LATE WISCONSIN-HOLOCENE HISTORY OF THE LOWER HUDSON REGION: NEW EVIDENCE FROM THE HACKENSACK AND HUDSON RIVER VALLEYS

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INTRODUCTION

The study area (Fig. 1) is the central and upper Hackensack River valley of northeastern New Jersey and adjacent New York State with reconaissance study of the surrounding area in Bergen County, N.J. and Rockland County, N.Y. In the text, town names will be in New Jersey unless indicated otherwise. Geologically, the area is the northern portion of the Trias-Jurassic Newark basin where a gently dipping (14°W) homoclinal sequence of Brunswick Formation red sandstones and shales form the deeply scarred bedrock surface. The Palisade Sill and basalt lava flows of the Watchungs, interbedded with the Newark series sediments, form prominent topographic ridges in the region. The western slope of the Palisade Sill, whose well-studied eastern escarpment forms the Hudson Palisades, is at the eastern margin of the Hackensack Valley. Resistant sandstones of the Newark group form the ridges and cliffs along its western border as well as the divide between it and the parallel drainage system of the Saddle River. The Ramapo fault system slices northeast at the northern terminus of the basin separating it from the rugged Precambrian crystalline mass of the Ramapo Mountain portion of the Appalachian chain. The Hudson River and glaciation have carved an impressive gorge through the Hudson Highlands. The Ramapo River lies in a similar but less spectacular gorge ten miles to the west at Suffern, N.Y. Continental glaciations overdeepened both gorges before overwhelming the Ramapos to push south to their maxima. The deep preglacial Hackensack Valley has been partially overdeepened by glacial ice, then mostly filled by proglacial lake sediments (Lovegreen, 1974). The present terrain is gently rolling, with drumlinoidal hills generally aligned north to south paralleling the strike of the bedrock. Essentially glaciation has subdued the preexisting topography, even occasionally reversing it.

Previous work: At the turn of the century Salisbury, et al. (1902) reported the glacial geology in the New Jersey portion of the study area. Geomorphic forms were described with great detail and accuracy with lesser emphasis on stratigraphy. There is a notable lack of description to distinguish between the two tills and their associated outwashes. The latter is not a reflection on their abilities but rather on the "state of the art" circa 1900. Reeds (1926, 1927) studied and counted the 2,550 glacial Lake Hackensack varves at Little Ferry. Heusser (1963) examined the recent vegetational history of the tidal marsh at Secaucus from about 2,000 YBP (radiocarbon years before present). Lovegreen (1974) compiled a mass of subsurface data indicating that prior to glaciation, the Hudson River, after passing through the Highlands Gap in the Ramapo Mountains, had flowed westward through the Sparkill Gap in the Palisades. Then turning south it excavated channels in the Newark series shales approximating the present course of the Hackensack River to the ocean.

