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RECUMBENT FOLD IN DISPLACED SLAB OF UPPER CRETACEOUS SEDIMENTS, PRINCES BAY, STATEN ISLAND, NEW YORK: FURTHER EVIDENCE THAT ICE FLOWING SOUTHEASTWARD DEPOSITED THE HARBOR HILL MORAINE

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INTRODUCTION

Near the navigation tower along the shores of Princes Bay, Staten Island, [UTM grid coordinates 566.70E, 4484.20N; Arthur Kill 7.5-minute quadrangle], ca. 1.5 km WSW of Seguine Point, is a coastal cliff in the Harbor Hill Moraine (Figure 1). Erosion of this cliff has exposed recumbently folded yellowish-weathering-, gray-, and brownish Cretaceous sediments that are enclosed within reddish-brown Pleistocene deposits. The Cretaceous strata here have been studied by many geologists; these strata are generally presumed to be nondeformed and in situ (Schuberth, 1968).

The inference that the Cretaceous strata are not in situ is based on the discovery of Pleistocene-type sediments (tills and outwash sands) beneath the Cretaceous, both in the coastal cliff and in borings made for the sewer line beneath Hylan Boulevard. In this paper, we present the evidence that the Cretaceous strata are not in situ but have been subjected to ice-thrust deforma-tion. The orientation of the recumbent fold here implies that the glacier responsible for the deformation and associated Harbor Hill Moraine flowed from NNW to SSE. If the Harbor Hill Moraine were deposited by ice flowing from NNW to SSE, then we argue that it cannot possibly be of Late Wisconsinan age (i. e., Woodford-ian) as most Pleistocene geologists since 1935 have presumed. Rather, this moraine must be older, possibly of Early Wisconsinan age, as originally assigned by Fuller (1914).

