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MIDDLE DEVONIAN CORAL BEDS OF CENTRAL NEW YORK

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ABSTRACT.—Two coral biostromes in the Ludlowville formation of central New York are of special interest because of their great size and almost exclusively coral thanatocoenoses. The lower bed, designated the Staghorn Point submember of the Otisco member by Smith (1935), averages some 4 feet in thickness over an area in excess of 120 square miles, extending from Skaneateles Lake to the east edge of the Tully Quadrangle, and possibly to New Woodstock. The upper coral bed, here designated the Joshua submember, attains a thickness of 50 feet but is smaller areally, extending from Skaneateles Lake to the Tully Valley, with an area of at least 40 square miles. The faunas of these two beds differ somewhat, but both are modified derivatives of Onondaga faunas. The beds represent temporary establishment of conditions favorable for the growth of solitary rugose corals. The most important condition seems to have been the presence of a hard platform. Together with other smaller coral beds these biostromes constitute a small but significant subphase of the calcareous gray shale (*Tropidoleptus*) phase of the Hamilton group.

PREVIOUS WORK

LITTLE has been published on the Ludlowville coral beds. In the seventy or so years since the coral beds were first definitely recognized, their areal extent has been roughly worked out, their stratigraphic position determined, and some study has been made of their nature and origin, mostly as a result of the work of Dr. Burnett Smith. The Skaneateles Lake exposure has received the most attention; Smith (1912) published a paper and a few others have mentioned it as a notable locality for corals. Other outcrops of the beds have been mentioned in literature, but little attempt to trace out the beds or interrelate the known exposures has been made. Most authors have preferred to speculate on their relationship to other limestone bands. With Cooper's

(1930) work on the Hamilton group this latter point has been fairly well settled.

Amos Eaton in the second edition of his *Geological Textbook* (1832) mentioned "Corniferous limerock" outcropping along Skaneateles Lake. Although the Corniferous (Onondaga) reference was incorrect it is interesting as the first mention in literature of the coral beds. In view of this early knowledge it is surprising that both Vanuxem (1842) and Hall (1843) in their reports on the Third and Fourth Districts failed to mention them. However, Hall (1877) figured several specimens from the "Hamilton group, Skaneateles Lake," indicating definite later knowledge of this exposure.

Luther (1897, p. 282) mentioned this same exposure and two others—Lord's Hill and "along the hillside west of Otisco Lake." His correlation with the Encrinal band (Portland Point) was incorrect, however.

Cleland (1903, p. 85) in mentioning the beds, said:

> "Since in Ontario, Seneca and Cayuga counties the most abundant coral faunas are in the Basal Hamilton, either this coral reef at Skaneateles Lake is (1) a continuation of the stratum called the "Basal Hamilton," which is several hundred feet above the Marcellus shales in the Cayuga Lake section, or (2) the Encrinal, or (3) the union of (1) and (2) or (4) a separate stratum."

Since the stratigraphic position of the coral bed is in the Otisco shale member, well above the "Basal Hamilton" (Centerfield) and below the Encrinal (Portland Point) horizons, the fourth alternative is the correct one.

Clarke and Luther (1905, p. 47) mentioned the Fellows Falls exposure.

The most important study of the coral beds yet made was by Burnett Smith (1912). In his introduction he said:

> "Locally, however, we find in the shales layers which are composed of corals to the practical exclusion of other forms of life. Such layers are, in the main, of small thickness, and in studying them we are confronted with the usual limited horizontal exposure. The coral reefs (if they can be dignified with the term) which form the basis for this description are an

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Fig. 1. Small terraces formed by the Centerfield member (C) and the platform (p). Ravines on left and right are localities 25 and 24 respectively.

Fig. 2. Portion of aerial photograph including area shown above. Terraces formed by the Centerfield (C), platform (p) and Portland Point (PP) layers are indicated. (A.A.A. Photo)

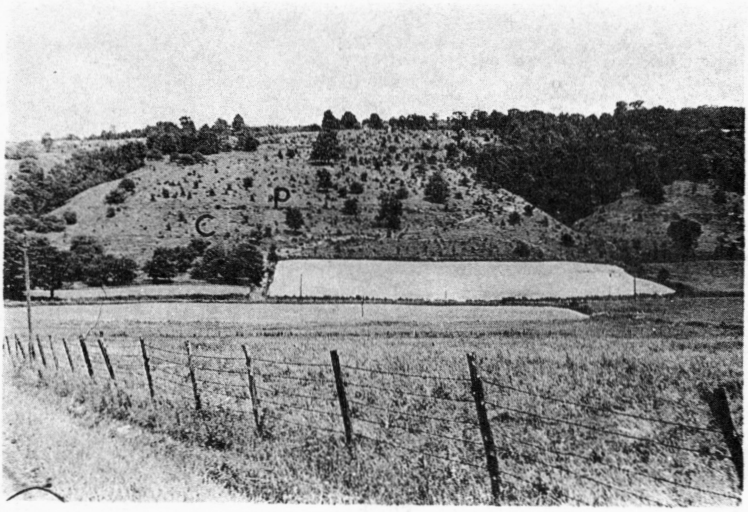

FIG. 1

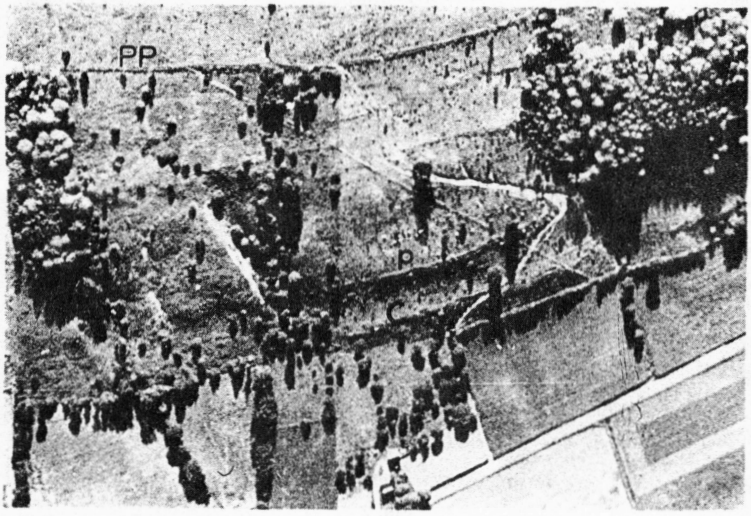

FIG 2

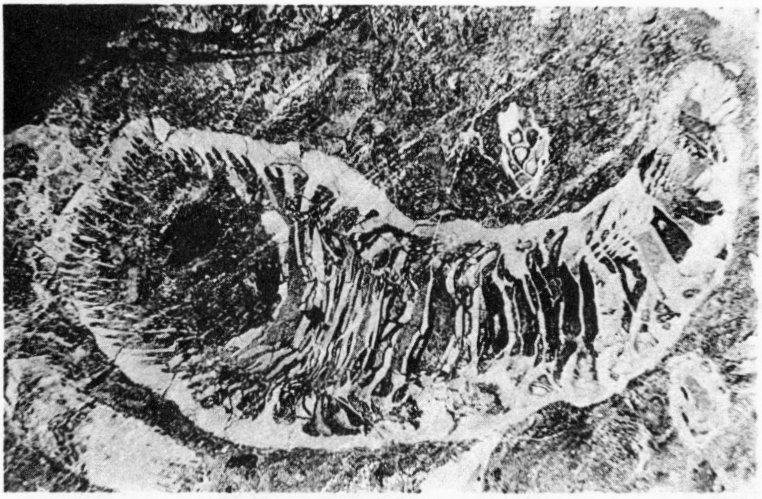

FIG. 1

FIG. 2

> exception in this last respect, for they present a large and very beautiful exposure of about a mile along the eastern shore of Skaneateles Lake in Onondaga County, New York." (Smith, 1912, p. 446).