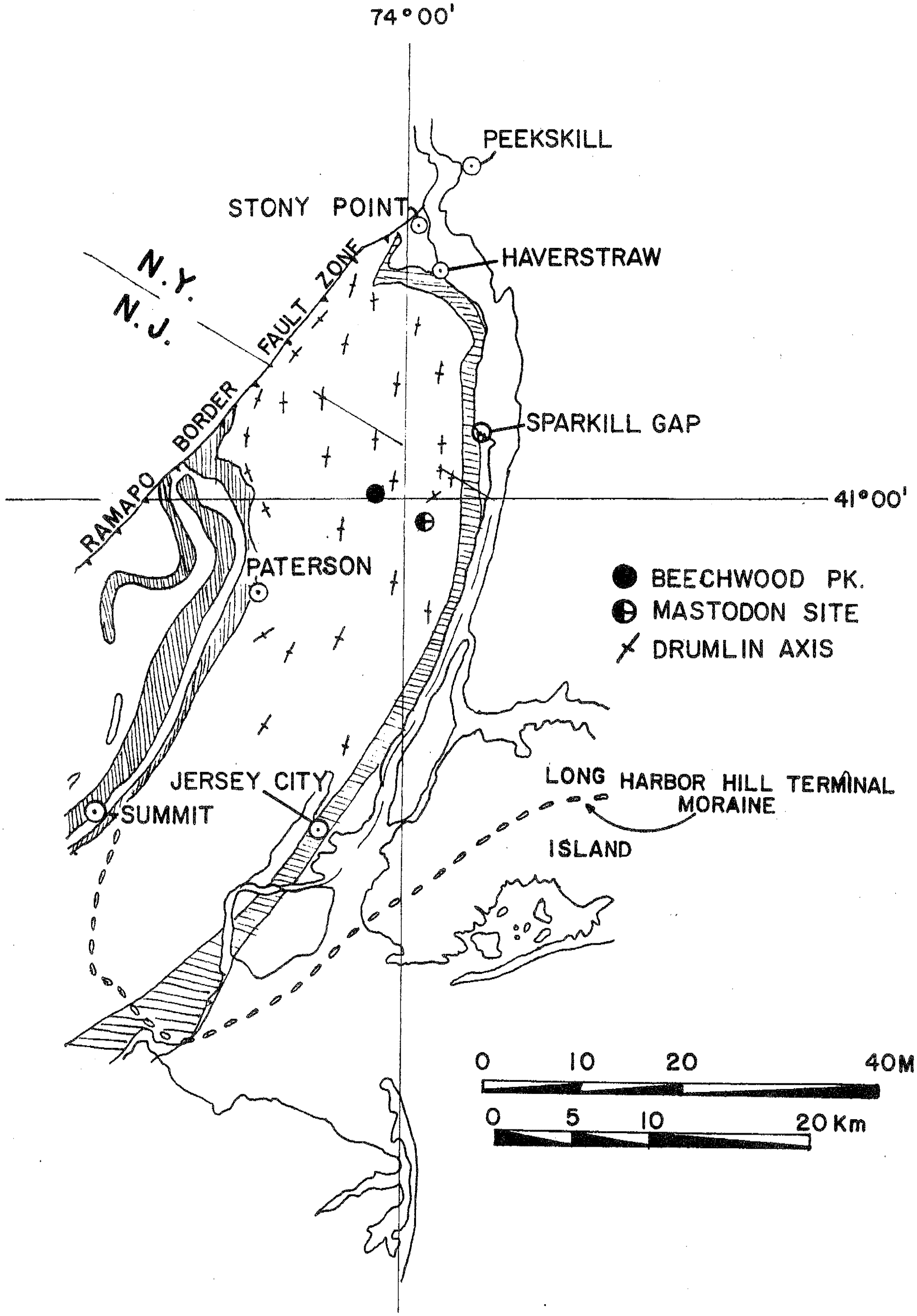

Fig. 1. Study area and adjacent region
Key: Watchung lava flows are lined vertically while the Palisade Sill is lined horizontally.

Glacial geology of the Hackensack Valley: The present study.

Within the study area, there is no surficial evidence of any glaciation earlier than late Wisconsin age. However, evidence of two earlier glaciations is present from the subsurface. Brown drift is known from deep borings along the New York State Thruway near Mt. Ivy, New York. In River Edge, excavation of red till revealed deeply weathered rock fragments whereas the red till examined in Norwood and elsewhere contained much more durable "fresh" clasts. This appears to agree with the till and drift sequence found on Staten Island by Sanders and Rampino (1978). These tills (the brown till and the "rotten clast" red till) are probably of early Wisconsin age or older.

The late Wisconsinian (Woodfordian) glacial maximum of the Hudson Valley ice lobe overrode the earlier drifts and built the Harbor Hill moraine across western Long Island, Staten Island, New York and at Perth Amboy, New Jersey across to Summit (Fig. 1) sometime after 22,800 B.P. (Sirkin & Stuckenrath, 1975). The thin Roslyn till overlies the Harbor Hill Moraine in western L.I. This undated till marks the most recent readvance to the terminal position by the Hudson lobe of the Woodfordian ice sheet (Connally & Sirkin, 1973).

Proglacial lakes Hudson, Flushing and Hackensack, conterminous (Reeds, 1926) and dammed on the south by the Woodfordian terminal moraine, expanded as the ice beat an oscillating retreat northward. Lake Passaic, which formed between the First Watchung Ridge and the Ramapo Mountains to the west, lay at a higher elevation and is presumed to have been essentially coeval with the other three.

The preceeding is relatively well known and has been presumed to have been the entire late-glacial history. It was thought to have been followed only by draining of the lakes and the stream flow that presumably deposited a three to six meter thick sheet of sand across the lake bed. Both events were believed to have been the result of postglacial differential isostatic rebound.

The present study indicates the occurence of a post-Lake Hackensack glacial readvance into the lower Hudson River Valley region following a significant interstade, and provides details of the post-glacial events. The supporting evidence includes stratigraphic, sedimentologic, geomorphic, seismic and palynologic data as well as a series of supporting C-14 dates.

SPARKILL GAP: SEISMIC STUDY

Sparkill (Spar Kill) Gap has been most important to the late and postglacial history of the Hackensack River. It breaches the otherwise continuous wall of the Palisades that extends from Jersey City, New Jersey to Haverstraw, New York. Because of the northward glacially induced isostatic crustal tilt, it served as the drainage for the Hackensack River on several occasions. For this reason, this detailed study of the Gap is presented.

Seismic Studies - Sparkill Gap

Sparkill Gap is underlain by the Triassic Palisades Formation (Perlmutter, 1959). These sandstones and shales are cut by several northeast-southwest trending normal faults (Thompson, 1959). Sparkill Gap is on the north end of a +180 ft. to +200 ft. A.S.L. (above sea level) terrace that was eroded by the southwest-flowing, preglacial Hudson River (Fig. 2a, and Woodworth, 1905, Johnson, 1931). The preglacial Hudson was consequent on a graben that broke the crest line of the Palisades ridge (Thompson, 1959). The Tappan and Sparkill Moraines lie west of the Gap; these moraines were deposited by ice lying in the valley between Orangeburg and Mt. Nebo (Fig 2a, and Woodsworth, 1905). Stratified drift (outwash) lies between the two moraines (Woodworth, 1905).

The Gap is filled by over 60 ft. (18.3 m) of glacial drift, based on test borings and water wells (Perlmutter, 1959). These wells, with supplemental test borings, unpublished USGS water well data, and NYSGS seismic refraction data, has been used to generate Figs. 2b and 2c.

Geophysics: Seismic refraction was used to provide additional data points in the Sparkill Gap area. Seismic profiles were run along rights-of-way and in town parks. Each of the profiles was reversed, and was 170 to 250 ft. (52 to 76 m) long; the length depended on the distance available between power lines, road intersections, and fences. "Shot points" were 10 feet (3 m) apart in the first 60 ft. (18.3 m) of each profile, and were 20 feet (6.1 m) apart for the rest. The "shot points" were impacts of a 16 lb sledge hammer on a 1 ft.^{2} (.4 m^2) steel plate. The signal was recorded on a Huntec FS-3 single-channel seismograph. The resulting time-distance graph was interpreted using both the critical distance and time-intercept methods (Mooney, 1973, Zohdy and others, 1974).

