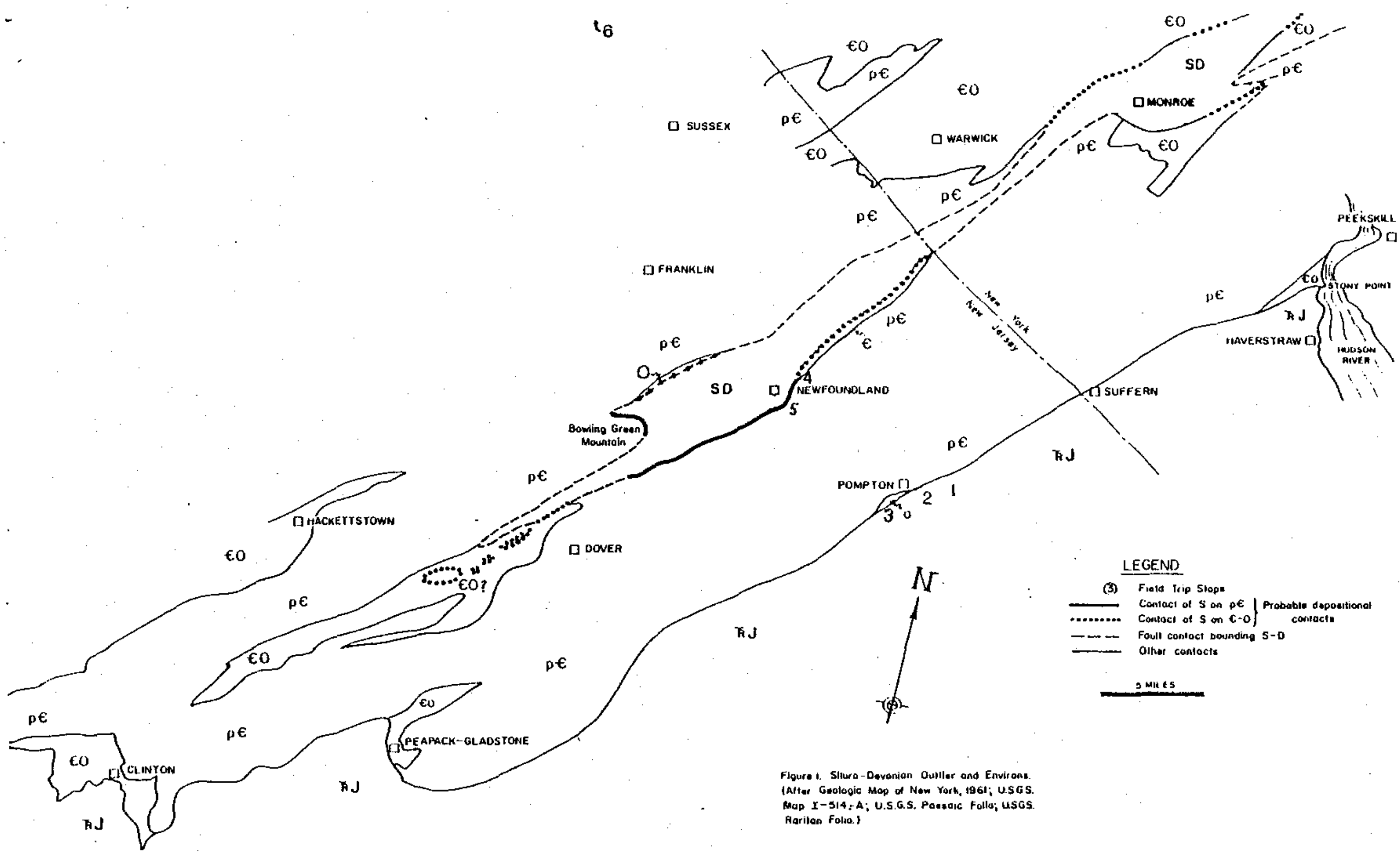


Figure 1. Siluro-Devonian Outlier and Environs. (After Geologic Map of New York, 1961; U.S.G.S. Map I-514-A; U.S.G.S. Passaic Folio; U.S.G.S. Raritan Folio.)

vesicular basalt, presumably Jurassic, and the remainder are sedimentary rocks. A large number of the latter are siliciclastic and most probably come from the upper part of the Paleozoic cover (Siluro-Devonian). The rest are Cambro-Ordovician dolomites from the lower part of the cover. You may be the judge of their relative proportions. A few clasts of Precambrian crystallines have also been found here.

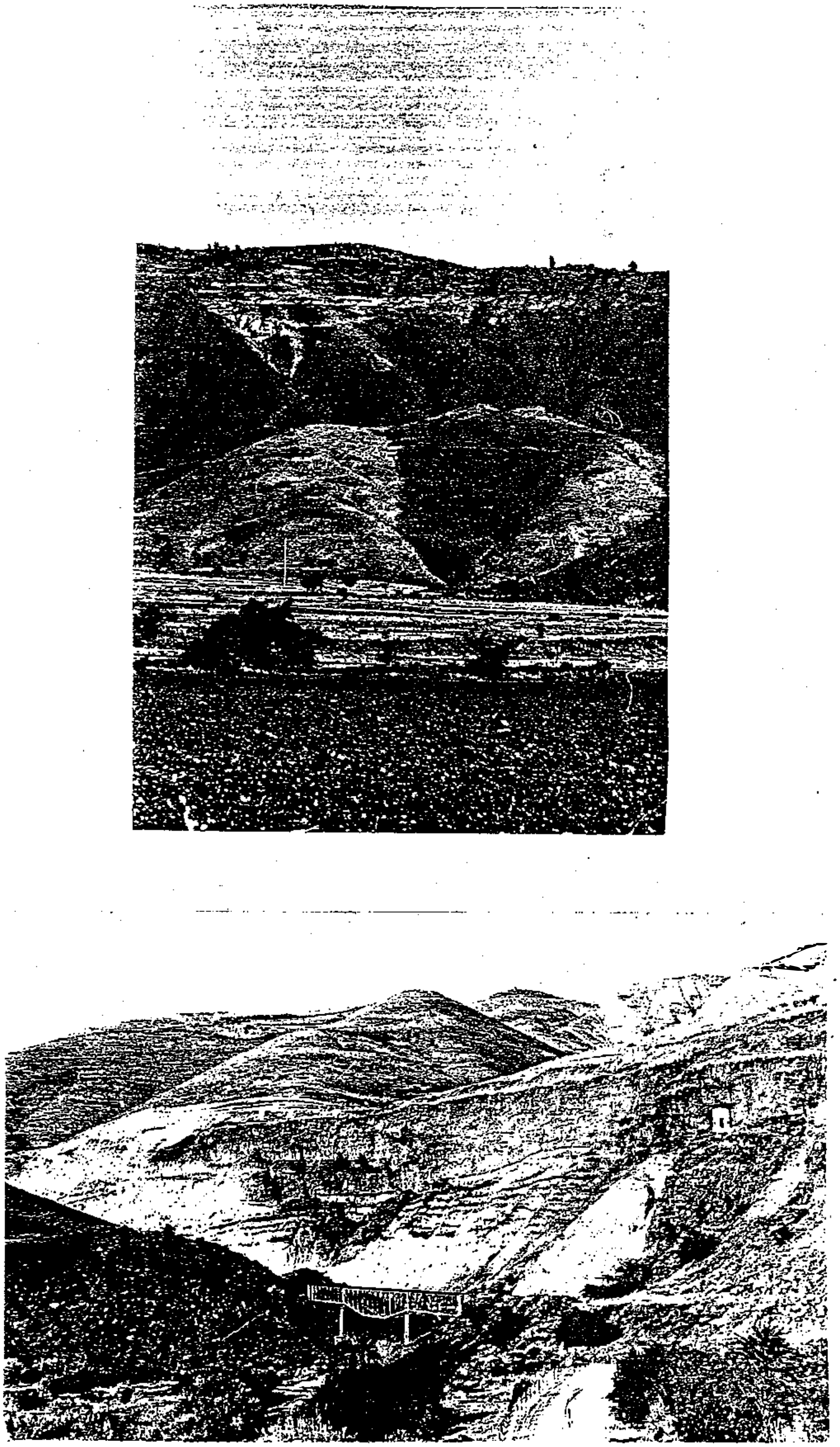
The fault-scarp immediately to the west must have had a cover of Jurassic basalt, beneath which was the Cambrian to Devonian sedimentary sequence, with only a bit of the Precambrian exposed, perhaps at the bottom of the deep valley carved by the river that built the fan.

The second conglomerate lies just beneath the Hook Mountain Basalt, and is thus younger than the first. One would expect the stream that formed it to have tapped deeper levels in the adjacent highlands. The fault scarp was continually renewed by uplift, as evidenced by the repeated development of alluvial fans. This, accompanied by erosion, progressively stripped-down the sedimentary cover. Indeed, the basalts are missing in this younger conglomerate, and the Cambro-Ordovician dolomites seem more numerous than the siliciclastics. There are, however, no Precambrian crystallines. Perhaps the stream valley was less deep than the one which produced the earlier fan. It should be noted that the two fans are separated by only 2.5 miles. Thus lithologic differences in the source area are more likely to be related to vertical than to horizontal changes. (A late fanglomerate at Montville, New Jersey, above the Hook Mountain Basalt, is rich in Precambrian cobbles.)