He divided this exposure into three parts: 1) The Large Southern Reef, 2) The Channel, and 3) The Small Northern Reef. Although these terms are useful in discussing this one exposure, they are not a strictly accurate statement of the situation. The two "reefs" may better be thought of as two western tongues of the main coral bed, the "channel" being an invagination in the western side of the bed. Smith made mention of the exposures on the west side of Otisco Lake, the Vesper (Fellows Falls) "reef" and the Joshua (Lord's Hill) exposures, and considered them to be essentially equivalent to the Staghorn Point bed. The origin of the bed was attributed by Smith (1912, p. 453) to a local clearing and shoaling of the Hamilton seas with consequent flourishing coral growth:

> "Though these changes, physical and faunal, were of short duration when compared with the whole of Hamilton time, they nevertheless represent perhaps the most striking episode in the history of the Hamilton Sea in this area, namely, a transitory return to Onondaga-like conditions, followed again by the mud-bearing waters and the mud-loving fauna of the typical Hamilton."

Cooper (1930, p. 228) described the Staghorn Point coral bed exposure as varying in thickness from one to 5 feet and extending nearly two-thirds of a mile north of where first seen, being separated by a "channel" from a small northern "reef":

> "The beds are composed mostly of cup corals, *Zaphrentis, Heliophyllum,* and *Cystiphyllum,* packed tightly together in a matrix of dark, sandy shale."

The Fellows Falls and Conklin's Falls exposures were mentioned.

> "East of Conklin's Falls a thin bed of corals occurs above the falls in the east branch of Limestone Creek at New Woodstock, Cazenovia Quadrangle. This has the same kind of corals and holds a stratigraphic position identical with that of the Vesper Reef." (p. 228).

Fig. 1. Surface of glacially smoothed and striated bed north of Jenney Point, Skaneateles Lake, showing natural, polished section of *Siphonophrentis.* Specimen is 4½ inches long. (Loc. 2k)

Fig. 2. Roadside exposure of Joshua submember at Lord's Hill, showing the concentration of corals which is typical of both coral beds.

An "upper reef," 65 feet thick, was mentioned as being exposed at Lord's Hill near Joshua. Luther's correlation of the beds with the "Encrinal band of the western counties" was held untenable as they are "stratigraphically below the Tichenor and Portland Point horizons, and above the Centerfield horizon."

Smith (1935, p. 46) described again the Skaneateles Quadrangle exposures of the coral beds. He included them in his Otisco member which is "the shale which lies upon the Centerfield and extends upwards for about 150 feet." (p. 45).

> "About fifty feet above the Centerfield occurs the lower coral bed with the hard and coarsely bedded platform on which it rests. The latter is transitional from softer shale below and ranges between five and ten feet in thickness. Its capping coral bed or 'reef' is commonly about three or three and one-half feet thick but may thin down to almost nothing."

The Staghorn Point exposure was mentioned, and the name Staghorn Point submember proposed for the "coral bed or reef typically shown just south of Staghorn Point." Exposures along Otisco Lake valley were mentioned and it was suggested "that a reef margin trending a few degrees east of north is indicated for the Staghorn Point submember in the belt between Skaneateles Lake and the eastern wall of the Otisco Lake valley." Exposures at Otisco Valley hamlet and Fellows Falls in the Tully Quadrangle were mentioned. The upper coral bed was described as being 90 feet above the Centerfield, with a maximum thickness of "somewhat over 30 feet," on the west side of Otisco Lake. The exposure of this bed in Tenmile Point ravine was mentioned, but no details were given. No discussion of the origin of the beds was included, reference being made to the author's earlier work (Smith, 1912).

Wells (1937) discussed in detail the "Individual variations in *Heliophyllum halli* Edwards and Haime found in the coral beds." He summarized the previous work done on the coral beds by enumerating the described localities, giving thicknesses and stratigraphic position where indicated by the earlier workers. A list of the coral species identified by him was included. A summary of Smith's interpretation of the beds (Smith, 1912, p. 453) was made and expanded upon:

> "Most of the corals listed above were related to, if not identical with, those of the Onondaga limestone of lower middle Devonian

> age which had scattered at the close of that epoch in New York. Returning once more in the early Ludlowville, they remained more or less abundant until the end of Tully time." (Wells, 1937, p. 6).

Cooper and Warthin (1942, p. 887) mentioned the lower coral bed in connection with their discussion of the Centerfield limestone fauna. They suggested that from the faunal point of view the lower coral bed "may belong to the Centerfield," pointing out that the Centerfield fauna continues up through the lower shales of the Otisco member.

There are a few other references to the Ludlowville coral beds, but they consist merely of brief mention of the beds as fossil collecting localities. They are indicated in the reference list by an asterisk(*).

ACKNOWLEDGMENTS

The writer wishes to express appreciation to Professor J. W. Wells of Cornell University for guidance and assistance in this work. Professor C. M. Nevin criticized the manuscript and gave several suggestions regarding the diagrams. Thanks are due Mrs. Mary H. Ross whose recent study of the tabulate corals of the New York Hamilton beds was important in paleoecological interpretation.

Field work in the summer of 1949 was aided by a grant from the New York State Science Service, for which grateful acknowledgment is here made. The work was done at Cornell University as partial fulfillment of requirements for the M. A. degree, June 1950.

SETTING OF THE CORAL BEDS

The general stratigraphic setting of the area under discussion is indicated in figure 1. The Otisco member of the Ludlowville formation includes the two main coral beds. This member is composed of very fossiliferous thin-bedded, gray shale, bounded below by the resistant, more massive argillaceous limestone of the Centerfield member and above by the harder and thicker-bedded shales of the Ivy Point member.

