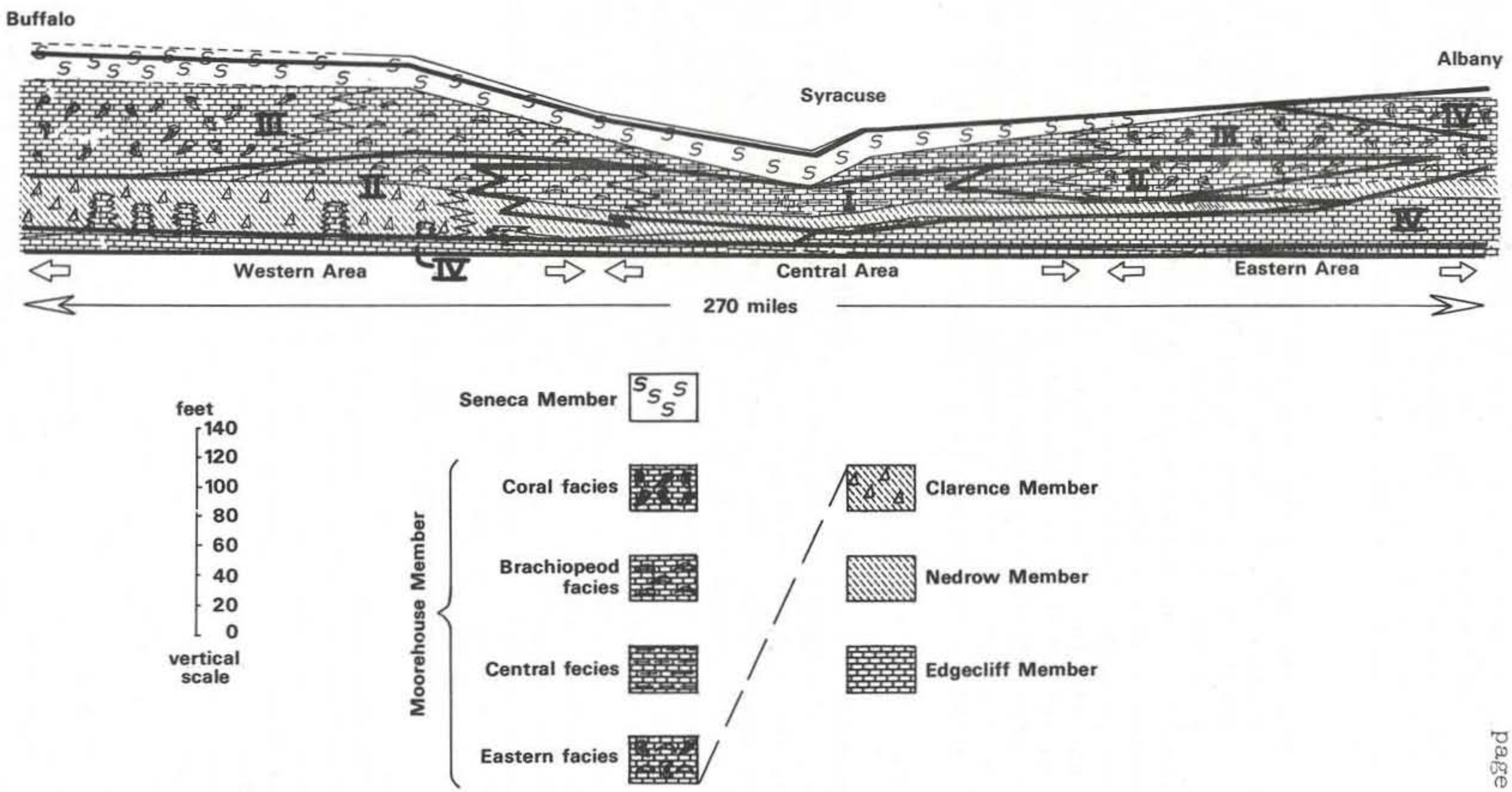

Fig. 2 - Cross section showing stratigraphic units and lithofacies (From Lindholm, 1967).

Formation. Between Sharon Springs and Richfield Springs the gradational contact is marked by phosphorite nodules and glauconite, indicating a slight unconformity. Westward from Richfield Springs the Onondaga rests unconformably on successively older formations. Often the contact is unmistakably erosional and the lower beds of the Onondaga contain quartz sand and lithiclasts reworked from the underlying formations.

At many localities in western New York the Onondaga rests unconformably on the Silurian Akron Dolostone. In some places, however, it rests on erosional remnants of the Early Devonian Bois Blanc Formation. At sites where the latter is the case the contact is marked by occasionally cross bedded quartz sand and is abrupt and undulatory, Sand concentrations are greatest in troughs of the contact indicating that its morphology is erosional in origin and not the result of post-depositional warping. The Bois Blanc Formation is the western New York equivalent of the Schoharie Formation (Oliver, 1967). Therefore, erosion of much of the Bois Blanc prior to Onondaga deposition indicates that the base of the latter is somewhat younger in western New York than in the east. Deposition in a transgressive sea is indicated.

Upper Contact

Throughout its entire range the Onondaga Formation is overlain by shales of the Marcellus Formation. Wherever exposures permit observation, the contact between the limestone and the shale can be seen to be gradational. When viewed on a statewide scale, the contact reveals a facies relationship between the upper two members of the Onondaga Formation and the Bakoven, Union Springs, and Oatka Creek members of the Marcellus Formation. Using the Tioga Bentonite and the base of the Cherry Valley Limestone as time planes it can be readily seen that limestone deposition was terminated as clastic mud prograded westward (Rickard, 1975). This diachronaity is so pronounced that limestone deposition had ceased in easternmost New York even before the first beds of the Seneca Member had been deposited in the more central and western parts of the state.

LITHOLOGY AND LITHOFACIES

The Onondaga Limestone lacks diverse allochems and is nearly devoid of sedimentary structures. As a result the carbonate petrology of the formation tends to be relatively monotonous in comparison with many other formations. Throughout most of the Onondaga, fossils, whole and fragmental, are the sole allochem constituents of any quantitative consequence and are usually the only ones present. The vast majority of particles recognizable in thin-section or polished-slab are crinoids, brachiopods, ectoprocts, trilobites, and corals. Microfossils, such as radiolarians, achritarchs, and sponge spicules are conspicuously absent in the limestone itself but can commonly be found in the chert (Ozol, 1963; Wicander and Schopf, 1974; Pfirman and Selleck, 1977). Other allochems such as pellets, ooids, and intraclasts are common at very few localities and only in the lowermost beds of the Edgecliff Member.