A MODERN STREAM AND THE PRE-JURASSIC BASEMENT

At Riverdale, New Jersey, not far from the last conglomerate, and adjacent to the border fault, is a unique exposure of the pre-Mesozoic basement in the bed and banks of the Pequannock River. This site also affords us the opportunity of comparing the bed load of a modern stream with those of the Jurassic streams that drained the same area.

The pre-Mesozoic rocks here are on the down-dropped side of the border fault. Because the Mesozoic basin-fill is some eight miles thick, the exposure of this rock implies its presence on a less down-dropped sliver of the graben floor. It is a black phyllite identical in lithology and structural position to the Ordovician Annsville Phyllite some 40 miles to the northeast along the border fault at Peekskill, New York (see Finks, 1968, p. 139 for original identification; the river, however, was misidentified as the Wanaque). It is appropriately intermediate in metamorphic grade between the correlative Manhattan Schist to the east and the Martinsburg Slate to the west. If the Green Pond Conglomerate immediately above the Ordovician extended this far east (and the large boulders of it in the fanglomerate only a mile and a half away imply that it was nearby) then this sliver must have been downdropped after the Green Pond Conglomerate had been removed by erosion. It seems less likely that such a resistant unit as the Green Pond would have been removed after downdropping. If this line of reasoning is correct, the time of downdropping would be well after the deposition of the second fanglomerate. Inasmuch as this fanglomerate is close to the top of the Jurassic basin-fill, the faulting could be late Jurassic or even later.



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The Pequannock River drains the upthrown block even as the Jurassic streams did. It does not form an alluvial fan because the scarp is much lower and the climate more humid. Its bedload is fairly coarse, but not so coarse as the Jurassic fanglomerates. Part of the coarseness of the Pequannock sediments is due to reworking of quite nearby glacial tills over which it flows. Most of the cobbles are of Precambrian gneisses and granites, in keeping with the wide present exposure of these rocks on the upthrown block. Green Pond Conglomerate cobbles are also common. The Pequannock flows over the outcrop of the Green Pond about ten miles upstream at Stop 5 of this trip, but at least some of them must come from much nearer glacial deposits. It would be an interesting exercise to determine how many of the cobbles show glacial faceting and striae.

The previous two stops sampled the exposed bedrock of the Jurassic indirectly, whereas the present stop does so directly. All three stops lie within a strip only 4.0 miles long and 1.5 miles into the basin from the main border fault (a position comparable to that of the viewer in Figure 2). The apparent absence (or paucity?) of Annsville Phyllite cobbles in the fanglomerate needs to be explained. Unless a major structural discontinuity existed along the main border fault, such as right-lateral fault transport (the nearest presently-exposed equivalent phyllites on the upthrown side of the Ramapo Fault are some 50 miles northeast in Dutchess County, New York) the Annsville should have been present nearby in the upthrown block. A small patch of a shaly equivalent is, indeed, present in the Outlier (Barnett, 1976). The least radical explanation is the ease with which the rock is broken up during transport. In fact, large shaly clasts of any kind are rare in the fanglomerates.

A SILURIAN STREAM VALLEY?

One of the intriguing mysteries of the Green Pond - Schunemunk Outlier is the fact that the Silurian Green Pond Conglomerate rests directly on the Precambrian in an area some 4 miles wide and 10 miles long between Kanouse Mountain, east of Newfoundland, and Bowling Green Mountain, west of Milton (Figure 1). At the latter locality the mapped contact is nearly horizontal and is unlikely to be a fault. (A thrust plane seems unlikely to follow exactly a conglomerate-gneiss contact over a wide area.) The original extent of the area of Precambrian beneath the Silurian is conjectural, but subject to fairly close constraints. Within the Outlier, it is constrained on the north by the contact of the Green Pond Conglomerate on Cambrian dolomite at the north end of Echo Lake (just south of our Stop 4), and by the Ordovician shale

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Figure 2. (Above) The fault-scarp of the Golan Heights on the east side of the still-active lake Kinneret rift-valley above Kibbutz Ha-On, Israel. The plateau is capped by Pleistocene basalt. This makes a good model for the New Jersey Mesozoic Basin and shows the possible kind of source of the basalt cobbles at Stop 1. Note the Recent fluvial cobbles in the foreground. (Photo courtesy of Zvi Erez, Open University, Tel Aviv, Israel.)

(Below) The Golan Heights looking toward the north bank of the Yarmuk River near Ḫamat Gader. Note the former tributary stream valley, at mid-height, filled with Pleistocene basalt. Again a model for the source of the basalt boulders in the Jurassic fanglomerate at Stop 1. (Photo courtesy of Zvi Erez.)

valley-filling. The asymmetry of the outcrop bend, with the sharper curvature on the right (north), can be explained by the valley hypothesis, because the valley would have a WSW-ENE trend along the axis of the Precambrian subcrop. The north side of the bend would be nearly perpendicular to the valley trend while the south side would be more nearly parallel to it. If the bend in the unconformity is solely due to a cross-syncline, those curious features which have been enumerated would have no obvious explanation other than coincidence. One should also note in this connection that the WSW trend of the proposed valley, when projected westward, intersects the area of greatest thickness of the Shawangunk Formation south of Delaware Water Gap (Epstein and Lyttle, 1987). This could represent the lower reaches of the valley itself, or a delta at its mouth.

Although it is not necessary for the stream valley hypothesis that the Green Pond Conglomerate be fluvial in origin itself (the stream could have preceded it), the lower part of the formation at Stop 5 does, in fact, show features compatible with fluvial deposition. This Lower Conglomerate Member (Finks, 1968) is characterized by fining-upward cycles of a few feet in thickness each, with coarse pebble conglomerate at the base of a cycle and cross-bedded sand at the top. The cross-laminations indicate a westward flow direction toward the Silurian epeiric sea. There is considerable argillaceous material and hematite in the sediment, more so than in the Shawangunk/ Tuscarora Formations to the west,(Tada and Siever, 1989, fig. 1, p. 95) The conglomerate pebbles are mostly milky quartz, but black, red, and green chert is common (often angular) and some chert pebbles show weathering rinds. Quartzite and shale pebbles are also present.

The higher beds at this locality, and elsewhere, are planar cross-laminated quartzites without pebbles (mostly), characterized by Liesegang rings of hematite (Upper Quartzite Member of Finks, 1968). This unit may or may not be fluvial.

The river valley hypothesis may also account for the discontinuity of the Green Pond Conglomerate along strike. It is missing between the south end of Greenwood Lake in New Jersey and the Monroe/Highland Mills area in New York. Although mapped as a fault (Figure 1), the gap may result from deposition in two separate valleys. This would also account for the lithologic differences between the two areas. The New York Green Pond contains a coarse arkose conglomerate with large feldspar clasts (Middle Arkose Member of Finks, 1968) which is missing in the New Jersey Green Pond.

Although the Green Pond/Schunemunk Outlier is sometimes considered to be a downdropped Mesozoic rift-block (without preserved Mesozoic sediments) it is possible that the original structural frame of the Outlier was a Silurian rift-valley, perhaps formed in a back-arc extensional setting. This would be compatible with the fluvial nature of the basal fill, its strong hematite content, and its locally arkosic nature. The first undoubted marine sediments above the Taconian unconformity are red near-shore muds, bearing Lingula, in the Upper Silurian (Upper Shale Member of the Longwood Formation of Finks, 1968). Although the highest Silurian and Devonian sediments of marine origin are sometimes extensions of facies in the main outcrop belt, such as the hematitic crinoidal limestone unit of the Decker Ferry Formation (Skyline Member of Finks, 1968), many highly siliciclastic units are confined to the Outlier, such as the Kanouse Sandstone and Skunnemunk Conglomerate. The postulated stream valley on the Taconian unconformity is also a characteristic of rift-basins. A similar incised valley beneath the Mt. Toby Conglomerate at Roaring Brook in the Mesozoic basin of Massachusetts was described by Bain and Meyerhoff, (1976, fig. 8, and pp. 24 and 119).

Some 12,000 feet of Cambro-Ordovician marine sediments were removed from the rather small, Newfoundland to Bowling Green Mountain, area in order to expose the Precambrian gneiss. The sediments are present in this thickness ten or twenty miles to the north, west and south of this area, and their metamorphic equivalents are a similar distance to the east. The area of removal is broader than the area of Precambrian subcrop, for the Silurian rests on Lower Cambrian for several miles north of Stop 4. One could imagine a persistent major river accomplishing this, but either a eustatic fall in sea level, or an accompanying local upwarp, is necessary, if only to bring these marine sediments up out of the sea. The upwarp (or upthrust) idea is the source of the senior author's 1968 suggestion of a "Taconian island" rising out of the Late Ordovician sea. A sliver of Martinsburg Shale north of Bowling Green Mountain (Barnett, 1976) is so closely adjacent to the place where the Green Pond Conglomerate rests on Precambrian that a pre-Silurian juxtaposition there of Precambrian and Middle Ordovician is implied. (See Figure 1.) This has to be a fault. However, if the fault is invoked to explain the uplift and exposure by erosion of the Precambrian subcrop, it has to be part of a broader upwarp, to account for the extensive Lower Cambrian subcrop to the NE of the Precambrian, in the area of Stop 4.