Two areas were studied - The northernmost area was at the mouth of the Sparkill (seismic profile 73-13, Fig. 2c), and the southernmost was just southwest of U.S. Rt. 9W crossing of the Sparkill (profiles 73-10, -11, -12, Fig. 2c). Each seismic profile generally had three seismic layers (Fig.2c). The uppermost, or low-velocity layer

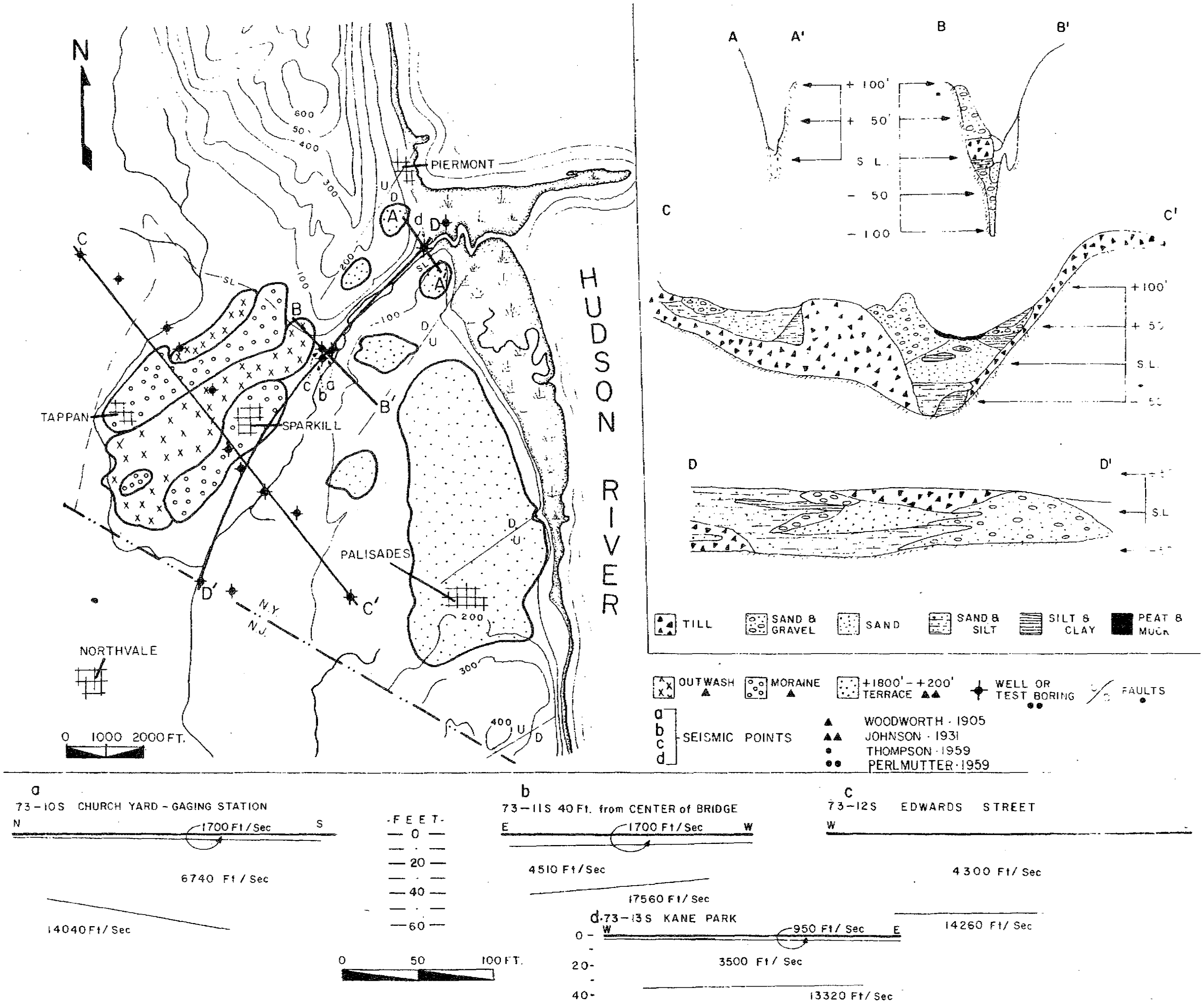

Fig. 2. a. Detailed map of Sparkill Gap and vicinity: contoursdrawn on bedrock surface.
b. Geologic cross-sections
c. Seismic profiles.

had seismic velocities of 950 ft./sec. to 1700 ft./sec. (290 m/sec. to 520 m/sec.) and was 0.9 to 6.9 ft. (0.27 to 2.1 m) thick. Test borings in the vicinity of the seismic profiles contained dry fill or silty sand in this depth range. Seismic layer # 2 had velocities from 3500 ft./sec. to 6740 ft./sec. (1070 m/sec. to 2050 m/sec.), and was 24 to 58 ft. (7.3 to 17.7 m) thick. Test borings indicate that this material is bouldery stratified drift (cross sections C-C', D-D', Fig. 2b). The bottom-most layer had seismic velocities from 13320 ft./sec. to 17560 ft./sec. (4060 m/sec. to 5350 m/sec.) and was bedrock, based on nearby wells.

Glacial Geology and Bedrock Topography (Fig. 2)

Sparkill Gap is a hanging valley, with a rock sill at an elevation of -25 ft. at Sparkill's confluence with the Hudson, the valley's gradient is down towards the southwest . A narrow V-shaped gorge is incised into a -25 ft. bedrock terrace (cross sections A-A', B-B', C-C'), the -25 ft. terrace widens towards the southwest. The floor of the inner gorge is at an elevation of -25 ft. at the mouth of the Sparkill, and deeper than -110 ft. at the US 9W crossing of the Sparkill (cross sections A-A', B-B', C-C').

The gorge is filled with a sequence of southwest-fining stratified drift (cross section D-D'). Till underlies the Sparkill and Tappan Moraines (cross section C-C'), and overlies part of the southwest-fining outwash sequence near Sparkill Village (cross sections B-B', D-D'). The high-velocity floodplain deposits fill the mouth of Sparkill Gap (cross sections A-A', D-D', seismic profile 73-13).