The positions of the beds vary somewhat (fig. 3) but in general they are about 50 and 95 feet respectively above the top of the Centerfield. Because of their position above the Centerfield limestone and well below the Portland Point horizon (fig. 1), the suggested correlations of Luther (1897,

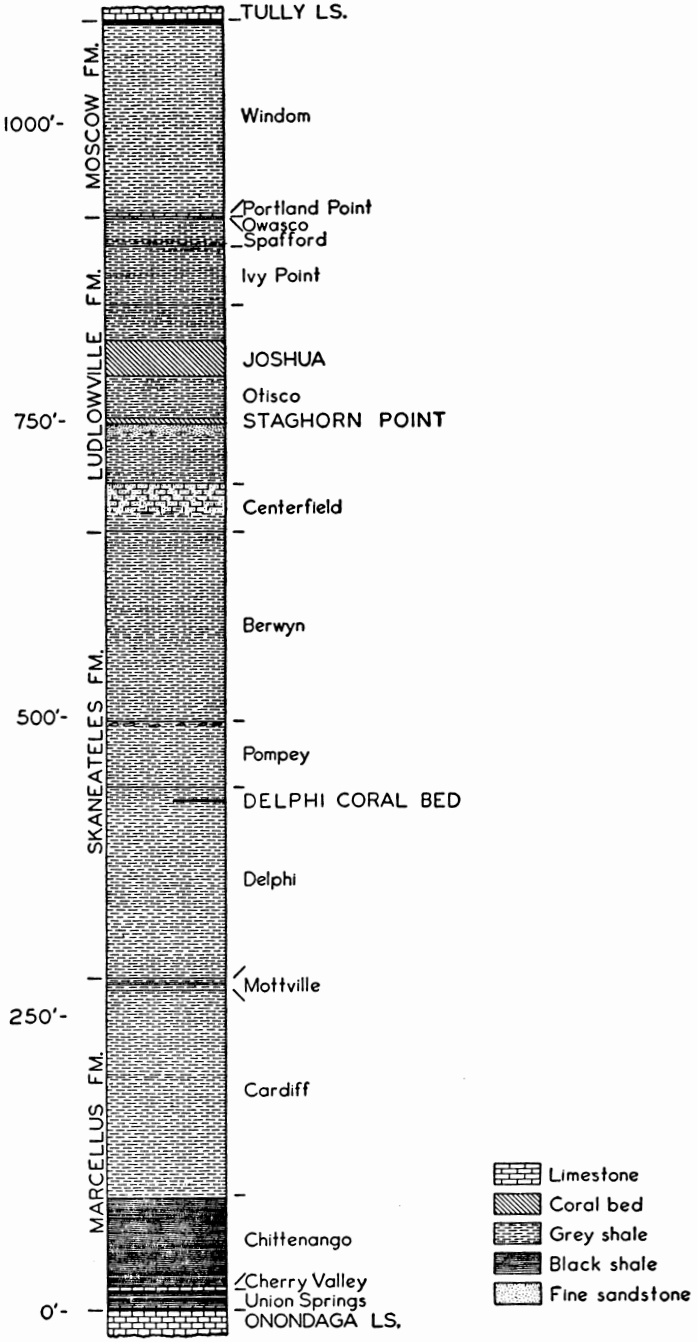

Fig. 1. Generalized Hamilton section for the Tully quadrangle. (Data from Cooper, 1930 and Smith, 1935).

p. 282) and Cleland (1903, p. 85) with the "Basal Hamilton" (Centerfield) or with the "Encrinal" (Portland Point) are not possible. No limestone bands are known from the Otisco shale or its equivalents either east or west of the area described in this paper, and the coral beds thus form distinct units within the Otisco.

The coral beds themselves consist of a mass of rugose coral skeletons so numerous and closely packed that only the interstices are filled with a matrix of the same shaly sediment which constitutes the body of the Otisco member (plate 2, fig. 2). Individual corals vary in length from one to as much as 24 inches. Most of the corals appear to have been turned over and rolled, but some are seen in their positions of growth. Colonial rugose corals are uncommon, except locally as noted below, but together with the equally scarce tabulates are found in their living positions. The faunas of the two beds differ in detail (table 1), but both are characterized by a great profusion of rugose corals and a relative scarcity of tabulate corals. Notable is the almost complete absence of other groups such as bryozoa, brachiopods, molluscs, crinoidal fragments and trilobites which are abundant in the Otisco shale proper.

The lateral relationships of the two beds are similar (figs. 3, 4 and 6). The greatest thickness of each bed is found centrally while toward the edges a gradual thinning is noted. At the extreme edge the beds interfinger with the surrounding shale. Occasional shale lenses or tongues are found more centrally located, indicating periods when the corals were locally overwhelmed by the muds.

The upper and lower contacts of the beds are sharply defined except in the fringing areas where there may be a complete gradation up into the normal shales. Of interest is the presence of a basal platform which forms the substrate on which the first corals grew. Later corals grew on the skeletons of their predecessors. The platforms were of the utmost importance in determining the areal distribution of the coral beds, only the thin, interfingering, lateral stringers of corals extending beyond their limits.

Over most of the area covered by the coral beds, the structure is relatively simple, the main feature being the gentle regional dip which averages about 50 feet per mile in a direc-

TABLE 1

Relative Abundances of the Rugose Species in the Joshua and Staghorn Point Coral Beds.*

	Joshua	Staghorn Point
Siphonophrentis halli E. and H.	○	○
Cystiphylloides americanum E. and H.	○	○
Cystiphylloides conifollis Hall	○	○
Bethanyphyllum robustum Hall	○	○
Heliophyllum halli E. and H.	○	○
Eridophyllum subcaespitosum Nicholson **	○	○
Heterophrentis simplex Hall	○	○
Cystiphylloides corrugatum Hall	○	○
Cystiphylloides varians Hall	○	○
Heterophrentis ampla Hall	○	○
Heliophyllum confluens Hall	○	○
Heliophyllum sp. nov.	○	
Hexagonaria prisma Lang and Smith	○	
Stereoelasma rectum Hall	○	○
Bethanyphyllum galerum Hall	○	
Amplexiphyllum hamiltoniae Hall		○

*Area of circle indicates relative abundances.
**Based on colonies, not individuals.

tion slightly west of south. This inclination causes the lower bed to dip out of sight to the south while both beds rise above the present erosion surface to the north, leaving little information on the original extent of the beds in those directions. Marked thinning of the lower bed toward the south, however, suggests the proximity of the edge of the bed in that direction (fig. 3).

One fault zone is worthy of mention because of its effect on the outcrop at Lord's Hill. It can be traced for a distance of 2 miles and has a maximum observable displacement of 46 feet. The fault plane strikes N 57° W and is almost vertical. The situation in the ravine at Lord's Hill (Loc. 41) is shown in figure 5. One-half mile southeast in another ravine (Loc. 40) the displacement is again observed. Here however the fault (or fault zone) passes between the lower bed and the Centerfield horizon, causing the vertical interval between the two to be some 40 feet greater than usual. In a third ravine at Case Hill (Loc. 39) in line with the other two localities, a 5-foot displacement is seen within the upper bed. This fault can not be traced west of the first ravine noted because of the jointed nature of the shales, but it certainly extends as far as the road exposure at Lord's Hill (Loc. 42) where it probably is responsible for the excessive thickness of the upper bed at that locality.