COEYMANS LIMESTONE REEF

This Lower Devonian reef is exposed as a hill north of Deckertown Turnpike about 1 mile east of Clove Road in Montague Township, New Jersey. The exposed reef outline is about 520 x 200 feet (160 x 70 meters). On the hill south of Deckertown Turnpike similar reef-rock is exposed along strike and may either be a part of the same reef or else an adjacent patch-reef. We will refer to the first hill as "the reef" even though it may be part of a much larger reef-tract.

The beds dip about 20° to the NW. A vertical section through the reef and underlying pre-reef calcarenites is exposed on the northwest side of the reef. The top surface is at present covered with a second-growth mixed hardwood and hemlock forest, with numerous outcrops of bedrock on which observations can be made. Many of the corals are silicified, and much of the information presented here was derived from study of field-oriented blocks etched with hydrochloric acid in the laboratory.

The reef-building fauna consists of Thamnopora sp., both branching and massive, slender branching Cladopora sp., solitary rugose corals (mainly Briantelasma americana Oliver, 1960, and Tryplasma sp.), stromatoporoids (probably Parallelostroma sp.), and Aulopora sp. Small bryozoan colonies, high-spired gastropods, and several species of small brachiopods are also present. The Aulopora usually encrusts stromatoporoids, and the Tryplasma is often attached to branching Thamnopora. The coral fauna of this Lower Devonian (Gedinnian) reef is different from that of the next youngest reefs in this area, namely, those of the Middle Devonian (Eifelian) Edgecliff member of the Onondaga Formation. The Onondaga reefs are dominated by very large colonial rugosa which are absent from the Coeymans reefs. (The nearest Onondaga reefs are in the Hudson valley, south of Albany, New York.)

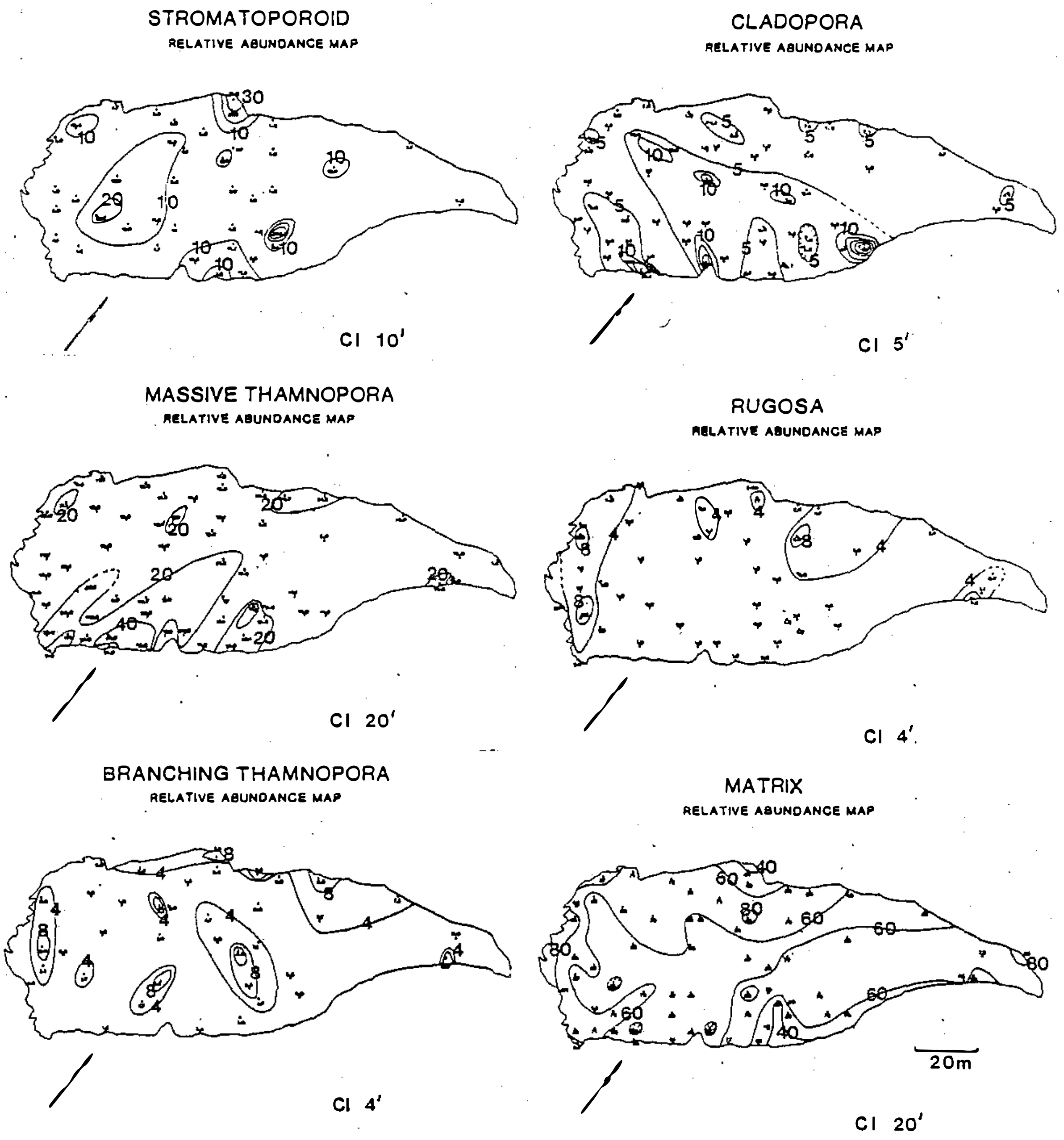

Figure 4. Maps of the Coeymans Limestone reef at Montague, NJ (Stop 6) showing percentages of the major reef-forming species, and matrix, over the top surface of the reef. Relative abundances were determined by point-counts with a one-inch grid at each of the data points shown. See text for discussion.

There are several similar-sized patch reefs, with the same coral fauna, along the belt of the Coeymans limestone outcrop in the Delaware River valley between here and the Tocks Island/Delaware Water Gap area to the south (described in Epstein, Epstein, Spink and Jennings, 1967). Reefs of the same age have also been described from the Knoxboro to Manlius area, south of Oneida, New York (Oliver, 1960) Reefs are apparently missing, however, along the Coeymans outcrop belt between the present reef and those of the Oneida area. Inasmuch as the New York reefs are north-northwest of the Delaware Valley reefs, there is a possibility that a reef-tract in the Coeymans Limestone runs approximately NNW-SSE, and that similar reefs exist in the subsurface beneath the Catskill/Pocono Plateau. The present reef was studied from a petrologic and paleoecologic point of view by Precht (Precht, 1982, 1984, 1987a, 1987b). Our present study is an expansion of Precht's study in a biological direction with special emphasis on species distribution, growth-form distribution and growth orientation.

Coral Distribution

The reef-building species show different patterns of abundance over the exposed surface of the reef (Figure 4) as determined by point-counts made with a one-inch grid over one or more square feet at each of 68 stations. Massive Thamnopora (Figure 7) is most abundant at the southern end of the reef along the southeast edge of the exposed area. The more delicate, branching Cladopora (Figure 9) is also most abundant in a similar, but wider, area, extending farther north. Much of the Cladopora is broken, rather than in growth position.

Branching Thamnopora (Figures 5, 6, and 10) is most abundant more northerly, in the center and along the northwest edge of the preserved reef. Most colonies seem to be in growth position. Solitary rugosa (Figures 5, 6, and 7) are most abundant along the northwest edge of the preserved reef, where they are also more frequently in growth position than they are further south. Stromatoporoids (Figure 8) are most abundant in the northern and central parts of the exposed area, rather similar in their distribution to that of branching Thamnopora. They are especially well displayed in the vertical cliff along the northern edge of the reef and on the top surface just behind this cliff.

The relative abundance of matrix is an inverse measure of total fossil abundance. As can be seen from Figure 4, the matrix is least abundant (less than 60%) in the central and southern parts of the preserved reef, and also in a small patch in the middle of the NW side. Most of the matrix is micrite, rather than the calcarenite of the pre-reef and interreef facies, and presumably results from the baffling effect of the coral colonies. This is strong support for the in-place nature of the corals. There are, however, channels filled with calcarenite, best seen on the vertical NW face.

Coral Orientation

One of the most interesting feature of this reef is the consistent orientation of both in-place corals and loose fragments. The strongest orientations are shown along the entire northwest margin of the reef by the branches of Thamnopora and Cladopora colonies and by attached solitary rugosa.