Interpretation:

The bedrock gradients suggest persistent southwestward drainage. The broad, − 180 to − 200 ft. terrace has been modified by proglacial drainage, but eroded by either preglacial or interglacial southwestward drainage, flowing into the Hackensack Valley from the Hudson Valley, over the col formed by the graben between Mt. Nebo and Alpine. The V-shaped gorge underlying Sparkill Gap is a fault that forms the north edge of the graben, the south edge is probably a fault in the Palisades area, based on the re-entrance of the + 150 ft. contour just south of Palisades. This terrace might have been formed during an interglacial period, particularly if the Hudson was dammed by a moraine south of Palisades. The Sparkill gorge was eroded along the northern fault by proglacial meltwater, its V-shape suggests that the erosion might have taken place during the late Wisconsinan. The divide or base level at -25 ft. in the mouth of the gorge controlled northward, reversed-drainage during the Woodfordian.

Distribution of the drifts:

Two surficial drifts exist within the study area, a red till and a yellow-brown till each with distinctive outwash and loess. Found throughout the central and lower Hackensack River region is a red (10 R 5/4) compact sandy to clayey stoney till. In Norwood, this till was found to be overlapped by the red varves of glacial Lake Hackensack and so correlates the lake with red till. The red color is so distinctive as to be easily identified in kames constructed of coarse outwash material. In the sandy and more distal portions of the stratified drift deposits, the red color is not nearly as prominent and it becomes more light brown in appearance. Its derived loess is red.

Yellow-brown (10 YR5/4 wet & 10YR7/4 dry), generally sandy, round cobble till covers the surface northward from a line extending across the Newark basin in New Jersey (Fig. 1) from Norwood (south of Piermont, New York) through Old Tappan, Hillsdale and Ridgewood to Oakland. This till is from 0.3 m to 2.6 m thick near its southern margin and is at least as much as 13 m thick in Montvale near the New York State line. The line of demarcation is not sharp and is more properly described as a zone several kilometers wide. Boring records indicate the red till and red varves lie beneath yellow-brown till in much of northeastern New Jersey and adjacent Rockland County, New York. However, outcrops demonstrating this relationship are rare. Salisbury (1902) also reports this relationship in the study area as well as to the west in the northern Passaic drainage basin. Averill has traced this yellow-brown drift through the Suffern-Haverstraw, New York axis and into the Highlands portion of the Hudson and Ramapo valleys.

The two tills show many of the same relationships and general characteristics of the upper and lower tills in New England (J. Hartshorn, 1976, pers. comm.) and present the same sort of "two till" dilemma (i.e., 1. two tills representing two glaciations; 2. two tills representing one glaciation [lodgement till overlain by ablation till]; or 3. two tills representing reorganization of ice flow direction of a single glaciation.) In the writer's (Averill) opinion, the two tills in the Hackensack valley represent two late Wisconsin stades separated by a significant interstade.

Stratigraphy

Recent excavation of a shallow northern segment of the Oradell Reservoir in Norwood has proven to be critical in determining the late- and post-glacial history of this region. The stratigraphy of the reservoir was visible in different parts of a 1.5 square kilometer area over a three year span. The entire section was never visible in