THE LOWER CORAL BED
(STAGHORN POINT SUBMEMBER)

The lower coral bed, designated the Staghorn Point submember by Smith (1935, p. 46) from the exposures north and south of Staghorn Point on the east side of Skaneateles Lake, is in the Otisco shale about 50 feet above the top of the Centerfield limestone (fig. 1). The position of the bed with the Centerfield as datum varies regularly, being slightly higher to the north and west than it is to the south and east.

The Staghorn Point bed can be traced in an east-west direction for a distance in excess of 15 miles, from Skaneateles Lake to the east edge of the Tully Quadrangle (fig. 2). On the west side of Skaneateles Lake (Loc. 1), at the proper horizon is found a very thin zone of the same corals which characterize the Staghorn Point exposure on the opposite side of the lake. This zone probably represents the western

or northwestern feather edge of the bed. The northwestern extremities of the bed are seen along the east side of Skaneateles and along Otisco Lake. Farther east the northern limits of the bed are indeterminable for reasons cited above. The southern limits are likewise unknown except in the Otisco Valley where the southernmost exposures (Loc. 7) show a marked thinning of the bed in that direction (fig. 6.).

The eastward extent is not precisely determinable, since good sections are infrequent east of Butternut Creek Valley. The more easterly exposures are of limited value, indicating only the presence of the bed. Cooper (1930, p. 223) mentions a "thin bed of corals . . . above the falls in the east branch of Limestone Creek at New Woodstock, Cazenovia Quadrangle," having "the same kinds of corals and . . a stratigraphic position identical" with that of the lower bed. Unfortunately, since Cooper did his work, a dam has been built at this site so that it is no longer possible to see the coral bed. Further, no other bedrock exposures at the proper horizon have been found in that area and structure projections from the known position of the bed would place it some 50 feet higher than Cooper's horizon, perhaps indicating that his bed is Centerfield in age. But assuming Cooper's identification to be correct, the coral bed is thus extended an additional 7 miles eastward. Exposures of the Otisco shale near Erieville, 5 miles farther east, indicate that the coral bed does not extend that far.

The thickness of the lower bed ranges from a few inches in the fringing areas to almost 12 feet at Conklin's Falls. There is no regular pattern of variation except at the extremities where it thins down to feather edges. The variation in thickness of the lower bed is indicated in figures 3, 4 and 6.

The commonest genera found in the Staghorn Point submember are *Siphonophrentis*, *Cystiphylloides*, *Heliophyllum*, *Heterophrentis*, *Bethanyphyllum* and *Eridophyllum*, in that order. *Stereoelasma*, common in the surrounding shales, is found only in the shaly or interfingering edges of the coral bed. *Favosites* is rather widespread, but specimens are comparatively scarce. A single stromatoporoid has been found. Tables 1 and 2 show the relative abundances of the rugose corals identified by the writer and their lateral distribution. In addition the following tabulates have been identified by Mrs. Mary Ross:

Aulopora elleri Fenton
Aulopora sp.
Ceratopora jacksoni Grabau
Favosites arbuscula n. subsp.
F. emmonsi Rominger
F. two new species
F. turbinata Billings

All of these are flat and expanded or branching in form.

TABLE 2

Lateral Distribution of the Rugose Species in the Staghorn Point Submember.

	Feather edge	Shaly edge	Edge of main body	Main body
Stereoelasma rectum Hall	X	X		
Cystiphylloides varians Hall	X	X		
Cystiphylloides conifollis Hall	X	X	X	X
Siphonophrentis halli E. and H.	X	X	X	X
Heliophyllum halli E. and H.	X	X	X	X
Amplexiphyllum hamiltoniae Hall		X		
Bethanyphyllum robustum Hall		X	X	
Heterophrentis simplex Hall			X	
Eridophyllum subcaespitosum Nicholson			X	X
Heterophrentis ampla Hall			X	X
Cystiphylloides americanum E. and H.			X	X
Cystiphylloides corrugatum Hall			X	X
Heliophyllum confluens Hall				X

Over most of its area the lower coral bed rests on a hard platform of ripple-marked silty sandstone, which grades downward within 5 or 10 feet to the shale of the Otisco member. This platform produces a small waterfall in almost every ravine which cuts across it. In addition it forms a small but prominent escarpment along the valley sides, at places being visible from a distance of one or 2 miles (plate 1). The coral bed is much less resistant to weathering and erosion than the platform, and is only exposed where ravines or gullies cut deeply across the platform. In some localities, even in steep ravines, the coral bed may be completely covered, its presence being indicated only by a concentration of corals and pieces of coral bed, on and just below the platform.

The lateral relationship between the coral bed and the shale

is exceptionally well known in the cliffs along the east side of Skaneateles Lake where the Staghorn Point bed is exposed with very few interruptions for a mile and a half. This section is shown in detail in figure 4. The northern part of this exposure shows the interfingering and shaly character of the edge of the bed. Just north of Jenney Point (Loc. 2k), what is apparently the lowermost of the fanning beds shows glacial striae on its upper surface and is overlain by glacial till, indicating that part of the fanning zone has been removed (plate 2, fig. 1).

THE UPPER CORAL BED (JOSHUA SUBMEMBER)

The upper coral bed is here designated the Joshua submember of the Otisco shale from the exposures at Lord's Hill near Joshua (Locs. 40 and 41). The interval between the coral bed and the Centerfield limestone varies regularly from 90 feet in the southern area to 100 feet in the more northern type area.

Smith (1935, p. 47) recognized the upper coral bed as a unit separate from the lower bed. In his earlier work (1912, p. 452) he had recognized that the Joshua exposure was at a much greater elevation, but thought that the regional dip was responsible and that the two beds could be stratigraphic equivalents.

The upper coral bed has a northeast-southwest extent of nearly 9 miles from the east side of Skaneateles Lake to Case Hill in the Tully Valley. The areal extent of this bed (fig. 2) is better known than that of the lower coral bed. Only in the area north and northwest of Lord's Hill where the coral bed horizon has risen above the present ground surface are the limits uncertain. Although the area covered by the upper bed is small compared to that of the lower bed, the thickness is much greater, as indicated by figure 3. The excessive thickness of 65 feet, however, mentioned in literature for the Lord's Hill road cut exposure (Loc. 42) is probably due to faulting as previously noted. The actual maximum of about 50 feet is found on the east side of Otisco Lake and in the type section. Laterally the bed thins and is marked at its edges by thin fingers extending into the shale (fig. 6).