Taken as a whole the formation is volumetrically dominated by silt-size carbonate particles having a mean grain-size of between five and fifteen microns (Lindholm, 1967, 1969a). These silt-size particles are found to be lacking or absent only in the eastern part of the state and in the Edgecliff Member throughout. Noting that the carbonate silt particles are poorly-sorted, of variable shape, and frequently associated with terrigeneous silt, Lindholm (1969a) concluded that they are of detrital origin rather than the result of the neomorphic alteration of micrite to microspar (Folk, 1962). Lindholm further concluded that the calcisiltite was produced by the mechanical and organic breakdown of invertebrate shell material. Although the breakdown of shells is known to produce large quantities of lime mud (Matthews, 1966), the lack of positive identification of the calcisiltite's origin leaves the door open for other possible sources such as the production of lime mud by algae (Stockman, et al., 1967).

Lindholm (1967) reported the presence of several terrigeneous detrital minerals which occur in varying abundances throughout the formation. The clay minerals "illite" and chlorite are most abundant in central New York, where they can comprise up to 20% of the rock. Biotite, which never makes up more than 1% of the rock, is nearly ubiquitous. Quartz silt is found in many samples. Dolomite can often be found as euhedral to subhedral overgrowths on originally round to subround silt-size detrital dolomite grains. Noting strong correlations in both size and frequency distributions between dolomite and quartz, Lindholm (1967, 1969b) concluded that both are detrital in origin. He further concluded that, with the exception of the pronounced influx of terrigeneous mud which caused the deposition of the Nedrow and lower Moorehouse members in central New York, most terrigeneous components of the Onondaga are the result of aeolian transport.

Lindholm (1967) recognized four basic limestone types within the formation. They are identified on the basis of relative proportions of fossil allochems, calcisiltite, and sparry calcite. The lithologies (distribution shown in Fig. 3) are described as

1. Fossiliferous Calcisiltite - Composed of 1-10% fossil material in a calcisiltite matrix. Dominant fossil types include crinoids, brachiopods, and trilobites. The latter attain their peak abundance within this lithology. Terrigeneous clays can comprise up to 20% of the rock volume and anhedral quartz silt less than 7%.
2. Sparse Bioclacisiltite - Composed of 10-50% fossil material in a calcisiltite matrix. Fossil constituents commonly include crinoids, brachiopods, and trilobites. Quartz silt, dolomite, biotite, and clays are common though not abundant.
3. Packed Biocalcisiltite - Composed of fossil material in excess of 50% with a calcisiltite matrix. Fossil content is dominated by crinoids, bryozoans, and corals. Terrigeneous materials are scarce or absent.
4. Biosparite - Composed of fossil material with sparry calcite. Calcisiltite is absent. Fossil content is dominated by crinoids, bryozoans, and corals. Terrigeneous components are usually absent. In eastern New York and the Edgecliff Member throughout, biosparite is interbedded with packed biocalcisiltite.

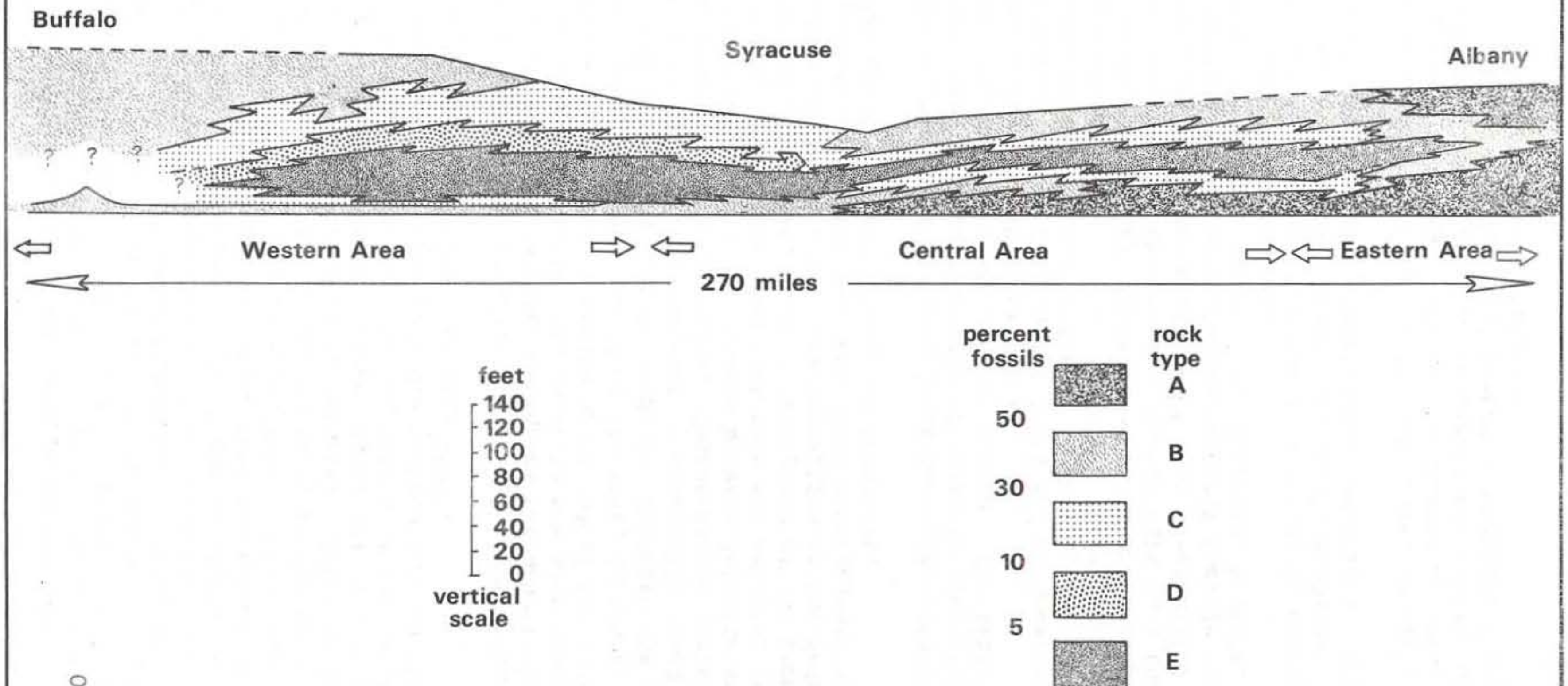

Fig. 3 - Cross section showing distribution of carbonate rock types (From Lindholm, 1967).