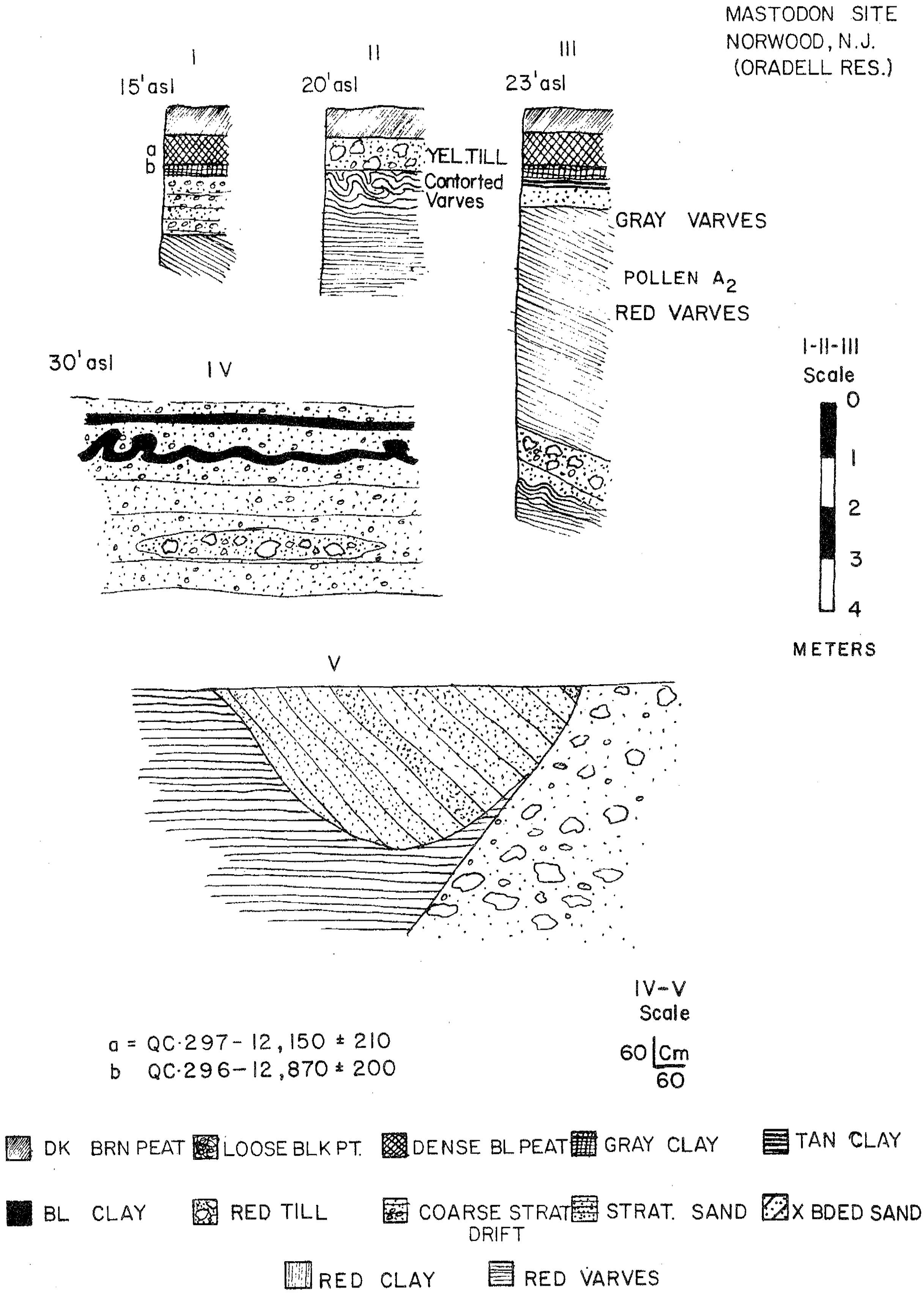

Fig. 3. Mastodon Site, Norwood, N.J. (Northern-most section Oradell Reservoir) Stratigraphic sections I-V

Fig. 4. Interstadial stream channel cut into red varves and red till. Channel is lined with red clay and filled with cross-bedded outwash sand. Location is 0.5 Km south of Mastodon Site, Norwood, N.J. (See Fig. 3V)

Fig. 5. Periglacial involutions
Black clay layer in outwash sand. Lower sand is fluvial outwash. Clay layer deposited in proglacial Lake Sparkill. Upper sand finer with small scale crossbedding deposited in the same lake prior to unblocking and drainage through Sparkill Gap. Location is 200 m east of fig. 4. (See Fig. 3IV; note large slab or red till enclosed in lower outwash.)

a single outcrop but sufficient outcrops were available to construct an accurate composite. It is as follows (Fig. 3): Red till overlain by a thick sequence of extremely compact red varves interrupted near the top of the sequence by 1.5 m layer of sand; 3 m of identical compact red varves continue the red varve sequence (most varves were about .5 cm thick). Red till, 1 m thick, overlies distorted varves and red sandy outwash in one exposure. Comformably overlying the red varves is 1.7 m of gray varves. Each gray varve is about .4 cm thick. Stream channels, one over 14 m deep, with a strike of N.40-60°E. are cut into the varves and/or red till (Fig. 4). The channels, where visible in cross-section, are lined on the bottom, or partially filled, with red clay. Sand, much of it coarse and exhibiting large scale cross-bedding, fills the channels and overlies the entire reservoir as well as the surrounding area. The overlying upper sand layers are interbedded with several organic black clay layers each about 8-10 cm thick. The lower of these is involuted (Fig. 5). Reeds (1926) reports virtually identical sand with clay layer stratigraphy over eroded inclined varves in Little Ferry. The uppermost sand (stratigraphically) at the Norwood portion of the Dwarskill valley floor is about 3 m lower in elevation than the black clay layers and exhibits reverse graded-bedding. It is a coarse sand grading upwards into coarse gravel with embedded cobbles and boulders (Fig. 6). One gigantic boulder, about 3 m in diameter and composed of very coarse Palisade diabase, has a lag concentrate of 30 to 40 cm boulders on its northeastern side. The boulder group tapered to a point toward the northeast (Fig. 6). Ten to fifteen cm of tan lacustrine clay overlies the coarse gravel and surrounds the embedded boulders. Gray clay succeeds this and rapidly grades into black organic rich clay 20 to 40 cm thick and then into .7 to 1.3 m of dense black peat. The bones of a mastodon, known as the Dwarskill mastodon, were found buried in the black organic clay (Fig. 7). Dark brown, "fluffy when dry", peat (about .5m) unconformably overlies the black peat (Fig. 4).

A single outcrop at the northernmost part of the reservoir reveals a different and highly significant part of the story. Stratigraphy from borings indicates a red till beneath 1.8 m of red varves. Excavation shows red varves overlain by about 20 cm of fine sand and succeeded by about 50 cm of yellow-brown sandy till containing many gneiss and quartzite cobbles and one slab of red sandstone. That it is till and not outwash is indicated by the clay-filled interstices. The fine red sand and upper 10 cm of varves are severely deformed as shown in the photographs (Figs. 8 & 9; also Fig. 3-II). Folds are overturned to the SSW parallel to the stream valley and opposite to the direction of the Sparkill Gap at Sparkill, N.Y. Black peat, about 40 cm thick and with many visible Spartina stems and roots, overlies the till. This thin till is found across the northern segment of the reservoir and the nearby Norwood kame grouping constructed of tightly packed red cobble outwash.

Beechwood Park in Hillsdale is about 9 km to the southeast, just north of the yellow-brown till margin. The park includes a kettle, situated in a sandy outwash head kame, immediately behind a head-of-outwash near the Hillsdale-Westwood border. Its stratigraphy is known only from numerous boreholes (Fig. 10). Drill-

Mastodon Site, Oradell Reservoir, Norwood, N. J.