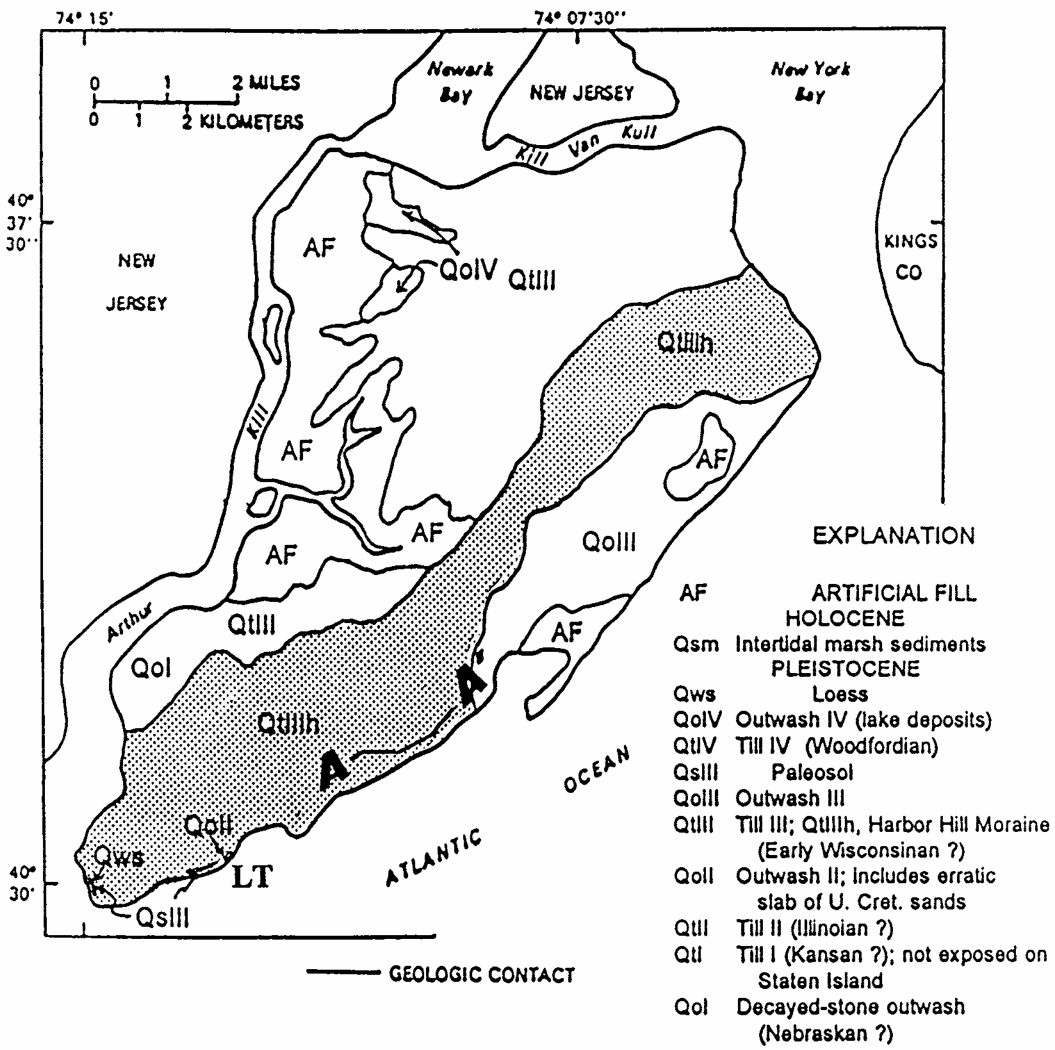

Figure 1 - Map of surficial deposits on Staten Island made by JES using the outline of Soren's (1988) map and most of the contacts from Cadwell's (1989) map, but with additions to show units in our classification. Stippled area, Harbor Hill Moraine; LT, navigation-light tower on shore of Princes Bay; A-A' locates profile-section of Figure 3.

GENERAL GEOLOGIC SETTING

Two major stratigraphic units composed of sediments, (1) the Upper Cretaceous coastal-plain strata and (2) the glacial deposits, are present in southern Staten Island. Both overlap two older geologic features in the bedrock, the Staten Island Serpentinite and the edge of the preserved wedge of Newark Supergroup strata with its included Watchung extrusives and Palisades intrusive sheet (not shown on Figure 2). The coastal-plain strata underlie perhaps 50% of Staten Island, but for the most part, have been buried by the glacial deposits. Exposures of the Cretaceous strata are not numerous and are confined to the SW part of the Island.

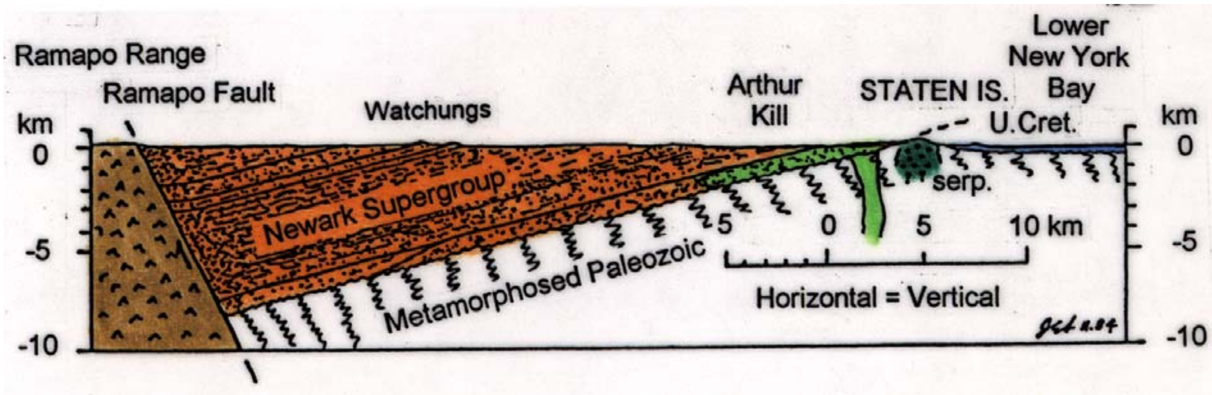

Figure 2 - Profile section from Staten Island to the Ramapo fault showing tilted- and eroded remnants of Newark basin-filling strata. Serp., Staten Is. serpentinite; subsurface relationships not known. (J. E. Sanders.)

Staten Island's general geologic relationships are displayed on the New York City Folio of the United States Geological Survey (Merrill and others, 1902) and on the map, based on the Folio, in the geologic report on the ground water (Perlmutter, and Arnow, 1953). Other colored geologic maps include the New York State geologic map (Lower Hudson sheet, Fisher, Isachsen, and Rickard, editors and compilers, 1970) and the Newark 1ø by 2ø quadrangle (Lyttle and Epstein, 1987). Maps of the surficial deposits on Staten Island are included in the New York City Folio, in the ground-water report by Perlmutter and Arnow and in another such report by Soren (1988), and on the surficial geologic map of New York (Cadwell, 1989). Various guidebooks also include geologic maps of Staten Island (for example, Benimoff, 1994; Merguerian and Sanders, 1989, 1991, 1994).