FACIES	I	II	III	IV
Fossil content	less than 10 per cent	less than 10 per cent	10 to 50 per cent	greater than 50 per cent
Dominant fossils	brachiopods trilobites crinoids	brachiopods trilobites crinoids	brachiopods trilobites crinoids	crinoids bryozoans
Dolomite content	10-20 per cent	5-10 per cent	less than 5 per cent (in western area up to 20 per cent)	less than 5 per cent
Clay content	5-25 per cent	2-5 per cent	2-5 per cent	less than 2 per cent
Biotite	present	none	none	none
Burrowing	distinct	distinct to vague	distinct to mottled	generally absent
Relationship to members	includes Nedrow and lower Moorehouse of central area.	Nedrow and lower Moorehouse of western area.	Upper Moorehouse and Seneca of central and western areas.	entire Edgecliff, as well as Nedrow and upper Moorehouse of eastern area.

Table 2. Composition of Lindholm's lithofacies. From Lindholm 1967.

Lindholm (1967) divided the formation into four lithofacies based on lithologic texture, composition, and mineralogy as well as spatial relationships. The compositions of the lithofacies are summarized in table 2.

Figure 2 compares and contrasts the distributions of Lindholm's lithofacies and Oliver's stratigraphic units. Lindholm (1967) suggests that discrepancies in spatial distributions between lithofacies and members are due the different observational scales used in the studies. Stratigraphic units were identified using macrofossils and overall lithologic character while lithofacies were identified using thin-sections. Lindholm further suggests that macrofossils were deposited at or very near their life sites while fine grained fossil debris underwent extensive transport. In reaching this conclusion Lindholm further supports his contention that the calcisiltite is indeed of detrital origin.

CHERT

Cherts occur commonly in many of the state's limestone formations. However, the cherts of the Onondage Formation are unusual in their occurrence and abundance. Though the chert content of any given interval or member is highly inconsistent between localities, there is a general tendency for increasing percentages to the west (Fig. 4). In general the Edgecliff Member contains $\leq$3% chert, the Nedrow 0-2%, the Clarence 40-75%, the Moorehouse 3-15%, and the Seneca $\leq$5% (Ozol, 1963). These percentages must be applied with caution due to rapid changes in form and abundance which the cherts undergo both vertically and laterally. Chert is unevenly distributed, tending to be concentrated in specific beds or intervals leaving others only sparsely chertified.

Morphologically, chert occurs as nodules, lenses, anastamosing networks, and beds. The nodules and lenses are usually scattered about within beds or in specific layers and are frequently elongate parallel to bedding. Nodules vary in shape from smooth and rounded to highly irregular with protruberences which transgress bedding. Irregular shaped nodules often coalesce with one another. Extensive nodular coalescence leads to the development of anastomosing networks which can result in intervals of massive chert enclosing small "islands" of limestone (Ozol, 1963). Discrete chert beds are not common in the formation. Those which do occur range in thickness from 5-25 cm and can be traced the full extent of the outcrop, but not between localities. Though no universally reliable association has been found between chert morphology and the texture or composition of the enclosing limestone, the more massive cherts are best developed in massively-bedded, homogeneous, fine-grained limestones (Ozol, 1963). This association appears to be confirmed by the recent work of Pfirman and Selleck (1977).

Chert in the Onondaga is primarily composed of microcrystalline quartz. Lesser amounts of chalcedony, cryptocrystalline quartz, megaquartz, and isotropic silica are also present (Ozol, 1963). Ozol has also noted that microcrystalline quartz usually occupies the former positions of solid parts of fossils while other silica minerals

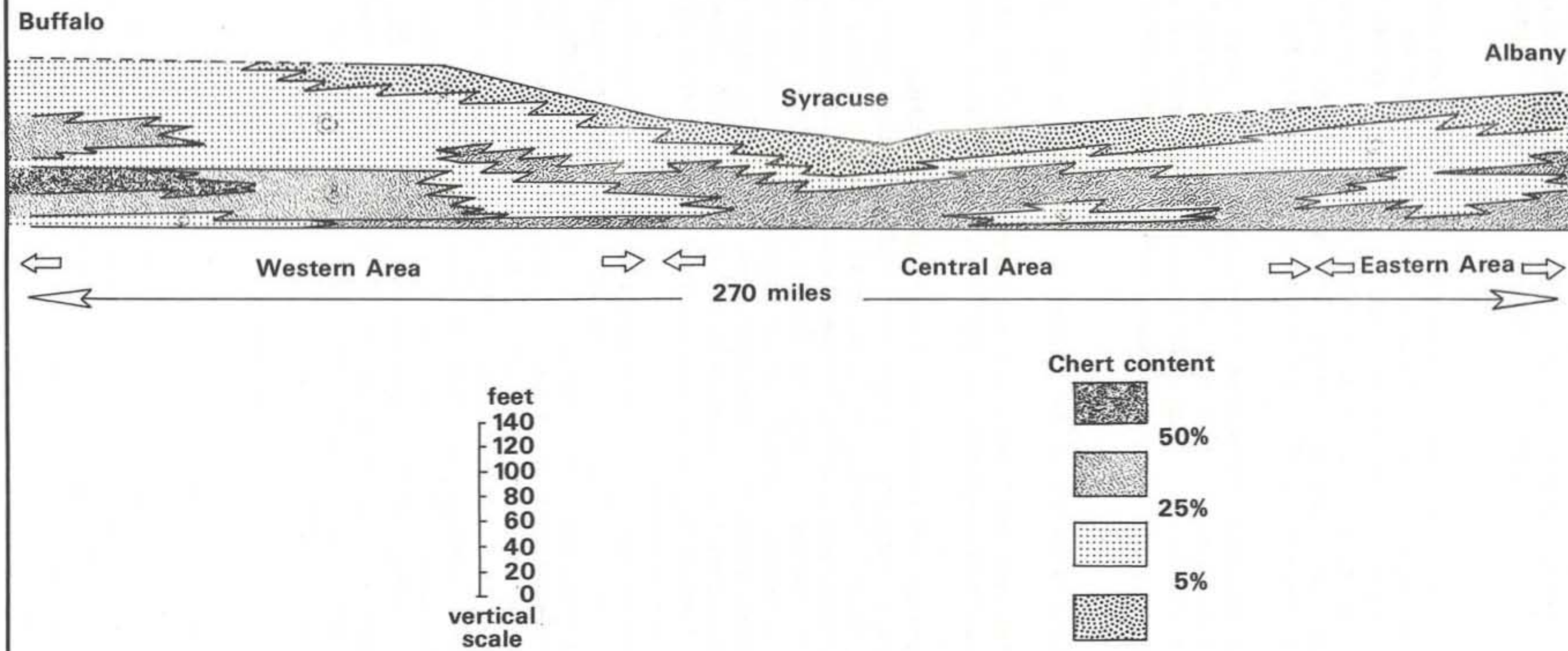

Fig. 4 - Cross section showing chert content (From Lindholm, 1967).

occupy the intersticies. Therefore the relative abundance of the various silica minerals within a given chert body may possibly be related to the original texture and composition of the limestone (or sediment).