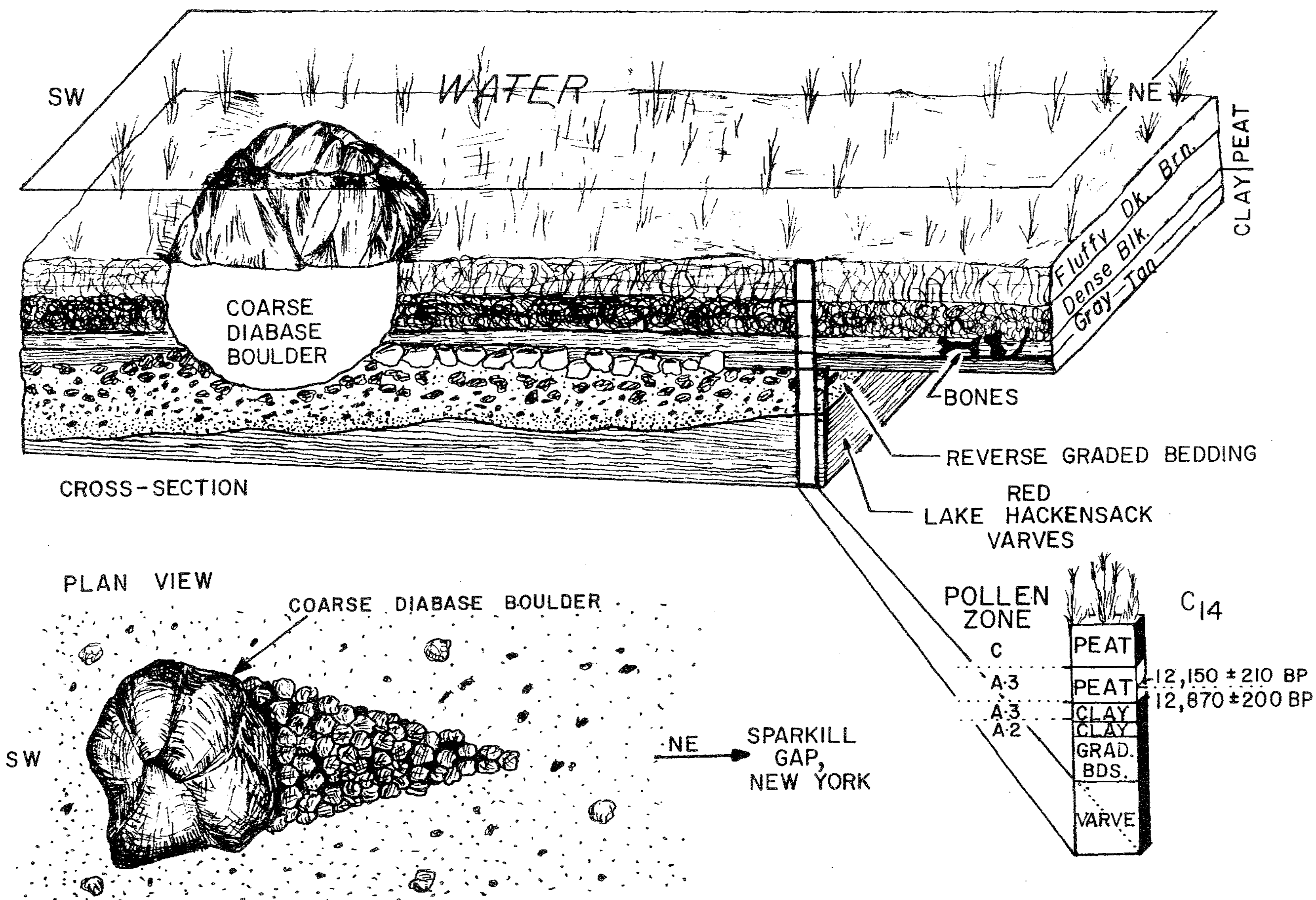

Fig. 6. Mastodon Site Reconstruction, Oradell Reservoir, Norwood, N.J.

The block diagram shows the area prior to excavation. The plan view shows the 3 m boulder after the peat and clay had been removed.

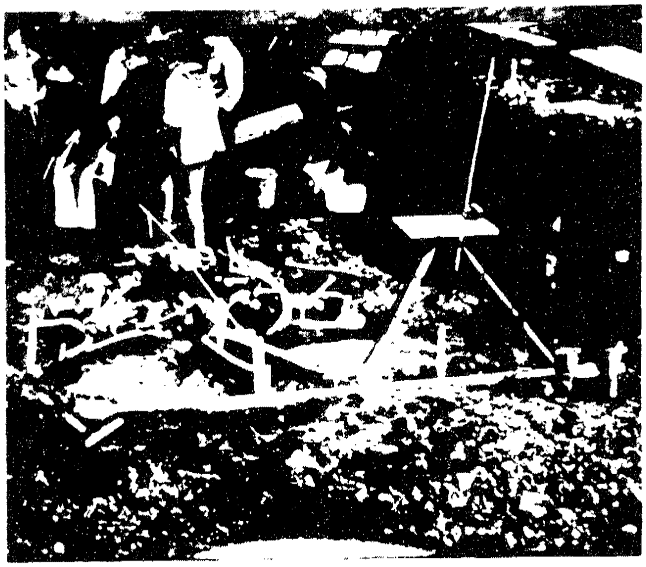

Fig. 7. Mastodon Site Excavation, Norwood, N.J.
Bones in pit, depth of pit 1.3 m. Reverse graded-bedded gravel in foreground; tan clay covers bottom of pit, bones (some already removed) had been encased in gray to black clay that graded up into the peat that formed the walls of the pit (See fig. 6)

Fig. 8. Yellow-Brown Tappan till over distorted Lake Hackensack varves.
Folds are overturned to the SSW (left). The Tappan till is above the black MnO2 line and the point of the trowel. Black recent peat at top contains roots of Spartina growing at the surface. Location is 50 m north of Mastodon Site

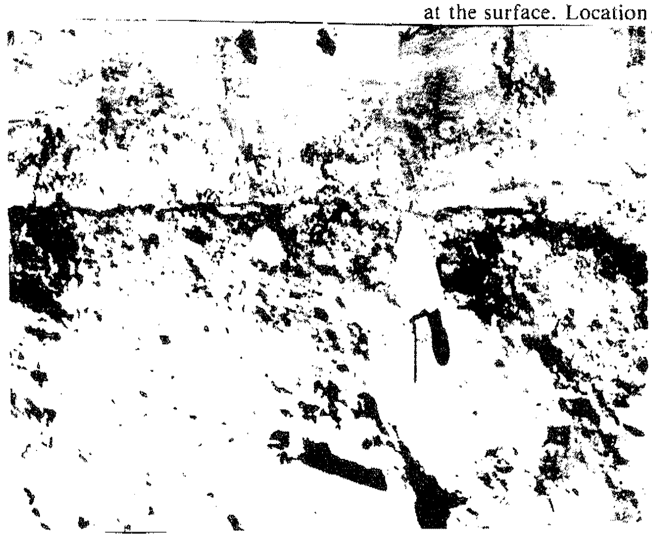

Fig. 9. Distorted red varves and fine red sand overlain by Tappan till. Close-up of Fig. 8. Note MnO2 stain at base of till. Trowel point at base of till.