DESCRIPTION OF CLIFF SECTION BY LIGHT TOWER, PRINCES BAY, STATEN ISLAND

The Pleistocene sediments beneath the Cretaceous by the light tower along the shore of Princes Bay became exposed, for the first time that we know of, after a severe coastal storm in the fall of 1980. The storm waves removed all the sandy talus and undercut the cliff, thus exposing reddish-brown till and coarse brownish outwash sands beneath the typical yellowish, well stratified Cretaceous. Previously, these reddish-brown Pleistocene sediments had been totally obscured by the slope-wash sediments that had accumulated at the base of the cliff. For many years, Sanders visited this site with classes from Columbia University. Merguerian, shovel in hand, was on one of these early 1980s digs. Each time we removed enough of the post-storm slope wash to demonstrate the existence of the reddish-brown Pleistocene sediments beneath the Cretaceous. This evidence indicated that the Cretaceous strata were not in situ and implied that glacio-tectonic action had taken place (Merguerian and Sanders, 1991; 1994).

In 1984, as part of the planning for project WP-136, the Oakwood Beach Water-Pollution-Control Project, the Engineering Services branch of the Subsurface Exploration Section of the Department of General Services, Division of Public Structures, Bureau of

Building Design of the City of New York, contracted for the drilling of numerous engineering-test borings along the route of the West Branch Intercepting Sewer beneath Hylan Boulevard (Figure 3). The geologic analysis of these borings prepared by Woodward-Clyde Consultants, Inc. showed a few examples in which Cretaceous-type sediments are both overlain- and underlain by Pleistocene sediments. The borings showed that the top of the in-situ Cretaceous along the shores of Princes Bay lies at -50 to -60 feet below the zero datum of the engineering studies, which is the Borough of Staten Island Sewer datum, +3.19 feet above MSL at Sandy Hook, NJ. (By contrast, the zero datum on the U. S. Geological topographic map of this area is mean sea level.)