In addition to silica minerals the cherts contain varying quantities of calcite, dolomite, limestone, minute vacuoles, and several minor accessory minerals. The former two minerals are often found as euhedral crystals up to 2 mm in size concentrated near the periphery of nodules. Among the minor accessory minerals found to be concentrated in the chert with respect to the enclosing limestone are Fe_2O_3 and TiO_2.

Chert in the Onondaga Formation originated by the post depositional silicification of carbonate sediments and the post lithificational silicification of limestone. Numerous items of evidence can be seen in the rock which support the replacement origin of the chert. Among others they include:

1. Partial silicification of the internal structures of corals and tabulates.
2. Fossils which are half enclosed in chert and half in limestone.
3. Fossils preserved as ghosts or partially silicified remnants within chert.
4. Isolated patches of limestone within chert nodules.
5. Preservation of original limestone bedding within chert.
6. "Incipient chert" (Ozol, 1963, p. 141) found as highly calcareous rims on nodules and nodular shaped patches of calcareous chert within the limestone. These zones of impure chert are believed to represent initial stages of silicification because they preserve original limestone textures more faithfully than the chert proper. When found as rims on nodules these zones often contain euhedral dolomite far in excess of that found either within the limestone or the chert.
7. In proximity to many chert nodules limestone laminae can frequently be seen to flare so as to pass above and below the nodule. The surfaces of some nodules bear slickensides-like lineations. These phenomena would occur only if the chert were a hard entity within a loose or semilithified sediment. They also support the contention of Shinn and others (1977) that carbonate sediments do indeed undergo compaction prior to cementation.
8. In a few instances styolites have been observed within chert bodies (Lindholm, 1967). Because styolites form within limestone and not within loose sediment, it is believed that some Onondaga cherts inherited these structures through the replacement of solid limestone.

BIOHERMS

Background and Description

Bioherms have been known to exist within the Onondaga Limestone since the mid 1800's when Hall (1859) described the present day Edgecliff Member as being composed of coral reefs. Hall and other early investigators who referred to reefs within the formation were probably impressed by the great abundance of coral in the Edgecliff Member and applied the term reef indiscriminately. Grabau (1903, 1906) provides the earliest mention of individual reefs complete with descriptions and locations. The first reef to be described was characterized as a domal mound with flanking beds dipping away at about 10°. This reef was located in the Fogelsanger Quarry in Williamsville, just east of Buffalo on Rt. 5. Quarry operations had ceased shortly after exposing this reef over its full extent. Unfortunately construction of the Youngman Expressway went directly through the reef and placed most of it, as fill, into a nearby swamp. The remaining exposures consist of only a small portion of the flanking beds, off-reef Edgecliff, and the overlying Clarence Member. A point of interest which may be worth noting is that this quarry was, for quite some time, a popular fossil collecting site for scientific supply houses, museums, and rock hounds alike. As a consequence, there are many fossils about bearing the citation "Onondaga Limestone, Williamsville, N.Y.". These are to be treasured as their point of origin no longer exists.

Between the time of Grabau's original work and the mid 1950s over 21 bioherms were found along the formation's outcrop. Oliver (1956) reported that all reefs with the exception of the one in Williamsville were located in eastern New York. Subsequent field work (Oliver, pers. com.) revealed nearly a dozen additional reefs in western New York and adjacent Ontario. Furthermore it appears that bioherms also exist in the central part of the state. Subsurface studies since 1967 have revealed the presence of several additional reefs in southwestern New York (Warters, 1972) and adjacent Pennsylvania (Piotrowski, 1976).

The bioherms, seen in outcrop, are generally round or ovoid in map view and domal or lensoid in cross section. They range from quite small to in excess of 370 meters (1200') in length and 22 meters (70') in thickness (Oliver, 1956). Oliver (1954, p. 636) reported finding several "micro-reefs" in western New York. These are less than 0.6 m (2') in height and 3 m (10') in diameter. They are individual coral colonies or thickets (Squires, 1964) which trapped lime mud and therefore appear quite different from the enclosing normal Edgecliff lithology. All size gradations exist between the "micro-reefs" and the full fledged bioherms which contain several coral species which are found nowhere else in the formation (Oliver, 1956). Flanking beds dipping away from the bioherms at 10-15° are well developed only on the larger bioherms. The fauna of these flanking beds grades from highly coraliferous near the mounds to a normal Edgecliff fauna at a distance. Oliver (1956) indicated that biohermal growth was, for the most part, therminated by the influx of terrigeneous mud which ended Edgecliff deposition and initiated the Nedrow Member.

The subsurface reefs of southwestern New York and adjacent Pennsylvania are quite different from those in outcrop. Despite their apparently similar faunas these reefs often exceed 55 m (180') in height (Piotrowski, 1976). They attain this height in areas where the entire formational thickness does not exceed 15 m (50') and therefore must project far above the remainder of the formation. Due to their inaccessibility little is yet known about the paleoecology of these subsurface reefs, however, it appears that they developed along a hinge line between a relatively stable epicontinental shelf to the north and a subsiding basin to the south (Warters, 1972).

Four Onondaga bioherms have been studied in detail to determine successional patterns, facies relationships, and paleoenvironments (Mecarini, 1964; Bamford, 1966; Poore, 1969; Williams, 1977). Each of these four investigators approached the problem with somewhat different view points, methods, and intentions. Despite this, their findings, though not identical, reveal quite similar successions of biofacies, or fauna-sediment associations, within the bioherms throughout the state. Poore (1969, p. 56) compiled the results of the first three above cited studies to develop a "typical" bioherm model which could be used in future studies. Though necessarily general in content, the "typical" Edgecliff bioherm appears to accurately depict the development of bioherms other than those which were used in its synthesis. A diagram of the model is shown in Fig. 5 and an annotated summary of the four basic facies is presented below.