The rugose genera found in the Joshua submember are

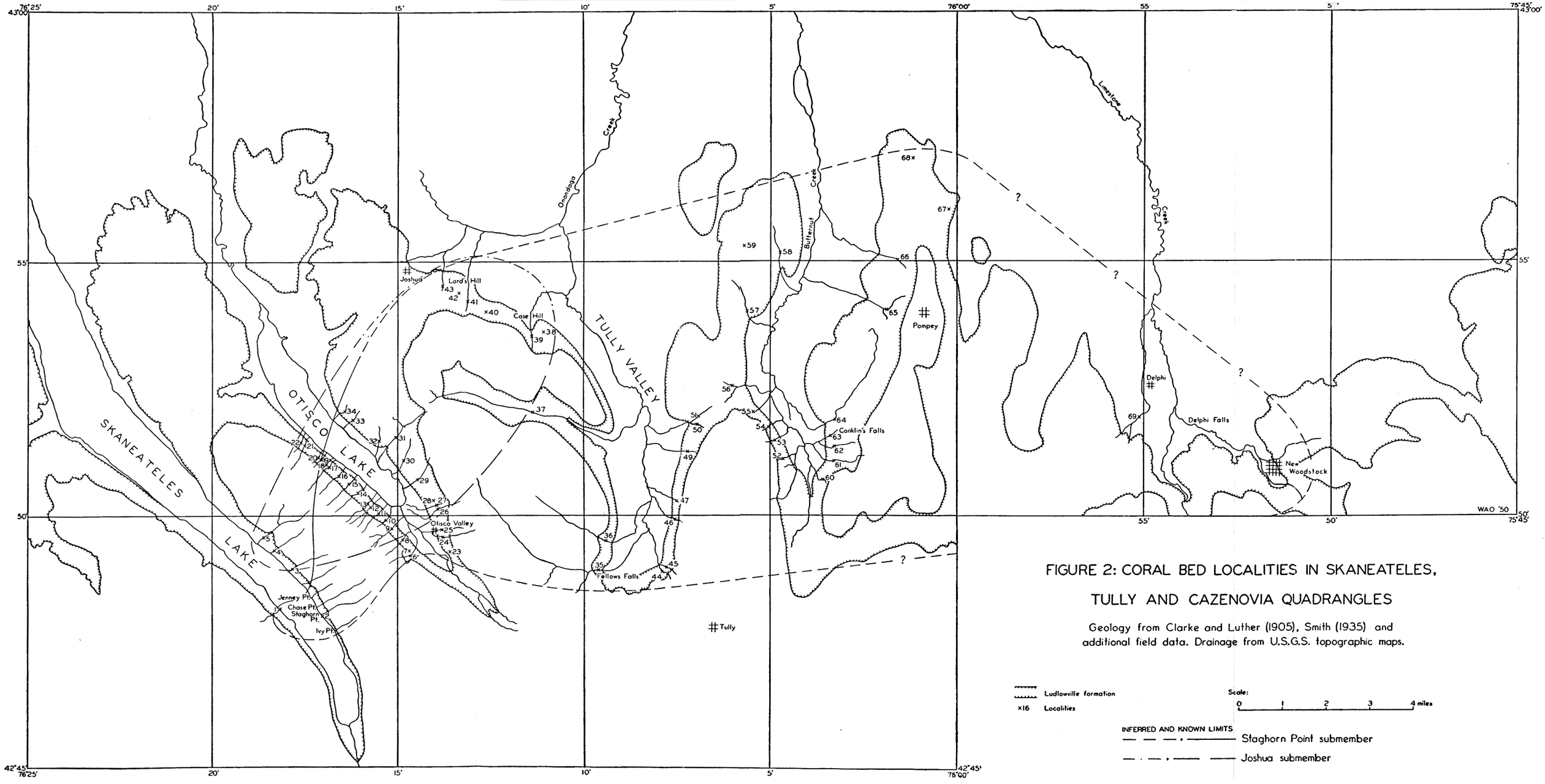

FIGURE 2: CORAL BED LOCALITIES IN SKANEATELES, TULLY AND CAZENOVIA QUADRANGLES

Geology from Clarke and Luther (1905), Smith (1935) and additional field data. Drainage from U.S.G.S. topographic maps.

Ludlowville formation

×16 Localities

Scale: 0 1 2 3 4 miles

INFERRED AND KNOWN LIMITS

Staghorn Point submember

Joshua submember

the same as those found in the lower bed, but they differ in abundance. The most common genera are *Cystiphylloides*, *Siphonophrentis*, *Bethanyphyllum*, *Heliophyllum* and *Heterophrentis*, in that order. *Heliophyllum* is not as common as in the lower bed and *Bethanyphyllum* and *Cystiphylloides* are more so. The colonial rugose form *Eridophyllum* is found irregularly distributed throughout the main part of the coral bed as in the lower one, and in addition forms a basal zone from 6 to 12 inches thick over most of the area covered by the bed. Table 1 shows the relative abundance of the rugose species in the bed. Mrs. Mary Ross has identified the following tabulates:

Favosites placenta n. subsp.
F. alpensis n. subsp.
F. wartheni n. subsp.

These are thick massive forms, some with knobby surfaces. None are delicate, branching forms.

The base of the upper coral bed lies in sharp contact on the shale of the Otisco member, with no sandstone platform. But at almost every exposure of the bed where the lower contact can be seen, there is the basal *Eridophyllum* zone. These colonial rugose corals probably colonized the area during an interval of favorable conditions and formed a crude platform on which the solitary corals grew.

OTHER HAMILTON CORAL BEDS

Although the two coral beds described in this paper are unusual because of their thickness, extent and almost exclusively coral composition, they are not unique, and many smaller coral beds have been reported from the Hamilton of New York and adjacent areas of Pennsylvania and Ontario. Two of these occurrences have been visited and another coral bed was found during the course of the present work. These and a few others will be discussed briefly to enlarge the general picture of the occurrences of coral beds and the environmental factors favorable for their development.

Meristella-Coral Zone.—This coral bed located in the basal part of the Otsego member of the Marcellus formation in eastern New York was named by Cooper (1934, p. 549) who mentioned two localities where the zone could be recognized. At one of the localities—Stony Creek, one mile south-