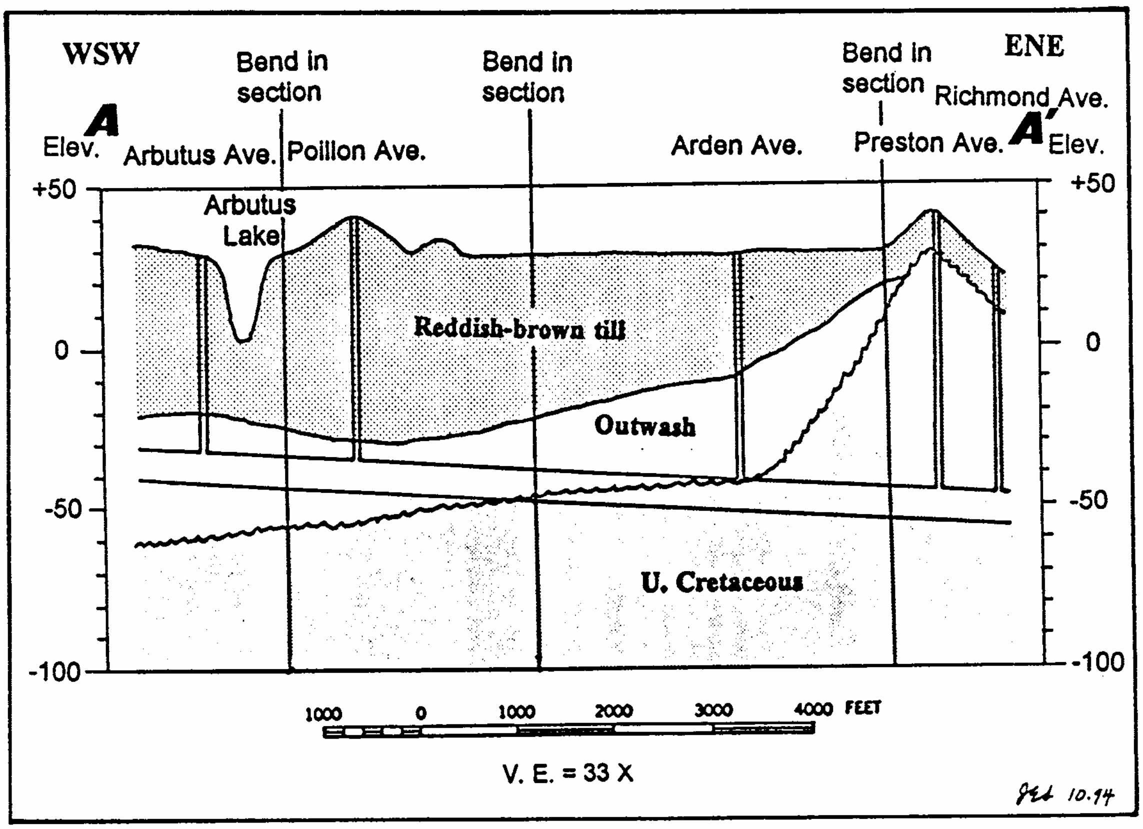

Figure 3 - Generalized profile-section along the Hylan Boulevard sewer line from Manhole No. 2 (Richmond Avenue) to Manhole No. 16 (Colon Street). Line A-A' on Figure 1 locates section. (Drawn by JES from data in Mueser-Rutledge Consulting Engineers Report to Moretrench American Corporation dated 05 January 1990.)

During August 1994, in preparation for a field trip to Staten Island by participants in the 1994 annual meeting of the Geological Association of New Jersey (GANJ), we visited this site along with Dr. Alan I. Benimoff. We spent only a short time here and dug only enough to display the red-brown sand. Our small dig did not expose any till. In our guidebook article, we emphasized the outwash and proposed that the Cretaceous slab had been displaced not by ice-thrust deformation but rather by ice rafting (Sanders and Merguerian, 1994, p. 293-294).

On 15 October 1994, the day of the GANJ trip, numerous geologists examined the cliff section in partial denial and disbelief. Undaunted, we dug enough of a face at the SW end of the exposure to demonstrate that coarse brownish Pleistocene sand underlies typical yellowish- and whitish Cretaceous sands and clays. We did not expose any reddish-brown till. Accordingly, most of the discussion centered on the hypothesis that we had proposed, namely that the displaced slab of Cretaceous, which we contended lacked any signs of deformation, had not been involved in ice-thrust tectonics. Instead, we preferred the notion that it had been ice rafted by glacial meltwater streams.

On the following day, Steven C. Okulewicz accompanied our New York Academy of Sciences On-the-Rocks trip to this same locality. As Sanders finished emphasizing that the lack of deformation in the Cretaceous supported an ice-rafting mechanism (as opposed to ice-thrust deformation), Okulewicz said: "Is that a recumbent fold in the Cretaceous? If so it shows it has been deformed!" (Figure 4).

Figure 4 - Close view of recumbent fold in ice-thrust slab of Upper Cretaceous, by light tower, Princes Bay Staten Island. Width of view is about 3 m. (Charles Merguerian.)

On Election Day, November 08, 1994, JES and CM revisited the site. Armed with shovels and an assistant (Christopher Merguerian), we dug our way to not only verify the fold but found ample evidence for at least seven discrete thrust surfaces within and around the Cretaceous slab (Figure 5).