1. Acinophyllum Facies. This, the lowermost unit of the bioherm, is dominated by the delicate compound rugose coral Acinophyllum. This branching coral baffled currents and trapped lime mud thus stabilizing the substrate and building upwards. This facies, which is the pioneer community of the bioherm, corresponds to the "basal stabilization zone" of Walker and Alberstadt (1975, p. 238).

2. Core Facies. This unit overlies the Acinophyllum facies and makes up the main body of the bioherm. The matrix material of this facies is predominantly lime mud however spar content increases upwards. The unit can frequently be divided into two subfacies. The lower subfacies has a low faunal diversity which is dominated by branching rugose corals or tabulates such as Cylindrophyllum or Coenites which trapped lime mud and continued building of the mound. This subfacies corresponds to the "overlying colonization zone" of Walker and Alberstadt (1975).

   The lower core subfacies grades into the upper core subfacies which, in addition to the branching rugose corals and tabulates, supports a well developed fauna of laminate to hemispheric tabulates of the Emmonsia and Favosites genera. This facies supports the highest faunal diversity of any on the reef. It corresponds to the diversification zone of Walker and Alberstadt (1975).

3. Flank-Cap Facies. This unit consists of those beds which both flank the bioherm, grading distally into the normal Edgecliff lithology, and override it. The bioherm cap contains sand and gravel size sediments with virtually no lime mud. Terrigeneous mud is also absent from this facies dispelling the contention that a terrigeneous influx killed off the corals.

4. Energy Shadow Facies. This unit is found on the "platform" side of the core facies. The Acinophyllum and Core facies of several bioherms contain corals which are strongly oriented in a direction

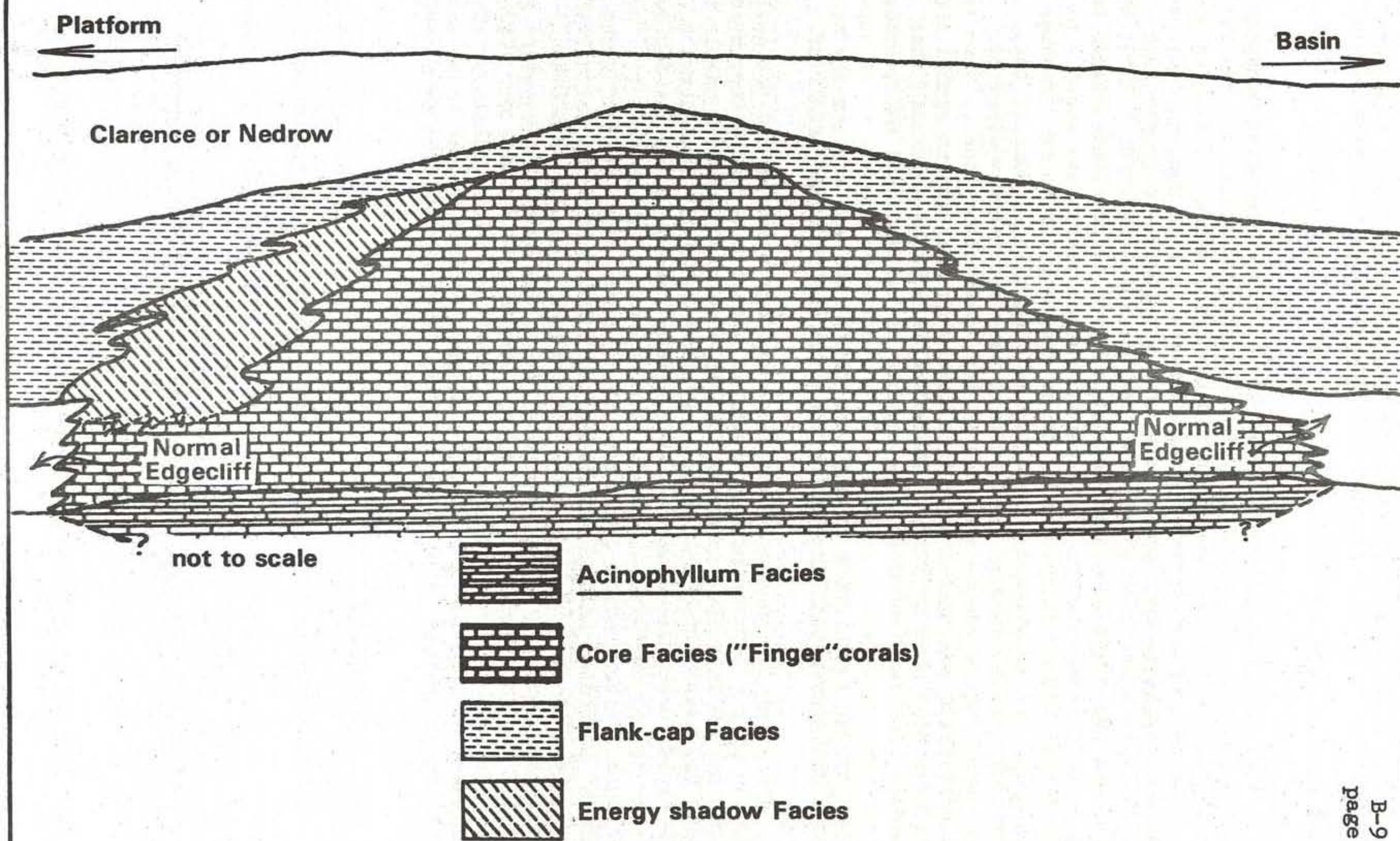

Fig. 5 - Cross section of a "typical" Edgecliff bioherm (From Poore, 1969).

interpreted as representing prevailing waves or currents. Opposite this direction is located the energy shodow facies which contains greater quantities of lime mud than "the core facies but less than the Acinophyllum facies" (Poore, 1969, p. 56). The fauna of this facies is interpreted as consisting of organisms tolerant of fluctuating and occasionally high turbidity levels.

Reefs or Bioherms?

It is the general consensus of those who have studied Onondaga bioherms that they contain discrete successional stages and result in the erection of a wave resistant topographic feature. Noting an upward increase in spar and corresponding decrease in lime mud, successional stages of bioherm development have been attributed to growth into successively higher energy waters. Walker and Alberstadt (1975), who developed the fourfold classification of reef successional stages to which the Onondaga bioherms correspond rather well, have stated the belief that faunal succession in those stages prior to the "domination zone" are principally biologically controlled. None of the previously cited Onondaga reef studies have described a stage of development which can be assigned to the "domination zone". This is the physically controlled zone initiated when reef growth enters the zone of strong wave activity. Therefore it must be concluded that Onondaga bioherms lacked a fauna capable of building and maintaining a true wave resistant structure. This conclusion appears to be supported by the recent work of Williams (1977) who was also unable to find a well developed "domination zone" in the Thompson Lake reef.