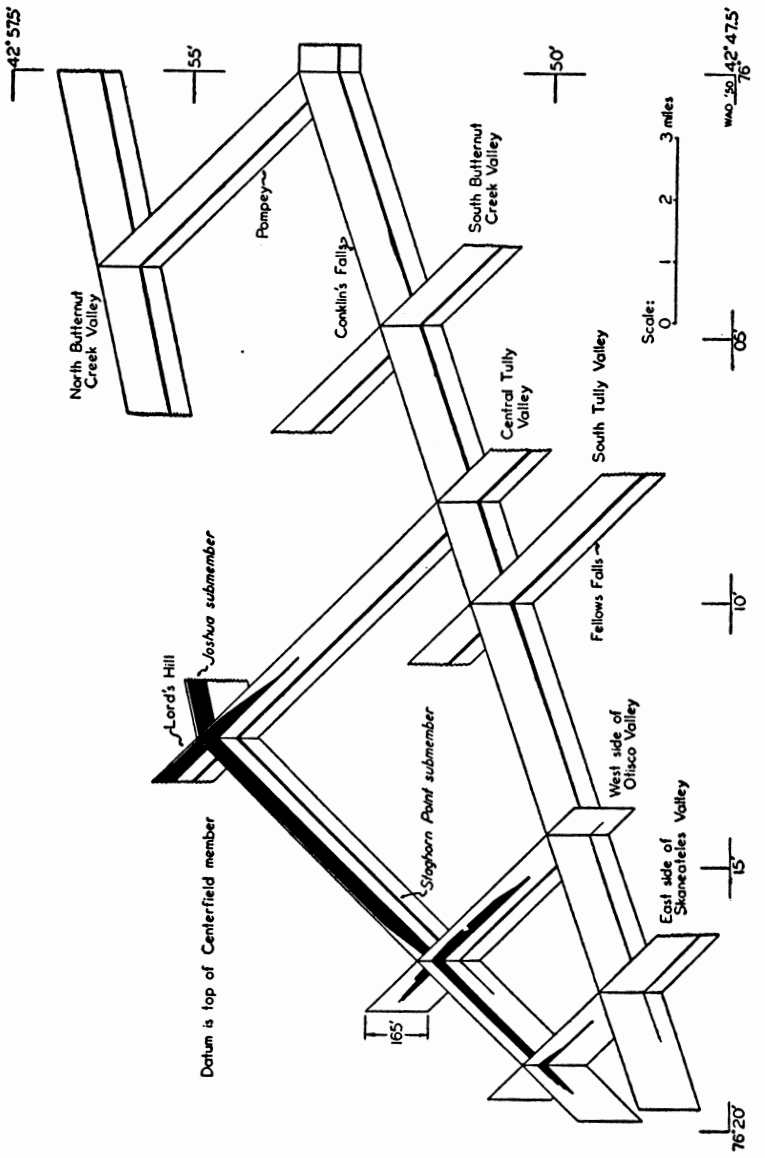

Fig. 3. Fence diagram, spatial relations of Ludlowville coral beds, central New York.

east of Middleburg, Schoharie Quadrangle—corals are rare. At the other locality—one and one-half miles southwest of East Berne, Berne Quadrangle—corals are abundant. Goldring (1935, p. 190) describes the bed in the latter locality as "a three foot coral bed, the lower two feet of which are calcareous and the upper one foot the main coral zone. '*Zaphrentis*', *Cystiphyllum*, several tabulate corals and representatives of other groups, brachiopods especially, form the principal faunal elements." Very little can be added to this description. The lower 2 feet of the zone is the upper part of a very hard, sandy layer, in which collecting is extremely difficult. The upper foot is shaly and corals, principally *Siphonophrentis* and *Cystiphylloides*, are easily extracted.

This bed differs from the Ludlowville beds in many ways. The corals seem to be concentrated in the middle part of the bed, becoming more sparse as the upper and lower limits of the bed are approached. As mentioned above, other animal groups, especially the brachiopods, are important constituents of the transition zones, although the middle part of the bed seems to be almost exclusively formed by corals. The areal extent of the zone is not known, although the fact that Cooper's two localities are some 15 miles apart indicates that it may not be inconsiderable. The Stony Creek occurrence, however, can hardly be called a coral "bed," and the extent of the true coral bed may not be very great.

Delphi Coral Bed, Skaneateles Formation.—A thin bed of zaphrentid corals was found in the upper part of the Delphi member of the Skaneateles formation, approximately three-quarters of a mile southwest of Delphi, Cazenovia Quadrangle (Loc. 69). The bed, which is only 6 inches thick, is in the midst of the "coarse sandy shales and sandstones abounding in pelecypods, which form the bulk of the fauna," described by Cooper (1930, p. 220) from the Delphi Falls section. It is tightly packed with individuals of *Siphonophrentis* and *Heterophrentis*, cemented by the gray sandy shale which forms strata above and below the coral bed. The top and bottom contacts are very sharp, only a slight faunal mixing being seen in the sandy shales above the bed. This coral bed was not found at Delphi Falls, a mile east, and the lateral relationships and extent of the bed are not known.

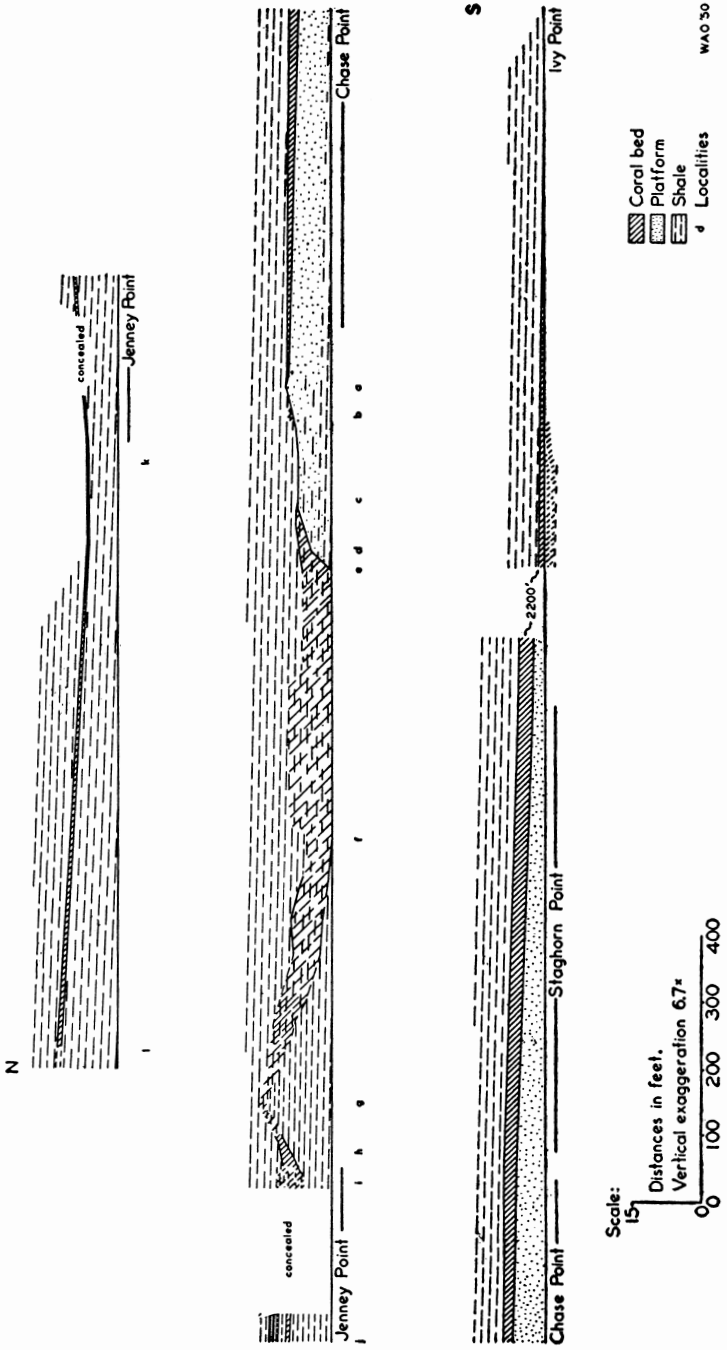

Fig. 4. Lower coral bed relations on the east side of Skaneateles Lake (locality 2).

The Delphi coral bed is much like the Ludlowville beds except for its small size and lack of a platform. The absence of fossils other than the rugose corals and the sharp contacts with the shale show that sedimentary and environmental conditions were similar to those of the larger beds.