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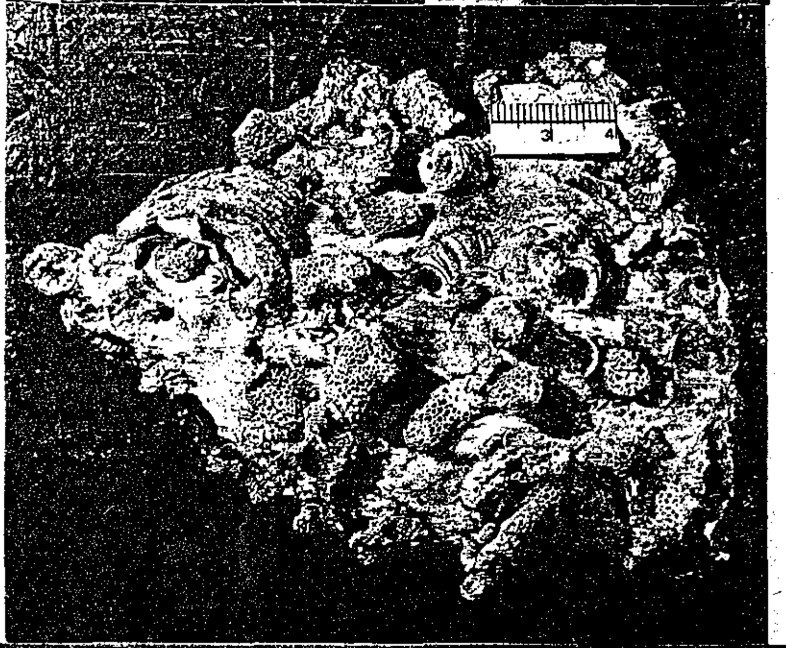

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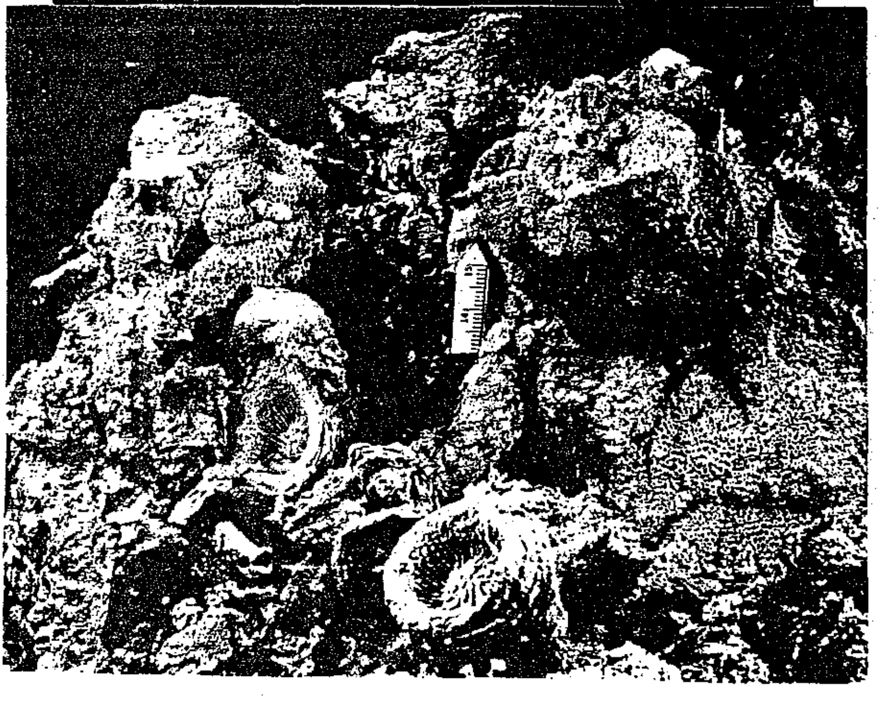

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The branches predominantly grow to the north at a low angle, and attached rugosa open to the north. It is clear that whatever determines the growth direction of the Thamnopora branches also determines the direction in which rugose corals open, for Tryplasma attached to Thamnopora uniformly open in the direction of the branch tips (Figure 6). As one crosses the reef to the southeast side, orientation gradually becomes less pronounced (see Figures 12, 13, 14, and compare Figures 6, 7 and 10). Loose, cylindrical fragments of Cladopora and Thamnopora branches are oriented roughly E-W over most of the reef (open bars on Figures 12,13). Unattached solitary rugosa have their apexes pointing north (open bars on Figure 14) as do high-spired gastropod shells on one etched laboratory sample. One can easily demonstrate with paper models of cones and cylinders that in a unidirectional current, cylinders will roll to orient across the current and cones will orient with apexes pointing into the current (see Figure 11, upper). Thus the data from loose fragments are consistent with a prevailing current from the north. (This would have been paleo-northeast because the Laurentian Plate has rotated counterclockwise by about 45° since the Devonian; see Seyfert and Sirkin, 1979, page 314).

Evidence from modern reefs concerning growth directions of living branching corals has been conflicting. Graus, Chamberlain and Boker (1977) presented theoretical grounds for branching colonies adopting an up-current growth in order to reduce mechanical stress on the skeleton of the branch. They also documented such an upcurrent growth in living Acropora palmata on a Caribbean fringing reef (ibid., p. 145) in the zone of strongest unidirectional currents, just lagoonward of the reef-crest. (However, in the "Strong Wave Zone" in front of the reef-crest, the orientation was bimodal, with the greater frequency down-current.) Wallace and Schafersman (1977, p. 45) documented the same species oriented into the current on the front of a Carribbean patch-reef. On the other hand, Shinn (1963) observed that Acropora palmata grew dominantly down-current in front of the reef-crest at Key Largo Dry Rocks on the Florida Reef Tract. Likewise, Bottjer (1980) found that A. cervicornis showed the same down-current branch growth in front of the reef-crest on a small barrier-type reef in the Bahamas. It is not clear how these conflicting orientations are to be reconciled. One may note that the down

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Figure 5. Branching Thamnopora sp. Briantelasma americana Oliver, from the southwest end of the reef. The corals are in life position and more or less vertical. They are silicified and were etched free with hydrochloric acid.

Figure 6. Branching Thamnopora sp. with attached Tryplasma sp., cf. T. fascicularium Oliver, and Briantelasma americana Oliver at the left. Note that all are facing in the same direction. The silicified specimen is float from the top of the reef and was partly etched with hydrochloric acid.

Figure 7. Massive Thamnopora sp., with three specimens of Briantelasma americana Oliver in life-position, oriented toward the north. Note the cylindrical fragments of Tryplasma sp. (?) oriented E-W by the same current. Elsewhere on this block are two high-spired gastropods with apexes pointing north (not visible in this photograph). The silicified specimens were etched out with hydrochloric acid. The sample is from the center of the northwest side of the reef.

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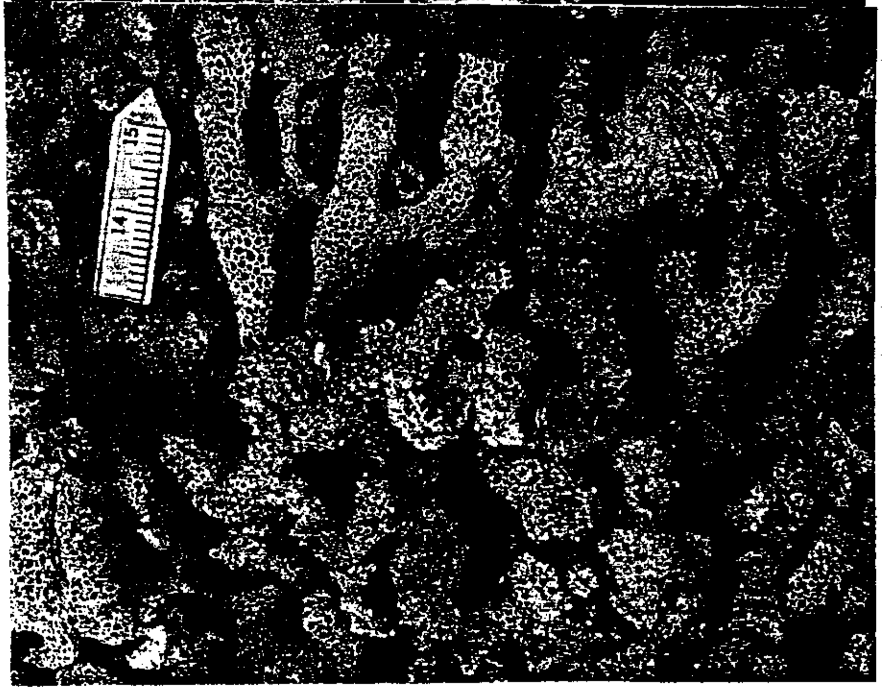

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current orientations are on the wave-dominated front side of elongate reefs, and the up-current orientations on the current-dominated lagoonward side. The cited patch-reef of Wallace and Schafersman (1977) was in an atoll lagoon near a channel through the atoll-reef. This suggests that where there are unidirectional currents, rather than back-and-forth wave-surge (even where one component dominates), the growth of branches will be dominantly into the current. If so, this has implications for the reconstruction of our reef.