The above stated conclusion that Onondaga bioherms did not build into the zone of strong wave activity is almost a foregone conclusion. Ever since Wells (1957) reported that Paleozoic corals were unable to expand the basal attachment area, they have generally considered to have lived "below wave base". The question remains as to the degree of wave agitation Paleozoic reefs were capable of withstanding. The reef core facies contain quantities of lime mud comparable to those found in sediments on and immediately adjacent to Florida patch reefs which are subjected to hurricanes and frequent squalls (Lindemann, unpublished work). Part of the solution to the agitation question may lie in a current investigation, by the senior author, into the stability and wave resistance potential imparted to branching rugose corals by the entrapment of lime mud. To date, Onondaga bioherms appear to be more accurately described as bioherms (Cloud, 1952) rather than true reefs (Heckel, 1974).

The Mount Tom Bioherm

Oliver (1956, p. 20-22) described a group of seven bioherms in the vicinity of Richfield Springs. The one he designated as "Mount Tom No. 1 reef" is 215 m (700') long, 155 m (500') wide, and 22 m (70') high. This bioherm was the subject of Mecarini's 1964 study. The facies identified by Mecanini are summarized in Table 3, and are briefly described below. The spatial relations of the facies are shown in Fig. 6.

Facies →	Basal Facies	Core Facies			Flank-Cap Facies		Inter-reef Facies
Subfacies →		Acinophyllum Subfacies	Tabulate Subfacies Ciacopore Unit	Tabulate Subfacies Emmonsia Unit	Typical Cap	Typical Flank	
Spar	6	2	9	18	24	8	2
Micrite	45	47	27	11	7	8	32
Quartz	-	-	-	-	-	-	2
<u>Acinophyllum</u>	1	40	5	-	-	-	-
Solitary Rugose corals	-	-	-	5	13	-	-
Emmonsia	-	-	-	14	-	11	-
Auloporids	-	-	2	2	1	-	1
Other Favositids	-	-	16	6	3	-	-
Crinoids	36	6	30	35	42	68	36
Ectoprocts	5	2	4	6	5	2	1

Table 3. Average percents of selected components as seen in thin-sections from Mt. Tom Reef from Mecarin, 1964.

Basal Facies. Consists of a tan and gray shale and limestone which grades upward into a crinoidal biomicrudite. The lower portion bears a fauna of platycerid gastropods and brachiopods, solitary rugose corals, trilobites, ostracods, and favositids. The maximum thickness of this facies is 3 m (9').

Core Facies. Forms the reef itself and is divided into two subfacies. <u>Acinophyllum</u> Subfacies - described as an <u>Acinophyllum</u> biomicrudite, this subfacies is dominated by <u>Acinophyllum</u> with a sparse fauna of crinoids and ectoprocts. It attains a thickness of about 4 m (12').

Tabulate Subfacies - Subdivided into two units.
<u>Cladopora</u> Unit. Ranges from a packed biomicrudite to a poorly washed, small tabulate biosparite. The percentage of spar increases upwards. In addition to <u>Cladopora</u> this unit contains a fauna of <u>Emmonsia</u>, <u>Thamnopora</u>, <u>Aulocystis</u>, and <u>Syringopora</u>. It attains a maximum thickness of 12 m (40').
<u>Emmonsia</u> Unit. This unit is a highly porous, coarsely crystalline, poorly to well washed, rich <u>Emmonsia</u>, crinoidal biosparudite. It