ing shows that from the surface downward there is up to 3.75 m of peat and just over 2 m of lacustrine gray grading to tan clay in the kettle bog. It is underlain by at least 1.3 m of coarse clean sand of the outwash sheet. Beneath that is 1.9 m of massive lacustrine gray clay and gray clayey silt with two thin layers of peat. Beneath that lies more than 5 m of red Lake Hackensack varves which become progressively coarser with depth until they can only be described as sand and gravel rythmites. Triassic-Jurassic red shale is penetrated at a depth of 16.9 m.

The southern and central Hackensack River Valley, south of Emerson, is known as the "Meadowlands" and has been a tidal marsh for at least the past 2,000 radiocarbon years (Heusser, 1963). The marsh is underlain by a sheet of sand over the generally flat surface of the eroded and carbonate leached varves of glacial Lake Hackensack. The varves are inclined south with a slope of .426 m/Km (2.25 ft./mile) (Reeds, 1933). South of Rutherford the varves are dessicated up to a depth of 17 m (Lovegreen, 1974). Reeds (1927) and Salisbury (1902) report peat up to .7 m thick between the varves or red till and the overlying sand in River Edge, and on both sides of the valley at Carlstadt. The "sand sheet" is variously glacio-fluvial valley train, loess and fluvially reworked stratified drift. At Little Ferry the "sand sheet" is interrupted by a thin black clay layer (Reeds, 1926).

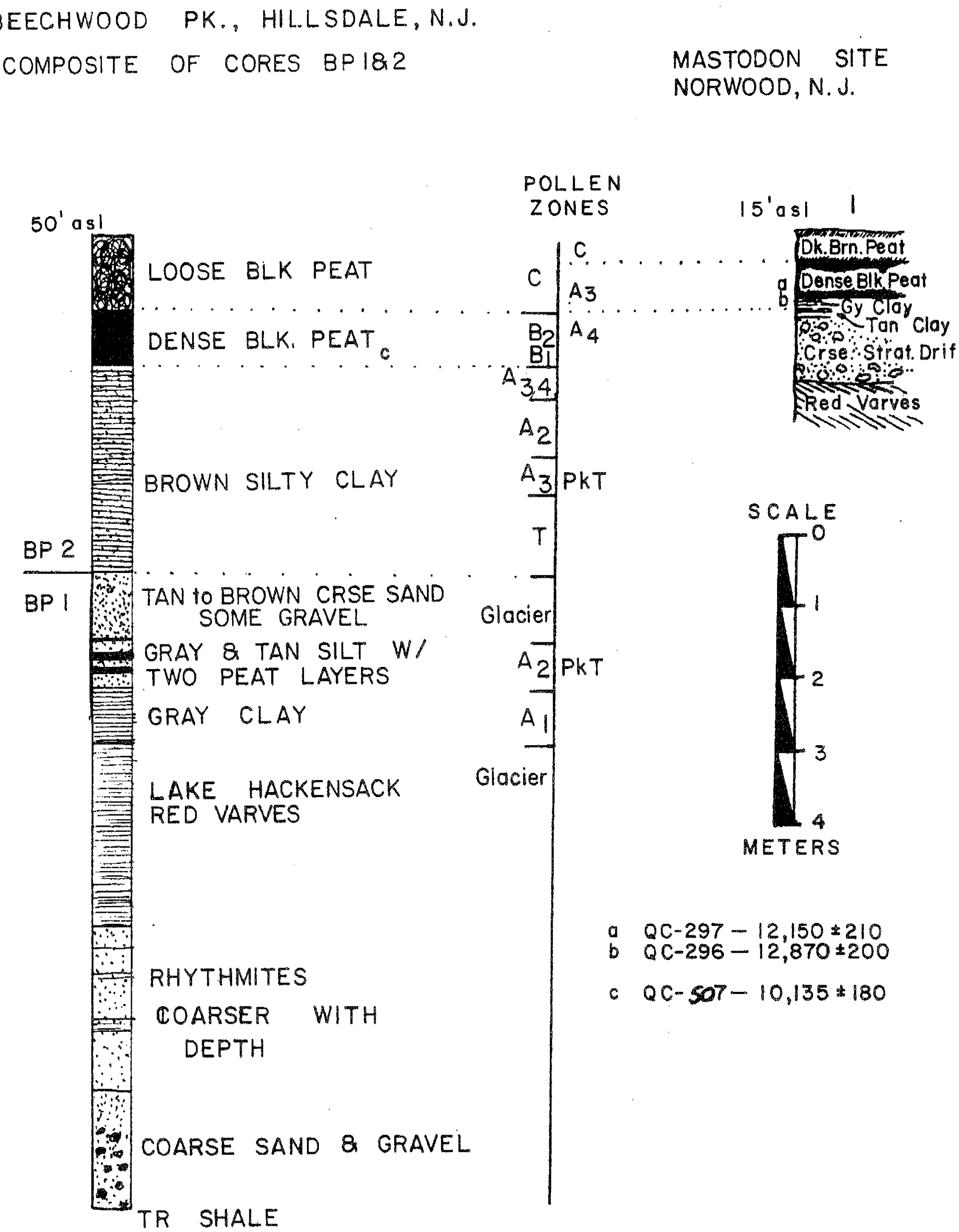

Fig. 10. Stratigraphy of Beechwood Park and the Mastodon Site compared. A summary of pollen zonation and C-14 dates are shown.