Centerfield Coral Zone, Pennsylvania.—The coral bed at the base of the Ludlowville formation in eastern Pennsylvania was designated the Centerfield coral zone by Willard (1939, p. 178). According to him (1936, p. 32) the bed extends for 150 miles along the Hamilton outcrop belt in eastern Pennsylvania, having a thickness of 20 feet in the east, but thinning westward to about 3 feet in the Susquehanna Valley. The best exposure of the bed is in a road cut 3 miles north of Stroudsburg, Pennsylvania, where the thickness is about 13 feet.

The bed is quite different from the Ludlowville coral beds previously discussed. The fauna is not composed almost exclusively of rugose corals. Bryozoa, brachipods, pelecypods, trilobites, crinoid remains and tabulate corals are important constituents. In addition the rugose species and genera are somewhat different. The upper and lower limits of the bed are not sharply defined, a 2 or 3-foot transition zone being seen at the top and bottom. Willard correlated this zone with the Centerfield limestone of New York because of its fauna and apparent stratigraphic position. The New York Centerfield is noted for the coral elements of its fauna, but only locally is it reported to approach a coral bed in composition and structure. Apparently conditions for coral growth were somewhat less than optimum over most of the Centerfield sea. Locally in the Stroudsburg area, however, conditions were adequate for the development of a dominantly coral biocoenose.

Coral Beds, Ludlowville and Moscow of Western New York.—In the Hamilton group of western New York and Ontario there are many thin, localized, and more or less well defined coral beds. Most of these beds are found at or near the Centerfield or Tichenor (Encrinal) horizons, indicating patchy, temporary conditions favorable to coral growth and expansion.

Payne (1938, p. 53) points out the numerous corals to be found in the Centerfield member in Jaycox Run, 6 miles south

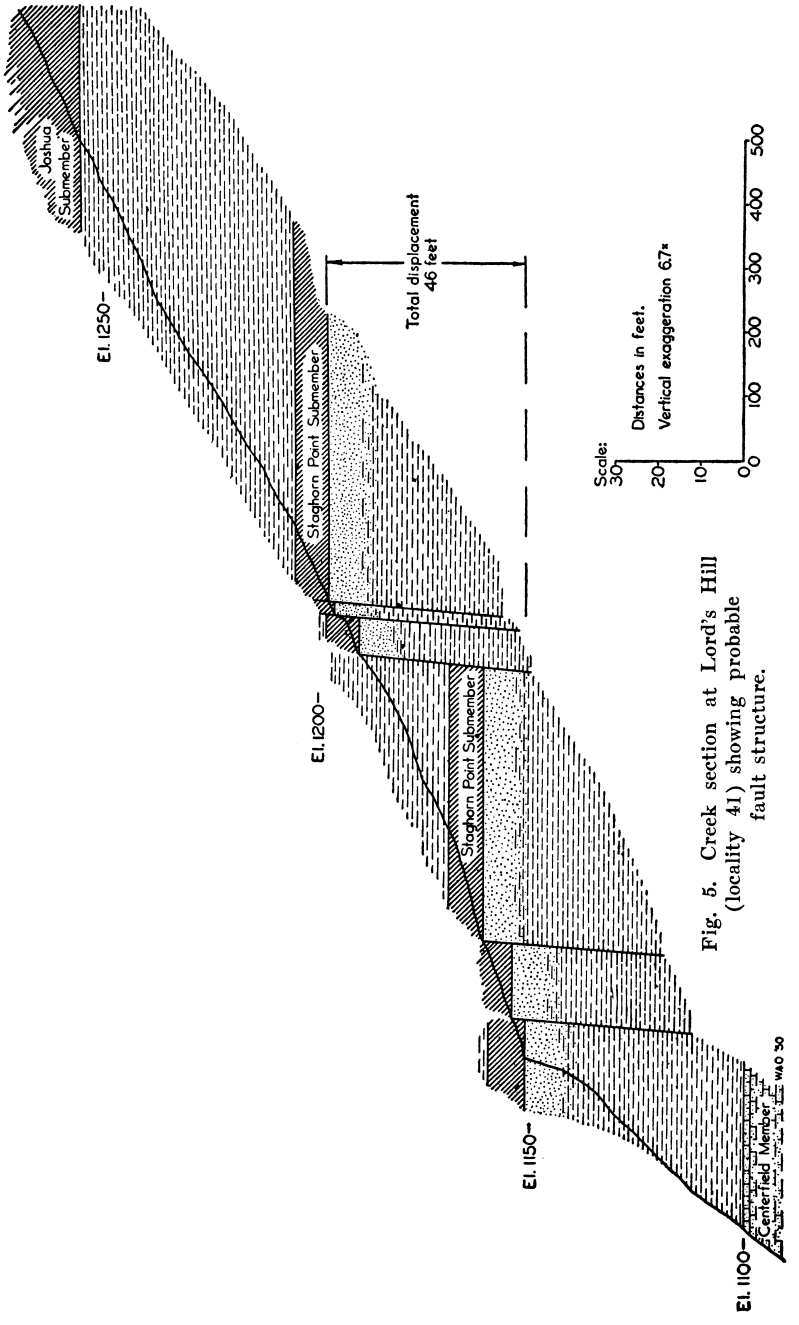

Fig. 5. Creek section at Lord's Hill (locality 41) showing probable fault structure.

of Avon, Livingston county. He says: "The sea bottom of Centerfield time like that of Onondaga time, must have been particularly ideal for the existence of corals, especially the individual cup corals, many types of which may be found." Farther to the west in the same county, "In the stream bed of a ravine just east of Rork a low dome-shaped reef structure packed with corals may be seen in the Centerfield." (*ibid.*). But according to J. W. Wells (personal communication), "It is hardly dome-shaped, rather lenticular, up to two feet thick, thinning east and west; there is a notable lack of *Siphonophrentis*, and other genera are represented by small individuals."

The Tichenor member in the York area is likewise described as virtually a coral bed. Hall (1843, p. 189) mentions a locality a mile west of York where the shale immediately below the Encrinal (Tichenor) limestone "is completely charged with Cyathophylli of different species, *Favosites* and other corals with some trilobites and shells." Further he states (p. 195) "some of the more abundant corals are identical" with these of the Onondaga.

Schuchert and Dunbar (1941, p. 204) refer to "local recurrences of coral reefs (as at East Bethany), made by species descended with little change from the Onondaga types that had persisted locally beyond the range of the early Hamilton black muds and now reestablished themselves where the waters were not too muddy." The occurrences west of East Bethany, Genesee County, are further discussed by Slocum (1906, p. 258) who mentions local coral concentrations in the shales just below the Encrinal [actually Centerfield, not Encrinal (Tichenor)]. Brachiopods and other fossils are commonly associated with the corals.

Grabau (1898, p. 29) discusses a "coral layer . . . eighteen or twenty inches above the Encrinal limestone." The layer is found in the Eighteen Mile Creek section and along Lake Erie, south of the creek mouth.