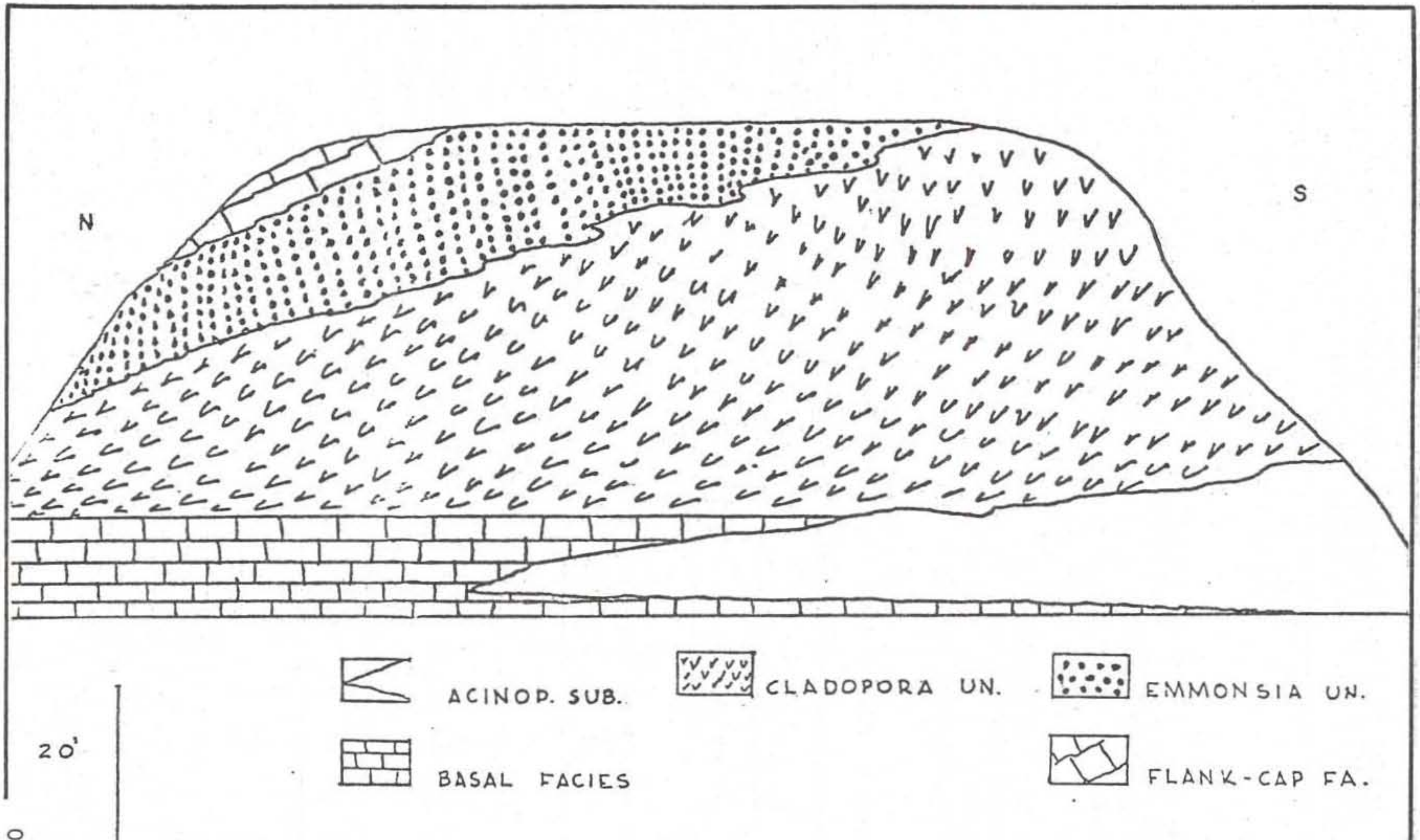

Fig. 6 - North-South cross section through the Mount Tom bioherm (From Mecarini, 1964).

bears a fauna of Emmonsia, Cladopora, Aulocystis, Syringopora, various ectoprocts, brachiopods, and particularly in its upper parts, Heliophyllum. It approaches 6 m (20') in thickness.

Flank Cap Facies. This facies overlies the core facies and is an extension of the flank deposits which dip away from the bioherm at 15°. The lithology ranges from an extremely coarse, crinoidal and solitary coral, biosparudite above the core to a poorly washed, gray, crinoidal biosparudite on the flanks. The fauna is dominated by Heliophyllum and Cystiphyllum.

PALEOENVIRONMENTS

The Onondaga Limestone was deposited in an initially shallow but subsiding epicontinental sea, within about 30° of the equator. A westward transgression of the sea across New York State is indicated by the base of the formation. The transgression resulted in the deposition of the Edgecliff Member in sahllow, wave-affected waters (Laporte, 1971). This is evidenced by the lithologic character and corals reefs of the member. Variations in turbidity and water agitation are indicated as major allogenic environmental controls on faunal character and distribution throughout the eastern half of the Edgecliff (Lindemann, 1974). Continued subsidence carried the sea bottom below the effects of waves and set the stage for deposition of the other members (Laporte, 1971). Deposition of the Nedrow Member took place during an influx of clastic mud which moved through a topographic depression or trough which then existed in central New York (Oliver, 1956; Lindholm, 1967). The source of the mud appears to have been quite some distance to the north, or possibly the south east, as indicated by clastic free deposition to the east and west, a rapidly subsiding basin to the south, and a general absence of nearby land (Wicander and Schopf, 1974). The Moorehouse Member marks a return to relatively nonturbid conditions. Unlike the Edgecliff the Moorehouse was deposited in quiet water. The Seneca Member was deposited during the westward progradation of the Marcellus shale. The gradational and interbedded relationship between the Seneca Limestone and the Marcellus Shale indicate that turbidity levels waves and waned for a time prior to the eventual inundation of the sea by clastic mud and termination of limestone deposition.

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ROAD LOG

Miles from last point	Cumulative Miles	Route Description
0.0	0.0	Leave the Oneonta State campus and proceed to Richfield Springs via West Street, Rt. 7, Rt. 205, and Rt. 28. In Richfield Springs remain on Rt. 28 until just north of Rt. 20. We will reassemble in the Flea Market parking lot on the east side of Rt. 28 just north of the intersection. Mileage will begin here.
2.8	2.8	Continue north on Rt. 28 to rock exposure on east side of road just north of Schuyler Corners.
		STOP 1. This exposure contains the uppermost Edgecliff and lowermost Nedrow Members. Though the contact cannot be seen, the pronounced differences in fauna and lithology are evident. Note the color and nature of the chert for future reference. The outcrop is typical of hundreds of other Onondaga exposures in extent and weathering characteristics.
2.8	5.6	Return to Rt. 20 and turn left (east) at the blinking light.
6.8	12.4	Remain on Rt. 20 until its intersection with Rt. 80 at Springfield Four Corners, turn left (north) onto Rt. 80.
0.2	12.6	Take the first left which is a winding, gravel-paved quarry entrance, and park on the first broad level area.
		STOP 2. Park in abandoned quarry entrance on left and walk up into quarry. In this quarry 57' of the formation are exposed; 19.5' Edgecliff, 12.5' Nedrow, 25' Moorehouse. The gradational beds between the Schoharie and Edgecliff can be seen in the road as you walk up into the quarry and in the pinnacle of rock to your left just as the road begins to level off on top. These beds grade from dark and glauconitic below into clean, coarse-grained, coraliferous Edgecliff above. The floor of the northern quarry section is in the transitional beds.
		The western quarry section which we will visit has exposed the upper Edgecliff, the entire Nedrow, and the lower Moorehouse. The main

Miles from last point	Cumulative Miles	
		floor of the quarry lies on the upper Edgecliff which can be recognized by its corals, large crinoid columnals, and pyrite. The water filled pit and ramp are entirely in the Edgecliff. The main quarry walls contain the dark, shaley Nedrow in their lower parts and the cherty Moorehouse above.
1.3	13.9	Leave the quarry headed north on Rt. 80 and take the second left onto Koenig Road.
0.7	14.6	Continue along Koenig Road to its juncture with Mt. Tom Road just beyond the large white house at the hill crest. Stop at house (Mr. Lamb) for permission to examine outcrops.
		STOP 3. The stop is the near (East) face of the knob directly ahead. Mount Tom Reef No. 1. This is the reef shown in Fig. 6 of the text. Study the reef zonation in the text before proceeding onto the reef. Exercise caution as much of the rock wall is unstable and footing can be tricky. The obvious characteristics of this, and all other bioherms in the Onondaga, are its massively unbedded nature and lack of chert. With patience and close examination you will be able to spot the different corals which comprise the framework of the reef. Examination reveals that the clear cut zonation shown in Fig. 6 is not nearly so clear cut in the reef itself. The matrix material between the corals consists mostly of lime mud, with the coarse crinoidal material typical of many Onondaga bioherms lacking.
1.0	15.6	Proceed west along Mt. Tom Rd. and stop just before reaching the long low hill which crosses the road from north to south.
		STOP 4. Another reef is exposed in the southern end of this hill. The exposure appears to be the "Core Facies" of a reef, but its actual position within the reef is uncertain due to lack of exposure. The reef seems to extend a considerable distance on the basis of the topographic expression.
0.6	16.2	Continue straight along this road until it terminates on Chyle Road and turn left.