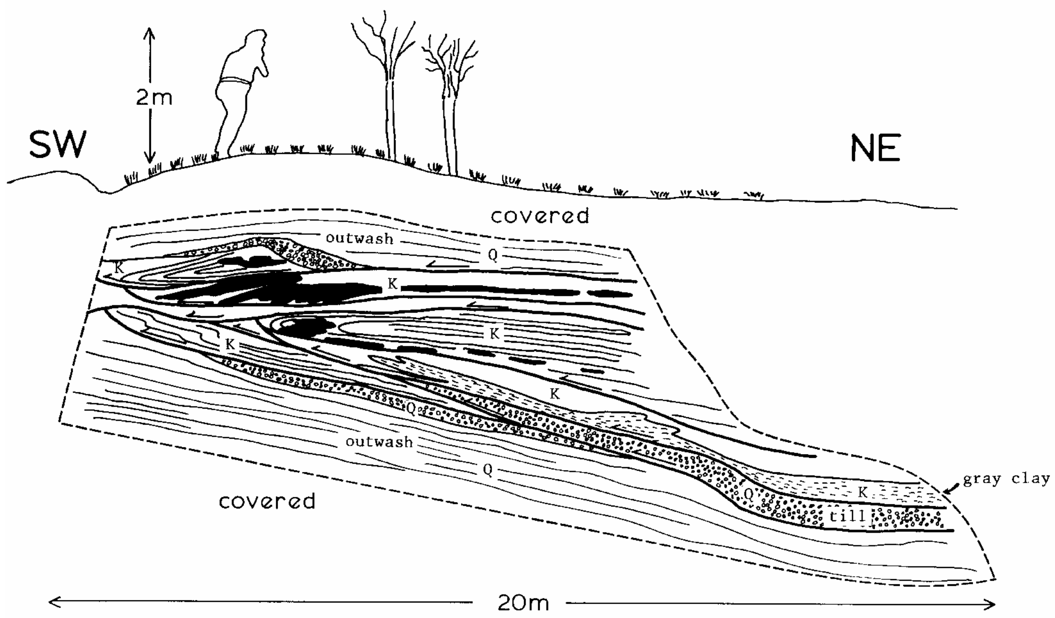

Figure 5 - Examples of ice-thrust tectonics exposed in eroding cliff by light tower on shore of Princes Bay, Staten Island. The cliff section includes numerous low-angle "thrusts" and recumbent folds. The Upper Cretaceous here has been thrust against itself and also over the red-brown Pleistocene sediments which have also been thrust against themselves. K = Cretaceous, Q = Pleistocene. Black = Cretaceous ironstones. Drafted by CM from field sketches and photographs as datum, no V.E.

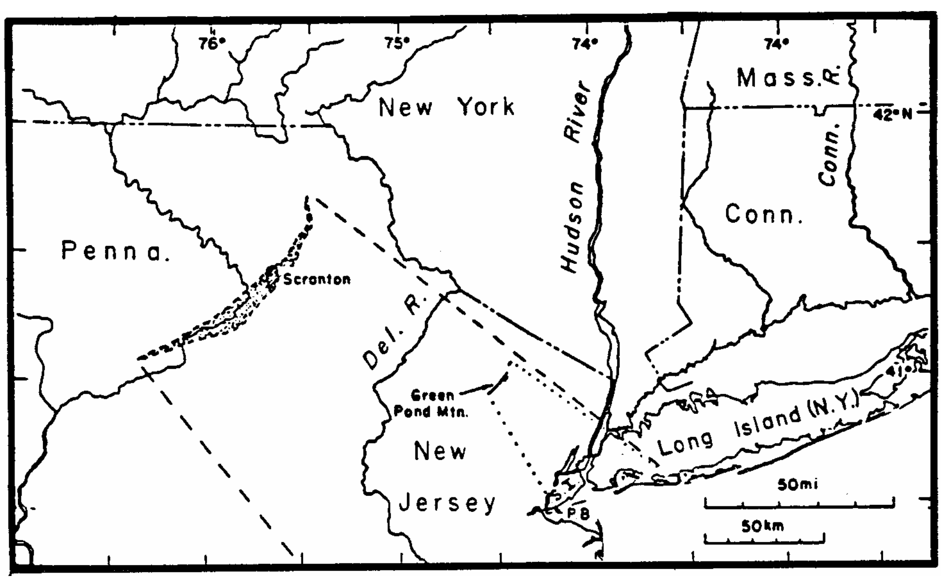

Figure 6 - Regional map showing parent areas of two distinctive indicator stones found in till forming Harbor Hill Moraine in southern Staten Island, New York City, NY: (1) anthracite from northeastern Pennsylvania, and (2) Green Pond Conglomerate from northwestern New Jersey. Stippled area, outcrops of anthracite coal; S. I. = Staten Island; P. B. = Princes Bay. (J. E. Sanders in G. M. Friedman and J. E. Sanders, 1978, fig. 2-1, p. 27.)

The eroding coastal bluff in the Harbor Hill Moraine at Princes Bay indeed exposes a slab of Upper Cretaceous sediments (consisting of interbedded white charcoal-bearing clay layers, cross-bedded sands, and hematite-cemented sandstone/conglomerate) that is enclosed within typical reddish-brown Quaternary sediments (tills and outwashes). The Cretaceous is here overlain by channelized Pleistocene pebbly outwash. Above this outwash is another reddish-brown till. Nearby to the SW, a buff-colored paleosol and a layer of loess overlie the upper till. The Cretaceous exposed here, formerly thought by most geologists to be nondisturbed and in situ, clearly is neither. As mentioned, it displays a recumbent fold (as outlined by cm-scale clay interbeds) with a sheared out lower limb. This fold plunges roughly 17° into S60°W; its axial surface is oriented N4°E, 20°NW. Within- and below the Cretaceous sequence are at least seven low-angle imbricate ice-thrust surfaces. (See Figure 5.) The hematite-cemented ironstone layer has been brecciated in situ and possibly has been duplicated along a thrust.