A Reef Model

The zone of strongly oriented, nearly-horizontal branches along the northwest side of our reef suggest that this is on the lagoonward side of a reef-crest, close to the crest itself. This would correspond to the "Current Zone" of Graus, Chamberlain and Boker (1977). The direction of wave-approach (i.e., the open sea) would be from the north, and would generate a strong flow to the south over the crest and into the lagoon. Several other lines of evidence favor the reef-crest being on the northward side. One is the presence of shallow calcarenite-filled channels on this side which may represent grooves of a spur-and groove system or, more likely, the less-deep channels through the reef-crest ridge itself (compare Rützler and MacIntyre, 1982, p. 24 figure 13c and p. 26 figure 15). The abundance of domal stromatoporoids here also suggests a reef-crest ridge, for they are noted by many authors to be characteristic of the roughest-water environments on Devonian reefs (Hoffman and Narkiewicz, 1977; Copper, (1974). Likewise domal to massive shape is assigned by James (1983, p. 374, figure 59) to moderate to high wave-energy and low sedimentation environments.

Further south the current would gradually diminish, as described by Graus, Chamberlain and Boker (1977, p. 145). It was still sufficiently strong to orient Cladopora branch fragments across it (Figure 13), but by the time one reaches the southern end of the preserved reef the orientations become random. That this area is a back-reef lagoon is also supported by the dominance of the delicate-branching Cladopora and the relatively high proportion of matrix (Figure 4). There are patches of stromatoporoid and branching Thamnopora dominance (Figure 4) which may represent micro-patch-reefs, so to speak, within the lagoon.

Figure 8. Domal stromatoporoids (Parallelostroma sp. ?) from the center of the northwest side of the reef.

Figure 9. A silicified colony of Cladopora sp. etched free with hydrochloric acid. The colony is upside-down. The specimen is float from the central area of the reef and its original orientation is not known.

Figure 10. A silicified colony of branching Thamnopora sp. freed with hydrochloric acid. The branches are horizontal and strongly oriented toward the north (shown by the arrow on the scale). The oriented specimen is from an outcrop at the northeast end of the reef.

At the southernmost edge of the reef there is an area dominated by massive Thamnopora. This growth-form suggests higher wave-energy (James, 1983, p. 374) and we may be at the back-slope edge of our reef. The general pattern corresponds to that shown by Copper (1974, figure 9, top diagram) as the climax stage of a Devonian reef. We have modeled our reconstruction (Figure 11, bottom) on Copper's diagram. Our reef may well be in a mature successional stage, for there is 3-4 m of reef-rock exposed in the NW cliff-face (at the SW end) above the bedded pre-reef crinoidal calcarenites. A similar recent model, almost identical to the scale of our reef, is the Montastrea-assemblage patch-reef illustrated by Wallace and Schafersman (1977, p. 44, figure 9). This is one of a number of small patch-reefs within the lagoon of an atoll, seaward of the barrier-reef off the coast of Belize. Our lagoon corresponds to their "patch backreef region dominated by Thalassia and low coral growths" (Wallace and Schafersman, 1977, p. 45 figure 11). A small patch-reef model supports the idea of Precht (1987b) that the hill is more or less coterminous with the original outline of the reef.

ACKNOWLEDGEMENTS

We thank Philip LaPorta for first showing us the Coeymans reef, William Precht for sharing his knowledge of the reef with us in the field, Peter Alessi for indispensable assistance in making the road-log, and both Mitchell Algus and Pamela Brock for critical reading of the manuscript. The senior author also thanks the participants in the 1968 trip, as well as many students taken to these locations, for stimulating discussion.

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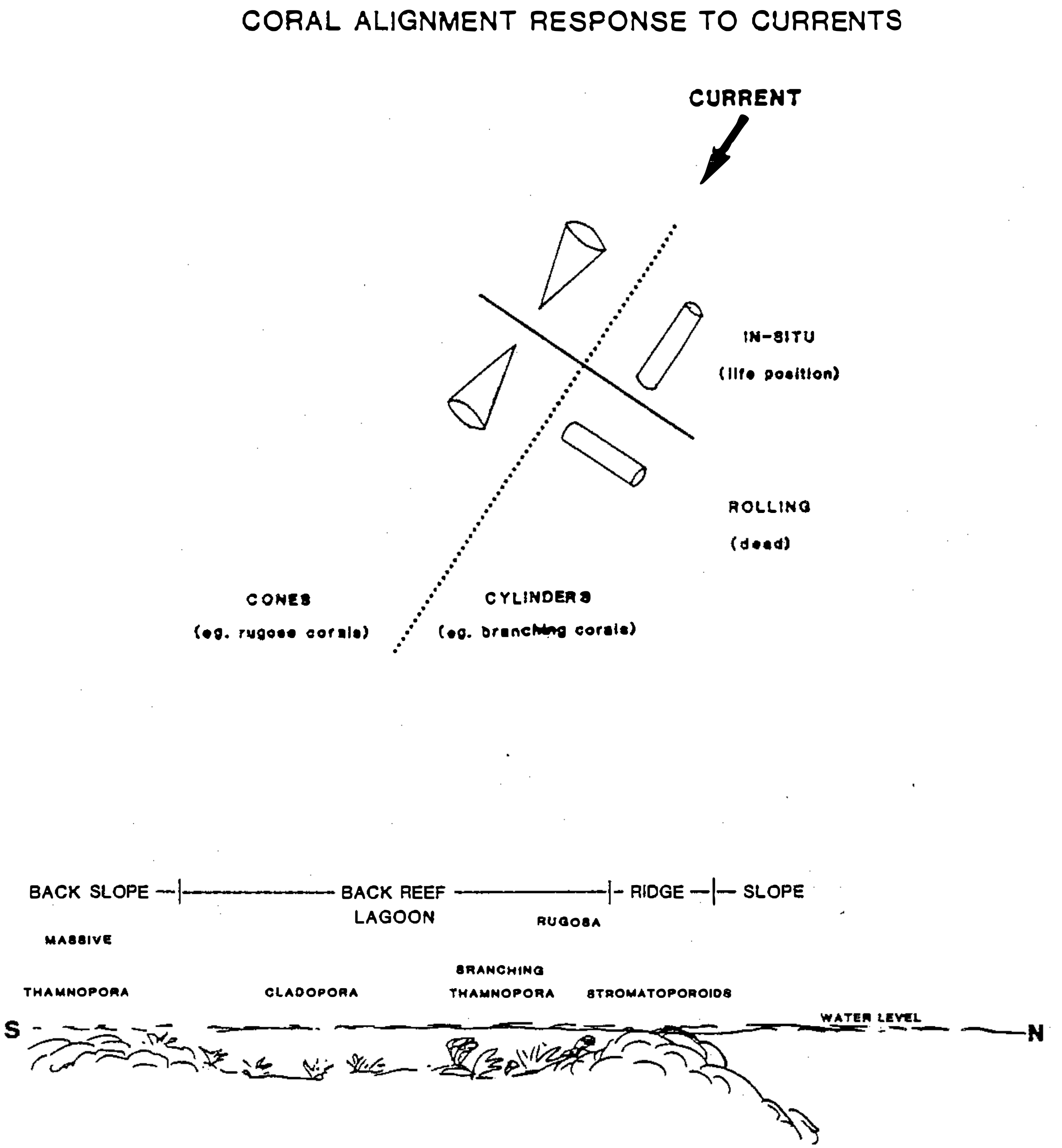
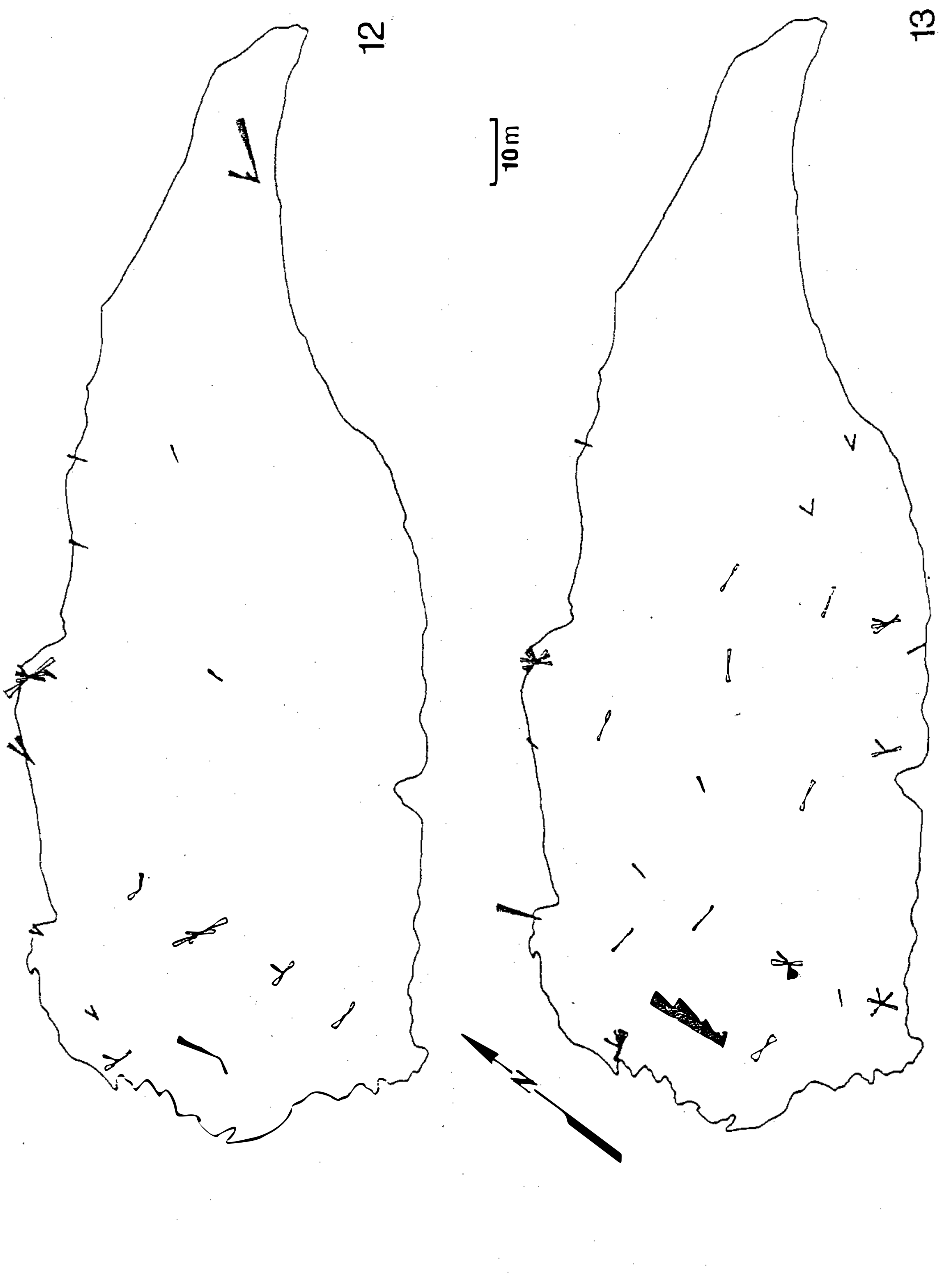