> "It is about three inches thick, and in most places consists entirely of an accumulation of cyathophylloid or cup corals. There are mostly of the genera *Heliophyllum* (*H. halli* E. and H.), *Cystiphyllum* and *Zaphrentis*, and nearly all lie prostrate...They show, however, no signs of wear, the delicate bryozoans and small corals which encrust many of them, showing that little if any disturbance has occurred...They there-

> fore indicate a flourishing coral reef or forest, which was suddenly overwhelmed, probably by the influx of muddy waters..."

Curiously enough, the average size of the individuals in this lower Moscow (Windom member) coral zone is much larger than at most of the outcrops of the Centerfield and Tichenor coral zones in the West Central part of the state.

Grabau also noted that the small rugose coral *Streptolasma* [*Stereoelasma*], common in the shales above and below the "coral layer," is not present in the "coral layer" itself, a situation similar to that found in the Ludlowville coral beds in central New York. Brachipods are common in the bed where the corals are not concentrated but seem to be almost absent in the well developed part of the coral bed (Grabau, 1899, p. 320).

A similar coral bed is described by Shimer and Grabau (1902, p. 152) from the vicinity of Thedford, Ontario. They state that it has the same position as the Eighteen Mile Creek bed, but more recent work by Cooper and Warthin (1942, p. 878) indicates that it is Centerfield, not Tichenor, in age. The bed differs from Grabau's "coral layer" in having a brachipod fauna equal in importance to the coral fauna. Differences are also noted within the coral faunas, although *Heliophyllum halli* and *Cystiphyllum vesiculosum* [*americanum*] are very important in both beds.

Summary.—These beds all have many features in common with the two great Ludlowville coral beds. They are thin, bedded structures of considerable horizontal extent. Further, they all have many coral genera and species in common which are closely related to, or derived from, the Onondaga coral fauna. Notably lacking, however, in the Ludlowville beds is the occurrence of the delicately ramose *Striatopora* and *Trachypora*, and hemispherical and pyriform forms of *Favosites* which are common in the other beds where the coral populations are not so concentrated.

With the exception of the Delphi coral bed and Cooper's *Meristella*-Coral zone, the beds described in this section are at either the Centerfield or Tichenor horizons. These two limestone bands are both of great lateral extent, and both indicative of rather calm, clear water environments where all forms of marine life, corals included, flourished. The coral

beds at these horizons seem to represent localized conditions here and there so favorable to coral growth that other organisms were more or less excluded, but nowhere so much so as in the Ludlowville coral beds in Onondaga County. They differ markedly from the Ludlowville coral beds in their lateral relations. Centerfield and Tichenor coral zones or beds are characterized by a complete lateral faunal gradation into the normal "limestone," with isolated individuals to be found at all exposures of the limestones. In contrast the Ludlowville beds are isolated structures whose horizon is not recognizable away from the coral beds proper either faunally or lithologically.

SUMMARY AND CONCLUSIONS

The coral biostromes of the Staghorn Point and Joshua submembers, represent recurrences of relatively clear, warm, shallow water conditions, but less than the reef optimum of Onondaga time. At these times of biostrome development, corals were able to multiply rapidly and colonize whole areas to the nearly complete exclusion of other organisms. Exceptionally favorable conditions for solitary rugose corals were reached during Staghorn Point time and repeated in Joshua time, and coral plantations spread over large areas.

Ripple marks indicate that the sandstone platform below the Staghorn Point submember was deposited by southeasterly currents which, probably as a result of shoaling over the area concerned, bypassed the muds and left a residue of fine sand. The cause of the shoaling as well as the relationship of the shallow area to currents is unknown but the ripple marks indicate that the current was roughly at right angles to the long dimension of the platform. The distribution of the platform determined the lateral extent of rich coral colonization.

With the sandy platform on which to establish a foothold, the corals were able rapidly to expand their holdings over a broad area. Succeeding generations used the skeletons of their predecessors as a substratum. Occasionally greater influxes of muds than could be bypassed overwhelmed local areas, overturning and abrading the corals. This is indicated by the coarse, irregular bedding of the submember and by the worn condition of many of the corals, most of which are

not in their living positions. Following such events the corals would quickly reoccupy the area. Fanning or interfingering zones of corals at the extremities of the bed indicate temporary extensions beyond the limits of the platform.

The history of the Joshua submember is very similar to that of the Staghorn Point. However, studies of the tabulate corals by Mrs. Mary Ross of Cornell University show that Staghorn Point specimens are flat and expanded or branching forms while the Joshua tabulates are thick, massive forms, many with knobby surfaces, with none of the delicate, branching types. Studies of recent corals (Vaughan and Wells, 1943, p. 60) have shown that branching forms are characteristic of quiet, shallow water and that encrusting or massive forms are indicative of rough water. While these criteria cannot positively be applied to the extinct tabulates, it is likely that the reactions to rough water would be similar in unrelated groups of similar form. The tabulates, then, suggest quiet, shallow water conditions for the Staghorn Point coral bed, as postulated above, and somewhat rougher water in Joshua times.

It has been pointed out that there is no sandy platform beneath the Joshua submember. Instead, at almost every exposure of the upper coral bed there is a basal *Eridophyllum* zone. Apparently this colonial rugose coral acted as a colonizer, the solitary corals only being able to establish themselves on the "platform" formed by *Eridophyllum* skeletons. The orientation of this "platform" (fig. 2) is more easily explainable. Modern coral reefs and banks are ordinarily positioned at right angles to the direction of food carrying, oxygenated water movements. A southeasterly current would thus be indicated by the Joshua bed. This is not inconsistent with sedimentary evidence of general current direction in this part of the Appalachian geosyncline during Devonian time.

After the establishment of the platform, further development was much the same as that postulated for the Staghorn Point bed. The corals did not spread over so great an area, but successful colonization endured longer. Extensions beyond the "platform" met with the same lack of success, and the lateral relations of the two coral beds with the Otisco shale are much the same.

The beds were probably developed too far offshore to bear

any special relationship to the eastern shore line. Easterly the Otisco gray shales grade into sandy shales, sandstone, and finally continental deposits in a distance of some eighty miles.

The other coral beds cited from the Hamilton of New York occur in the same gray shale phase (*Tropidoleptus* fauna) as the Ludlowville beds. There is a progressive stratigraphic rise westward with this phase. The easternmost bed, Cooper's *Meristella*-Coral Zone (Berne Quadrangle), is found in the top of the Marcellus formation; in the Cazenovia Quadrangle, there is a thin coral bed in the Skaneateles formation; in the Tully and Skaneateles Quadrangles are the great coral beds of the Ludlowville formation; and there are weak coral beds in the Ludlowville and Moscow formations farther westward in the state. This regressive westward shift parallels the corresponding regressive shifts of the more westerly dark or black shale phase (*Leiorhynchus* fauna) and the more easterly sandy, pelecypod phase. This westward regression is presumably correlated with steadily rising land masses to the east.

Coral bed development is but one aspect of the overall phase-facies relations of the Hamilton group of deposits. This development reached its peak in the Staghorn Point and Joshua biostromes when "forests" of corals covered many tens of square miles, maintaining themselves for long periods of time, but ultimately being overwhelmed by the muds.

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