The orientation of the recumbent fold and ice-thrust surfaces constitute additional evidence that the ice which deposited the segment of the Harbor Hill Moraine exposed on Staten Island flowed from NNW to SSE. Other evidence that the glacier responsible for the Harbor Hill Moraine flowed from NNW to SSE includes indicator stones from localities lying NW of Staten Island. Examples are: anthracite coal from NE Pennsylvania, Silurian Green Pond Conglomerate from the Appalachians in NW New Jersey (Figure 6), Proterozoic gneiss boulders, and rocks from the Newark basin-filling strata (reddish-brown conglomerates and -sandstones and Palisades dolerite). These indicator stones from such distant localities as the anthracite district in NE Pennsylvania prove that the SSE-directed ice flow was not a local change-of-speed phenomenon at the margin of a fast-flowing ice tongue (as inferred by Salisbury and co-workers and published repeatedly during the interval from 1890 to 1933 in the New York City and other folios of the U. S. Geological Survey and in the guidebook to the geology of the New York City region published by the 16th International Geological Congress; Figure 7).

Rather, according to our analysis of the Pleistocene deposits in the New York City region (Sanders and Merguerian, 1994), the most-recent glacier flowed from NNE to SSW, a direction that is down the Hudson Valley, not across this valley.

Our proposed NNW to SSE flow direction for the till which surrounds the displaced slab of Cretaceous supports a pre-Woodfordian age, as previously found in Queens County by J. B. Woodworth (1901). (See companion paper in this volume on the age of Long Island's terminal moraines.)

CONCLUSIONS

The Cretaceous strata exposed in the coastal cliff that is eroding the Harbor Hill Moraine along the shores of Princes Bay, Staten Island, near the light tower, is both overlain- and underlain by reddish-brown Pleistocene sediments, including tills and outwashes. That the Cretaceous has been deformed by ice-thrust tectonics is demonstrated by the presence of low-angle thrust surfaces and a recumbent shear fold within the Cretaceous strata. The orientation of this recumbent fold indicates that the deforming ice flowed from NNW to SSE. Provenance data also indicate that this flow direction was rectilinear and regional and was not confined to the SE margin of a fast-flowing ice stream centered in the Hackensack Valley lowland.