CORAL ALIGNMENT RESPONSE TO CURRENTS

Figure 11. (Above) Diagram showing alignment of different coral shapes in response to the same current. Such alignments were used to construct the orientation maps (Figures 12, 13, 14).

(Below) A proposed model of the reef along a N-S transect, north at right.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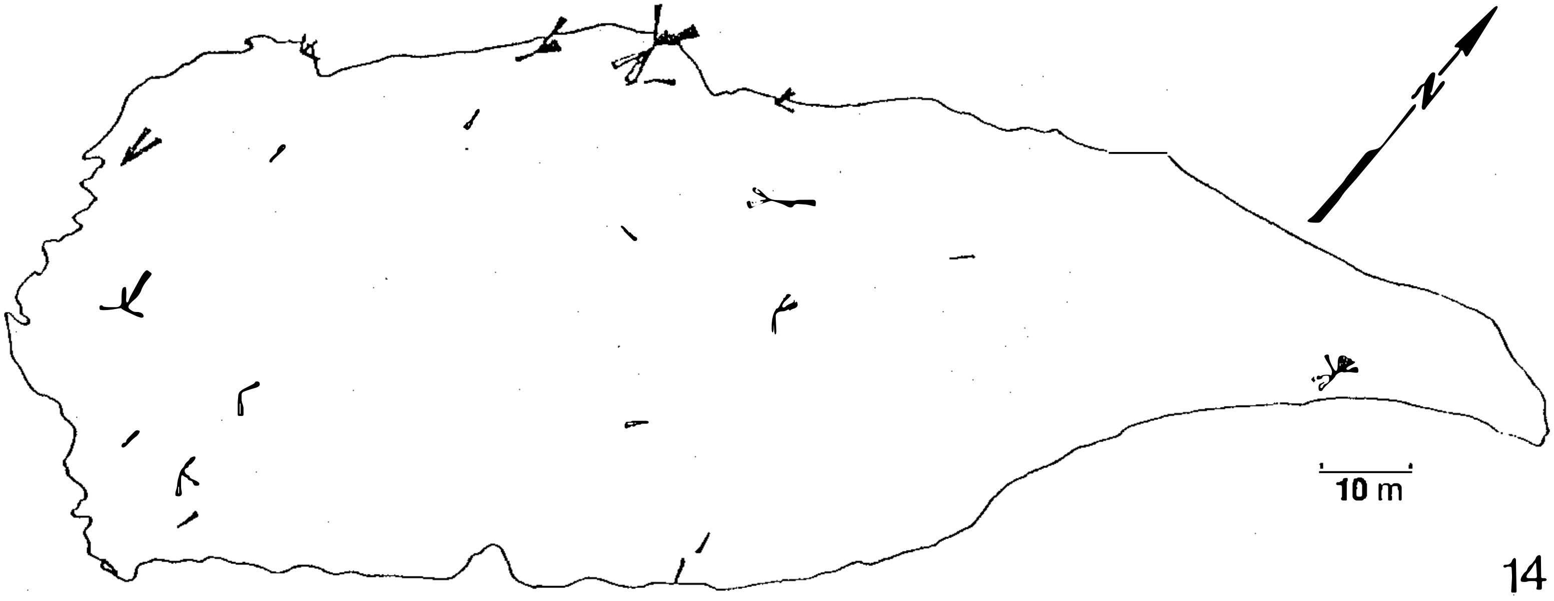

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Figure 12. Orientations of branching *Thamnopora* shown by rose-diagrams at specific localities. Solid bars are in-situ colonies, open bars are fragments of branches. The solid bars expand toward the facing of the branch tips. The open bars are parallel to the branch-fragment axis in both directions. Length of bars proportional to the number of observations within a 10° bin.

Figure 13. Orientations of branching *Cladopora*. (For explanation see Figure 12.)

Figure 14. Orientations of solitary rugose corals. Bars, both solid and open, expand toward the open end of the corallite. Their appearance in fact mimics the position and shape of the fossils. Solid bars are attached in-situ corals, open bars are loose ones. Length of bar proportional to number of observations within a 10° bin.

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ROAD LOG FOR ANCIENT LAND SURFACES IN AND AROUND THE GREEN POND OUTLIER, A DEVONIAN CORAL REEF, AND "TACONIAN ISLANDS" REVISITED.

CULMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Juncture of ramp from I-84 (North)East with NY 17 (South)East, Near Middletown, NY. START OF TRIP. Proceed east on NY 17.
1.6	1.6	Anticline in Martinsburg Formation (Ordovician) on left. Zone 13 (possibly Zone 14) graptolites were collected here by Alejandro Vargas and identified by W.B.N. Berry (Vargas, 1976, p. 32 and fig. 5A). Distal turbidites can be seen here.
6.4	4.8	Martinsburg Slate on both sides of the road.
9.2	2.8	Martinsburg Slate on both sides of the road again.
10.1	0.9	Klippe of Precambrian gneiss on right, forming hill.
12.5	2.4	Exit 129. Museum Village Road.
12.7	0.2	Klippe of Precambrian gneiss on left, in thrust contact with underlying Cambro-Ordovician dolomite. The thrust plane and accompanying fault breccias can be seen.
BONUS STOP.		This exposure may be visited by exiting here, turning left (north) on Museum Village Road to cross over NY 17, then taking the first left (Old Mansion Road) for 0.2 mile and parking just before first house on right. Walk into woods on left (south) side of road downhill toward NY 17, crossing the old, low stone wall left of the barbed wire. At highway level the thrust plane is exposed, dipping about 30° SE, with garnet-gneiss above and white-weathering dolomite below. Immediately above the fault

plane you may collect samples of gneiss mylonite-breccia, and immediately below it, tectonic breccia of dolomite. To resume trip, return to Museum Village Road, turn right over NY 17, then left onto service road, making another sharp left just before bus stop area, to enter NY 17 east at mileage 13.0 of log.