Miles from last point	Cumulative Miles	
0.7	16.9	Take the right off of Chyle Rd. onto Merry Hill Road.
0.2	17.1	Go down Merry Hill Road and stop.
		STOP 5. The hill on the east side of the road is Mt. Tom Reef No. 7. Though it has been referred to as a bioherm, this hill is composed of bedded, cherty limestone: characteristics not found in biohermal structures. The fauna here is not typical of other bioherms or the "normal" Edgecliff. The fauna is dominated by small broken twigs of the branching tabulate *Coenites* and doesn't contain anything which could be considered a framework. At present the significance of these beds is uncertain.
0.2	17.3	Return to Chyle Rd. and turn right (west).
1.4	18.7	Take a left (south) onto Little Lakes Road at the first intersection.
2.2	20.9	Turn left (east) on Rt. 20 in Warren.
10.8	31.7	Stay on Rt. 20 until reaching the Parking Area just east of the Cherry Valley exit. Enter Parking Area.
		STOP 6. This exposure and its twin across the valley are two of the most continuous and complete exposures of the Onondaga Formation. Here the formation is exposed from its phosphoritic based transitional beds, through the shaley Nedrow, and into and including most of the cherty Moorehouse. For the thicknesses, fauna, and lithologies of the members refer to Figure and to the text. Figure 7 is provided to show member thicknesses here and at STOP 7 as well as the characteristics and continuity (or lack thereof) of chert bodies within the formation.
0.6	32.3	Continue east on Rt. 20.
		STOP 7. In many respects this set of exposures is quite similar to STOP 6. It is however significant in its continuity with STOP 6 and the differences between the two with respect to chert. This stop is further significant because it's the easternmost exposure of the

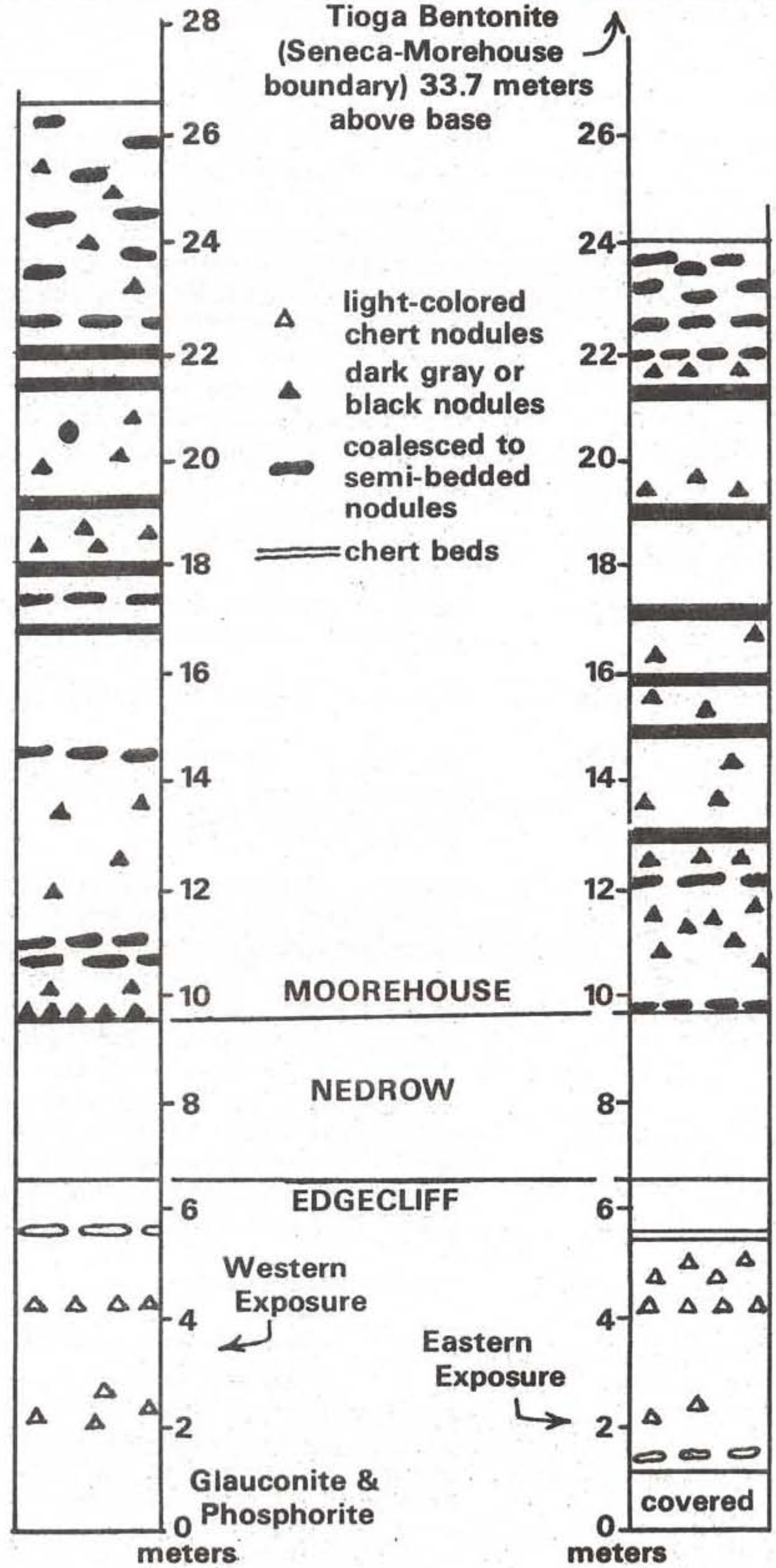

Fig. 7 - Exposures on Rt. 20 at Cherry Valley showing thickness of members and distributions of chert. Percentages not represented.

Miles from last point	Cumulative Miles	
		Nedrow Member as defined in central N.Y., the Tioga bentonite, and the Seneca Member. The latter two are exposed a half mile east of the rest area and can be seen to lie on about two meters of nearly chert-free Moorehouse. East of the uppermost member of the Onondaga is the Moorehouse.
		End of field trip. Return to Oneonta via Cherry Valley and Rt. 166 to Milford; thence southwest on Rtes. 28 and 7.