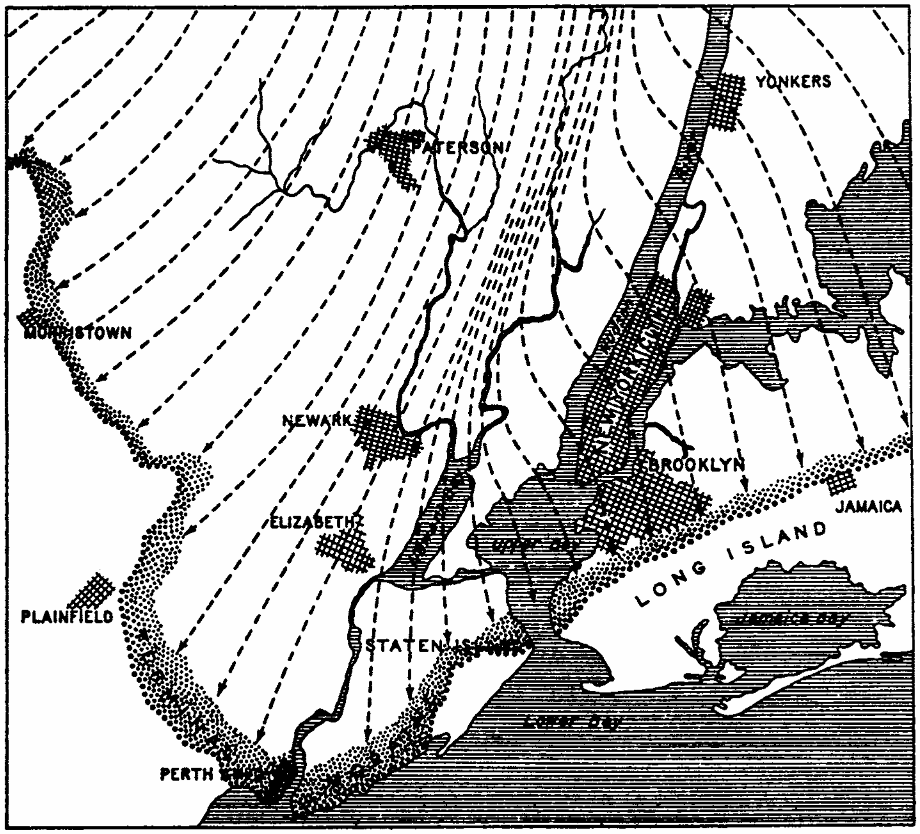

Figure 7 - Map of northeastern New Jersey and southeastern New York showing inferred flow lines in the latest Pleistocene glacier. Further explanation in text. (Kummel, 1933, fig. 13, p. 66; original by R. D. Salisbury.)

ACKNOWLEDGMENTS

We thank Alan I. Benimoff for providing a copy of a Mueser-Rutledge report and for allowing us the opportunity to present our synthesis in oral presentations and as a field trip at the GANJ meeting in October 1994. We are indebted to Barnard- and Columbia students for much digging and to Chris Merguerian for a little digging and to James P. Gould (Mueser-Rutledge Consult-ants) for sharing the details of the Hylan Boulevard sewer project for participants of our October 1994 On-the-Rocks trip to Staten Island. Tanya Eshaghoff assisted in printing the photograph of Figure 4.

JES thanks the late Professor Emeritus of Biology of Barnard College, Donald Richey, for his suggestion that the small-pebble rock from the Lower Silurian Green Pond Formation looks like braunschweiger sausage; and Eileen Schnock, Moretrench, for sharing the geologic sections along the Hylan Boulevard sewer line.

REFERENCES CITED

Benimoff, Alan, ed., 1994, The Geology of Staten Island, New York: Geological Association of New Jersey Annual Meeting, 11th, Somerset, NJ, 14-15 October 1994, Field Guide and Proceedings, 296 p.

Cadwell, D. H., 1989, Surficial geology map of New York, Lower Hudson sheet: New York State Museum Map and Chart Series 40, scale 1:250,000.

Chamberlin, T. C., 1883, Preliminary paper on the terminal moraine of the second glacial epoch, p. 291-402 in United States Geological Survey Annual Report, 3rd (1881-1882), 564 p.

Fisher, D. W., Isachsen, I. W., and Rickard, L. V., editors and compilers, 1970, Geological map of New York: New York State Museum and Science Service Map and Chart Series Number 15, scale 1/250,000.

Fleming, W. L. S., 1935, Glacial geology of central Long Island: American Journal of Science, 5th series, v. 30, p. 216-238.

Flint, R. F., 1961, Two tills in southern Connecticut: Geological Society of America Bulletin, v. 72, no. 11, p. 1687-1691.

Flint, R. F., and Gebert, J. A., 1974, End moraines on and off the Connecticut shore (abstract): Geological Society of America Abstracts with Programs, v. 6, no. 7, p. 738-739.

Flint, R. F., and Gebert, J. A., 1976, Latest Laurentide ice sheet: new evidence from southern New England: Geological Society of America Bulletin, v. 87, p. 182-188.

Fuller, M. L., 1914, The geology of Long Island, New York: U. S. Geological Survey Professional Paper 82, 223 p.

Fuller, M. L., 1937, Comment on "Correlation of Late Pleistocene marine (sic) and glacial deposits of New Jersey and New York" by Paul MacClintock and H. G. Richards: Geological Society of America Bulletin, v. 47, p. 1982-1992.

Gale, L. D., 1843, Diary of a geological survey of the Island of New York, p. 581-604 in Mather, W. W., The geology of New York, Part I. Comprising (sic) the geology of the First Geological District: Albany, NY, Carroll & Cook, Printers to the Assembly, 653 p., 46 pl.

Kummel, H. B., 1933, Glacial history of the Passaic Valley and related geologic features, p. 64-77 in Berkey, C. P., ed., International Geological Congress, 16th, United States, Guidebook 9: New York Excursions, New York and Vicinity, 151 p.

Lyttle, P. T., and Epstein, J. B., 1987, Geologic map of the Newark 1ø by 2ø quadrangle, New Jersey, Pennsylvania, and New York: United States Geological Survey Miscellaneous Investigations Series Maps, Map I-1715 (2 sheets; scale 1:250,000).

MacClintock, Paul; and Richards, H. G., 1936, Correlation of the late (sic) Pleistocene marine (sic) and glacial deposits of New Jersey and New York: Geological Society of America Bulletin, v. 47, no. 3, p. 289-337.