13.0	0.3	Entrance ramp from Museum Village Road. The western border fault of the Schunemunk Outlier crosses approximately here, shown on the 1971 NY State Map as a small offset of the main fault at this point. (Fisher, Isachsen and Rickard, 1971.)
13.3	0.3	Bellvale Sandstone on left, dipping SE. (Mid-Devonian)
13.7	0.4	Axis of Schunemunk Syncline plunging NE. Horizontal pebble beds of Bellvale Sandstone on left. Between 13.7 and 14.1 is a 2,000-foot complete section of the Bellvale Sandstone (measured section in Finks, 1968) from submarine prodelta silts at 14.1 to subaerial piedmont conglomerates at 13.7 It is a part of the Catskill Delta. The beds dip NW on the east limb of the Schunemunk Syncline.
14.1	0.4	Basal beds of Bellvale Sandstone, dipping steeply NW.
17.4	3.3	Exit south on 1-87. Main mass of Ramapo Mountains (Hudson Highlands) are ahead (Precambrian of Reading Prong) and to your left as you swing south. You are in a valley on Cambro-Ordovician dolomitic limestones. This is also part of the Green Pond - Schunemunk Outlier, although the NY State Map has a structural discontinuity (normal fault) between these rocks and the Siluro-Devonian just passed through (Fisher, Isachsen and Rickard, 1971).
19.0	1.6	Outcrop of Cambro-Ordovician limestone on left.
19.8	0.8	Outcrop of Cambro-Ordovician limestone also on left.
20.5	0.7	Greenwood Furnace on left. This smelter served the small magnetite mines in this vicinity during the 19th Century. The ore is from the Precambrian rocks. About three miles further on is another historic locality, the town of Tuxedo Park, where the Tuxedo jacket was invented.
30.6	10.1	Precambrian gneiss outcrop on left.
31.8	1.2	Exit at Suffern.
32.4	0.6	Stay left, and continue south into New Jersey on Route 17.
32.8	0.4	Crossing Ramapo Fault into Mesozoic Basin, a rift-valley formed during the opening of the Atlantic Ocean. The Green Pond-Schunemunk Outlier has a similar structure and may be a Mesozoic basin in which no Mesozoic rocks were preserved. (Or a Siluro-Devonian extensional basin?)

33.9	1.1	Turn right at exit for US 202.
34.0	0.1	Turn left (south) on US 202.
34.8	0.8	Old stone house on right. Historic marker.
35.1	0.3	Good view of Ramapo fault-line scarp on right.
36.5	1.4	Crossing Orange Mountain Basalt (Lower Jurassic).
37.0	0.5	Outcrops of Orange Mountain Basalt on left.
40.1	3.1	Another basalt outcrop on left.
40.6	0.5	Junction with US 208. Continue on US 202.
41.8	1.2	Turn right to continue on US 202.
42.2	0.4	Turn left into parking lot of Hillside Diner.

STOP 1. OAKLAND. JURASSIC FANGLOMERATE BENEATH THE PREAKNESS BASALT.

The most accessible outcrops are on the south side of the diner parking lot on the east side of US 202. Look for the boulders of vesicular basalt. Search for gneiss boulders. Some Paleozoic formations to look for are: white-to-buff-weathering Cambro-Ordovician dolomites, the purple with white quartz Green Pond Conglomerate, the red with white quartz and red quartzite Skunnemunk Conglomerate, the subgreywacke Bellvale Sandstone. Note their proportions.

42.4	0.2	Outcrop of Preakness Basalt on left.
44.0	2.4	This is Stop 2. Do not stop here but proceed to Moyias Road.
44.1	0.1	Moyias Road. Turn right and right again. Park off road next to pumping station. Walk back to outcrop on east side of US 202. LOOK BOTH WAYS WHEN CROSSING ROUTE 202. YOU ARE ON A CURVE AND A HILL. VISIBILITY IS LIMITED. WALK FACING TRAFFIC AND STAY OFF THE ROADWAY.

STOP 2. POMPTON LAKES. JURASSIC FANGLOMERATE BENEATH THE HOOK MOUNTAIN BASALT.

Note the large boulder of Green Pond Conglomerate near the south end of the outcrop, and the many boulders of whitish-weathering Cambro-Ordovician dolomite. Note also the interbeds of finer sand and shale. How do the proportions of lithologies among the clasts compare with those of the preceding stop?

44.4	0.3	Outcrop of Hook Mountain Basalt on left. The outcrop crosses the bed of the Ramapo River on the right, on top of which is a dam and waterfall.
44.5	0.1	Turn right onto Hamburg Turnpike. Cross Ramapo River.
45.2	0.7	Bear left at fork.
45.4	0.2	Crossing Wanaque River.
45.6	0.2	Park in the professional building parking lot on the right.

STOP 3. RIVERDALE. ANNSVILLE PHYLLITE (ORDOVICIAN) AND BED-LOAD OF THE PEQUANNOCK RIVER.

Descend carefully under the bridge and walk to the south side of the east abutment. There is also a path to this point from the south side of Hamburg Turnpike. CAREFUL CROSSING ROAD. The outcrop of the Annsville Phyllite is exposed here. PLEASE DO NOT HAMMER ON THIS RARE OUTCROP! THERE ARE PLENTY OF LOOSE PIECES LYING ABOUT. Another small outcrop lies upstream of the bridge in the channel and on the west bank.

Unless the river is in flood, a large sample of the Pequannock bed-load is exposed beneath and downstream of the bridge. Look for imbricated cobbles. See how many different Precambrian lithologies you can find. Green Pond Conglomerate cobbles are common. Can you find any Cambro-Ordovician dolomites? This river crosses the Green Pond outcrop about ten miles upstream, but much closer glacial moraines may be the source of most of the cobbles.

46.0	0.4	Turn left at light onto County 511. (Before you turned there was a quarry in Precambrian granite visible ahead.)
46.1	0.1	Washington's Headquarters on left.
47.0	0.9	Turn right onto NJ 23 Northwest.
47.3	0.3	Crossing Ramapo Fault. Road climbs hill on Precambrian with extensive cuts exposed in ramps for I-287. A gravel pit was formerly present to the left (south) in a delta built into Glacial Lake Passaic. Moraines on left about a half mile ahead.
54.1	6.8	Outcrops of Precambrian on right, Pequannock River valley on left.
54.6	0.5	Kanouse Mountain ahead, made of Green Pond Conglomerate on Precambrian. You are on the area of the radar mosaic Figure 3.
54.7	0.1	Turn right (north) onto Echo Lake Road (clearly visible on Figure 3). You are paralleling Kanouse Mountain.
57.0	2.3	Turn left on Macopin Road.
57.8	0.8	Turn left on Gould Road.
58.4	0.6	Bend in road. Hill of Precambrian ahead.
58.8	0.4	This is Stop 4. Do not stop here but proceed to wider shoulder.
58.9	0.1	Park off road on right and walk back to 58.8. WALK TO THE LEFT FACING TRAFFIC AND STAY OFF THE ROADWAY. SIGHT DISTANCE FOR CARS IS LIMITED. Enter woods road running uphill to west (on your present right).

STOP 4. GOULD QUARRY. PRECAMBRIAN GNEISS, HARDYSTON SANDSTONE AND LEITHSVILLE DOLOMITE (LOWER CAMBRIAN), BASAL GREEN POND CONGLOMERATE (SILURIAN) IN KARSTIC POCKETS.

Outcrops at entrance to the road are Precambrian gneiss. Continue uphill on this road to the SW. Where the road bends to the left (south) continue straight ahead into the woods. You will soon reach a small swale. The lower Hardyston Sandstone underlies this swale. As you face SW, the hill on your left is Precambrian gneiss and the low ridge on the right exposes ledges of the upper part of the Hardyston Sandstone and the base of the Leithsville (or Stissing) Dolomite dipping NW. Walcott (1893) reported the trilobite

Olenellus from the same beds a mile or so north, proving their Lower Cambrian age (and for us, their position on the Laurentian Plate).Follow this ridge a short ways to its southern end, where there is a small depression and cross-valley in the ridge. In the depression, against the ledges to the left, is a small pocket of conglomerate in the basal Leithsville Dolomite. (It may be covered by leaves.) This is a karstic cavity filled with the Silurian Green Pond Conglomerate which has infiltrated from above. A thin red shale lines this pocket. Walk to the top of the Leithsville ridge at this point through the small notch and descend its west side. Immediately to the right you will see a small patch of conglomerate on top of the steeply northwestward dipping beds of the Leithsville Dolomite. If you examine the dip-slope below it you can see a narrow extension of this patch apparently filling a fissure in the Leithsville. This must have been the entrance for the gravel into the pocket represented by the patch. PLEASE DO NOT HAMMER ON THIS RARE OUTCROP! IT IS THE ONLY RELIC OF THE KARSTIC INFILLING. PLEASE PRESERVE IT FOR POSTERITY. This outcrop was illustrated by Rodgers (1971, p. 1160, fig. 9B). In the valley to the west is a small outcrop of the Green Pond Conglomerate just west of a small brook. The main mass of Kanouse Mountain, composed of the conglomerate, lies beyond. If you have time, note the ruins of the old lime kiln, north of the quarry, with its partly melted walls of stone blocks. The Leithsville was quarried here for lime. This tree-filled hollow was once an active quarry. The geologic relations here are illustrated in Kümmel and Weller (1902, figure 1).

Return on Gould Road. Make the U-turn at the driveway of the log house on the left if you wish to preserve road-log mileage. THE U-TURN SHOULD BE DONE WITH EXTREME CAUTION BECAUSE OF THE LIMITED SIGHT DISTANCE FOR CARS ON GOULD ROAD. A SAFER, BUT LONGER, WAY OF GETTING TO STOP 5 IS TO PROCEED ON GOULD ROAD (WITHOUT TURNING BACK) AS FAR AS UNION VALLEY ROAD AT POSTVILLE, TURNING LEFT (SOUTH) ON THAT ROAD TO NJ 23, THEN LEFT (SOUTHEAST) ON NJ 23 TO ECHO VALLEY ROAD, THEN RIGHT ON JUG-HANDLE TO ECHO VALLEY ROAD NORTH (LEFT) AND LEFT AGAIN ONTO NJ 23 NORTH AT TRIP MILEAGE 63.0.