Mather, W. B., 1843, The geology of New York. Part I. Comprising (sic) the geology of the First Geological District: Albany, New York, Carroll & Cook, Printers to the Assembly, 653 p., 46 pl. (Includes report of Dr. L. D. Gale on New York Island based on survey of 1828 and 1829.)

Merguerian, Charles; and Sanders, J. E., 1989, Trip 04, Geology of Staten Island and vicinity, 15 April 1989: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 49 p.

Merguerian, Charles; and Sanders, J. E., 1990, Trip 15, Glacial geology of Long Island, 17-18 November 1990: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 96 p.

Merguerian, Charles; and Sanders, J. E., 1991, Trip 19, Geology of Staten Island and vicinity, 29 September 1991 (revision of 1989 Trip 04, 15 April 1989): New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 78 p.

Merguerian, Charles; and Sanders, J. E., 1992, Trip 25, Geology of Croton Point and Peekskill Hollow, 21 November 1992, (revision of Trip 10, May 1990): New York Academy of Sciences Section of Geological Sciences 1992 Trips on the Rocks Guidebook, 107 p.

Merguerian, Charles; and Sanders, J. E., 1994, Trip 33, Staten Island and vicinity, 16 October 1994: New York Academy of Sciences 1994 Trips on the Rocks Guidebook, 151 p.

Merguerian, Charles; and Sanders, J. E., 1995, Evidence for pre-Woodfordian age of Long Island's terminal moraines (extended abstract): this volume

Merrill, F. J. H.; Darton, N. H.; Hollick, Arthur; Salisbury, R. D.; Dodge, R. E.; Willis, Bailey; and Pressey, H. A., 1902, Description of the New York City district: United States Geological Survey Geologic Atlas of the United States, New York City Folio, No. 83, 19 p. (Includes colored geologic map on a scale of l:62,500).

Mueser Rutledge Consulting Engineers, 1990, Ground conditions encountered Oakwood Beach Water Pollution Control (sic) Project Contract 6B-3, East Heading, Staten Island, New York: Report submitted to New York City Department of Environmental Protection for Moretrench American Corporation, not paginated.

Muller, E. H., 1964, Quaternary geology of New York, p. 99-112 in Wright, H. E., and Frey, D. G., eds., The Quaternary of the United States: Princeton, NJ, Princeton University Press, 922 p.

Perlmutter, N .M.; and Arnow, Theodore, 1953, Ground water in Bronx, New York, and Richmond counties with summary data on Kings and Queens counties, New York City, New York: New York State Water Power and Control Commission Bulletin GW-32, 86 p.

Sanders, J. E., 1974, Geomorphology of the Hudson Estuary, p. 5-38 in Roels, Oswald, ed., Hudson River Colloquium: New York Academy of Sciences Annals, v. 250, 185 p.

Sanders, J. E.; and Merguerian, Charles, 1994, Glacial geology of the New York City region, p. 93-200 in Benimoff, Alan, ed., The Geology of Staten Island, New York: Geological Association of New Jersey Annual Meeting, 11th, Somerset, NJ, 14-15 October 1994, Field Guide and Proceedings, 296 p.

Sanders, J. E.; Merguerian, Charles; and Okulewicz, S. C., 1995, Glacio-tectonic evidence for SE-directed glacial flow in displaced slab of Upper Cretaceous sediments exposed in the Harbor Hill Moraine, Princes Bay, Staten Island, New York (abstract): Geological Society of America Abstracts with Programs, v. 26, no. 1, p. 79-80.

Schafer, J. P., and Hartshorn, J. H., 1965, The Quaternary of New England, p. 113-128 in Wright, H. E., Jr.; and Frey, D. C., eds., The Quaternary of the United States: Princeton, NJ, Princeton University Press, 922 p.

Schuberth, C. J., 1968, The geology of New York City and environs: Garden City, NY, Natural History Press, 304 p.

Soren, Julian, 1988, Geologic (sic) and geohydrologic reconnaissance of Staten Island, New York: United States Geological Survey Water Resources Investigations Report 87-4048, 22 p.

Upham, Warren, 1879, Terminal moraines of the North American ice sheet: American Journal of Science, 3rd series, v. 18, p. 81-92, 197-209.

Woodworth, J. B., 1901, Pleistocene geology of portions of Nassau County and Borough of Queens (N. Y.): New York State Museum Bulletin 48, p. 618-670 (includes geologic map).

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