60.0	1.1	Turn right on Macopin Road.
60.8	0.8	Turn right on Echo Lake Road.
63.0	2.2	Turn right on NJ 23 northwest.
63.2	0.2	Turn right into rest area.
63.3	0.1	Park.

STOP 5. NEWFOUNDLAND. GREEN POND CONGLOMERATE (SILURIAN) AND PRECAMBRIAN GNEISS.

The parking area is a loop of old Route 23 and is the original width of the two-way road. Note the historical marker with original relics of local iron smelting. To the south of NJ 23 is Charlotteburg Reservoir. Copperas Mountain to its right (west) comprises the extension of the Green Pond outcrop on the south of the Pequannock watergap. Seen in the distance to the west-southwest, are the ridges of Green Pond Mountain and Browns Mountain, also composed of Green Pond Conglomerate on Precambrian, repeated by folding and faulting.

The nearest ledges north of the parking area show well the steep westward dip and the fining-upward cycles in the Lower Conglomerate Member of the Green Pond Formation. Look for colored chert clasts (red, green, black) in the conglomerate layers. Many show weathering rinds. Follow the base of the cliff uphill to the east (right). A short distance up is a good place to see the cross-bedding. Note the consistent westward dip of the cross-laminations, indicating a westward current.

Continue upward along the base of the cliff and pick up a trail which heads uphill into the woods parallel to the base of the cliff but some distance from it. Keep on this trail in a northeastward direction. After several hundred feet you will come upon ledges of Precambrian gneiss. They are about 50 feet from the base of the cliff, the intervening area being strewn with large talus blocks of the conglomerate. The actual unconformity is not exposed here but it is clear that the conglomerate must rest directly on the gneiss.

When you return via the same trail you will see on the right (west) just above the ledges next to the parking area, beds of the higher non-conglomeratic part of the Green Pond Formation ("Upper Quartzite Member" of Finks, 1968). You can climb up to them if you have rubber-soled shoes or hiking boots (STAY AWAY FROM THE CLIFF EDGE TO THE LEFT) and observe the banded tongues (Liesegang rings) of hematite, showing former groundwater flow to the left (southwest) when the quartzite still had porosity.

63.5	0.2	Drag folds in Upper Quartzite Member of Green Pond Conglomerate. We are continuing northwest on NJ 23.
63.6	0.1	Small outcrop of Longwood red shale (Upper Silurian) on right.
64.8	1.2	Type locality of the Kanouse Sandstone (Lower Devonian) in the village of Newfoundland to the right.
67.2	2.4	Outcrops of Precambrian. We have just crossed the normal fault bounding the Green Pond-Schunemunk Outlier on the northwest. Oak Ridge Reservoir on left. The fault-line scarp bounds the reservoir on the west. This is called the Reservoir Fault (see Malizzi and Gates in this guidebook).
74.5	7.3	Turn left on County 631. Town of Franklin.
74.6	0.1	Franklin Lake on left. Source of the Walkill River.
74.7	0.1	Outcrop of Cambro-Ordovician limestone on right.
75.0	0.3	Old Buckwheat Mine dump (zinc mine in Precambrian Franklin Marble; type locality for Franklinite) and Franklin Mineral Museum on right.
75.1	0.1	Bear right on County 631. Crossing Walkill River. This river flows northeast to join the Hudson River at Kingston, following the Great Valley on the Cambro-Ordovician outcrop belt. Water from Franklin Lake flows 75 miles northeast, then another 100 miles south before it reaches the sea.
75.5	0.4	Wildcat Road on left. 0.5 mile down this road is an exposure of the Precambrian-Lower Cambrian unconformity (described in Finks, 1968). The first

		archaeocyathids from New Jersey were found here in the basal Leithsville Dolomite by Frank Markiewicz on the 1968 NYSGA field trip.
75.7	0.2	Turn left following County 631.
77.1	1.4	Turn left (southwest) on NJ 94.
77.9	0.8	Outcrop of Cambro-Ordovician limestone on right.
78.3	0.4	Outcrop of Cambro-Ordovician Limestone on left.
78.7	0.4	Old Monroe School on right.
82.0	3.3	Turn right on NJ 15 north.
82.3	0.3	Continue north on NJ 15.
83.3	1.0	Bear left on NJ 15 north.
83.5	0.2	Outcrops of Cambro-Ordovician limestone on left.
84.3	0.8	Outcrops of Martinsburg Slate on right.
84.9	0.6	Straight ahead on US 206.
86.8	1.9	Continue on US 206.
90.1	2.2	Culver Lake on right. Ahead is Kittatinny Mountain, held up by the Silurian Shawangunk Conglomerate.
92.6	2.5	Bear right on US 206.
94.7	2.1	Old log house on left.
99.1	4.4	Turn right on Clove Road (County 653).
99.7	0.6	Turn right on Deckertown Turnpike (County 650).
99.8	0.1	Outcrop of New Scotland Limestone (Lower Devonian) on right.
100.0	0.2	Park off road on right. Mile marker 1. Enter woods-trail ahead on left, opposite outcrop of pre-reef limestone on right.

STOP 6. COEYMANS LIMESTONE REEF LOWER DEVONIAN).

Approach the reef by the trail which leads toward the high southeast cliff and attain the top by climbing the slope to the right (east) of it. Here you are at the supposed back-slope area dominated by massive *Thamnopora*. A good outcrop to start with, showing most of the coral species, is just west of the large glacial erratic boulder of shale. From here one may walk along the edge of the high cliff to the west and then north. The reef-ridge area of strong orientations, with dominant branching *Thamnopora*, solitary rugosa, and domal stromatoporoids, is best exposed at about halfway along the northwest face. (Compare Figures 5, 7, and 8.) From here one may walk south along a series of outcrops toward the highest part of the hill, seeing the back-reef lagoon facies and finally reaching the back-slope area at the top of the hill. From here one may walk northeast, past the old stone wall on the right (east) to a fine outcrop at the northeast tip of the reef, with silicified oriented branching *Thamnopora* well displayed, again part of the reef-ridge. (Compare Figure 10.) A walk back along the base of the northwest-facing cliff paralleling the reef-ridge will show some calcarenite channels in cross-section (or grooves of a spur-and-groove system) near the northeast end, some fine stromatoporoid colonies in vertical section about half-way along, and the pre-reef calcarenites at the southwest end. Note that the matrix of the main part of the reef is mostly micrite. Use the maps of Figures 4, 12, 13 and 14 as guides.

END OF TRIP. Return to Clove Road by going ahead (east) for 0.2 mile and making a sharp left onto Birch Tree Road, which reaches Clove Road at 0.85 mile. This is less dangerous than making a U-turn on Deckertown Turnpike because of limited sight distance. Those who wish to return to Middletown, NY should turn right (northeast) on Clove Road and proceed for seven miles to NJ 23. At NJ 23 turn left (north) and follow signs to I-84 East which will return you to Middletown, where I-84 intersects NY 17. Those who wish to return to the New York City area should turn left (southwest) on Clove Road, left again at US 206 (a right turn takes you to Milford, PA and points west) and retrace the trip route as far as NJ 15. Continue southeast on NJ 15 to I-80 and take I-80 east. This is the fastest route to New York City from Stop 6. (Two interesting localities not far from Stop 6 are the kimberlite-like diatreme at Libertyville, with inclusions of Precambrian and Cambro-Ordovician, and the nepheline-syenite at Beemerville. Consult the New Jersey State Geologic Map.)

MAPS

Stops 1 and 2 are on the Wanaque, NJ, 7½-minute quadrangle, Stop 3 on the Pompton Plains, NJ, 7½-minute quadrangle, Stops 4 and 5 on the Newfoundland, NJ, 7½- minute quadrangle, and Stop 6 on the Milford, PA-NJ, 7½-minute quadrangle. The Bonus Stop is on the Monroe, NY, 7½-minute quadrangle.

ADDENDUM

The two expansions in the Outlier, near Newfoundland and Monroe respectively, suggest pull-apart basins along a Silurian right-lateral transform fault. Both expansions are of the same dimensions (about 8 miles in a NE-SW direction). If it were true, it could supply an alternative to the stream-valley hypothesis. The removal of the Cambro-Ordovician in the Newfoundland basin could have resulted from the intial anticlinal upwarp which is often a precursor of a pull-apart. In the Monroe basin the Ordovician shales, which constitute most of the stratigraphic thickness of the Cambro-Ordovician sequence, are in fact apparently missing in the southern part of the basin, for the Green Pond is mapped as resting on the Cambro-Ordovician carbonates east of Highland Mills (Fisher, Isachsen and Rickard, 1971). The present folds within the Outlier are the result of post-Devonian compression.