Geomorphology

North of Oradell the broad monotonously flat meadowlands give way to an irregular but gently rolling terrain which becomes much higher and hillier to the north. The western margin of the Hackensack Valley is flanked by steep hills and cliffs of Triassic sandstone. Eastern margins of the valley and its tributaries usually exhibit more gentle slopes.

More than 100 drumlins are to be found in this northern segment of the Newark basin (Fig. 2). With some significant exceptions, their long axes strike approximately north-south. In most of the region the drumlin axes are parallel to the regional strike of the bedrock and in the area south of the recurved arm of the Palisades (Hi-Tor) at Haverstraw many are rock-cored. North of Hi-Tor, the bedrock strike is significantly different (N50°E) and drumlin orientation shows no particular relationship to bedrock structure and is not believed to be bedrock-cored.

All the red till drumlins studied in Oradell, Rutherford and Paramus are rock-cored. They indicate southerly ice flow in the Hackensack Valley. Yellow-brown till drumlins are found north of the yellow-brown till border into the Hudson Highlands. These indicate ice flow from the Hudson River valley into the Haverstraw lowland and south into New Jersey as well as down the Hudson axis. In the Oakland and Franklin Lakes areas adjacent to the ridge of the First Watchung Mt. lava flow, drumlin orientation (NW-SE) and the Oakland moraine indicate topographic control of ice flow near the thinner terminal margin of the yellow-brown till ice. Yellow-brown till and stratified drift deposits indicate ice also entered the Newark basin through the Sparkill Gap, penetrating as far south as the Norwood kame grouping and the Dwarskill valley mastodon site (Fig. 1).

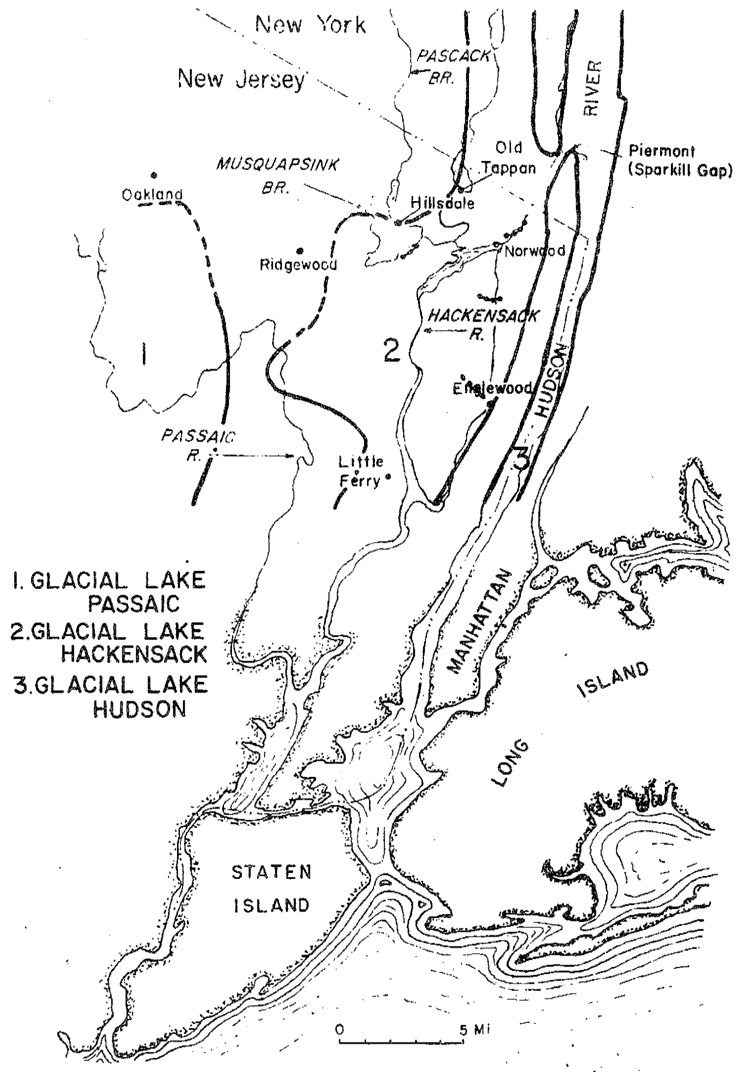

Fig. 11. Location Map of Proglacial Lakes Hackensack, Hudson and Passaic
Shorelines are approximate-lakes not shown to full extent. Dotted lines in Lake Hackensack are kame groups built into the lake.

Red drift ice-contact deposits, essentially kame deltas, were built into Lake Hackensack at numerous localities (Salisbury, 1902). Major deposits relevant to this study are shown on Fig. 11. The kame grouping at Englewood has produced the divide between Tenakill and Overpeck Creeks. The kames and outwash at Westwood were formed across the location of the present southernmost east flowing segment of the Musquapsink Brook (Fig. 11). The kame grouping at Norwood was built out into Lake Hackensack. Its sediments overspread the red varves eastward to the Palisade ridge and to the south. Associated red till and outwash in the subsurface indicate the arcuate kame grouping was built after the ice had readvanced into the lake. Use of Koteff's (1974) ice-contact sequence, slope projections and grain size analysis indicates that the outwash banked on the eastern side of the broad valley against the western slope of the Palisades is the distal portion of the east-spreading outwash fan. Varve deposition continued after the retreat of the ice front from the kame group. The southwest-northeast Dwarskill valley across this outwash fan was apparently initially cut many years later when the lake drained, at least in part, through Sparkill Gorge. At present the valley is occupied by two underfit streams which head near the New York State line where a low sandy divide separates their drainages. The Dwarskill is tributary to the Hackensack River drainage while Sparkill Creek flows northeast through the gap of its name to join the Hudson at the Piermont salt marsh.

Along the southern margin of the yellow-brown till is a series of ice-contact deposits (Fig. 12). They are chiefly kame groups as found in River Vale, Ridgewood and Old Tappan, a crevasse filling tributary to a massive

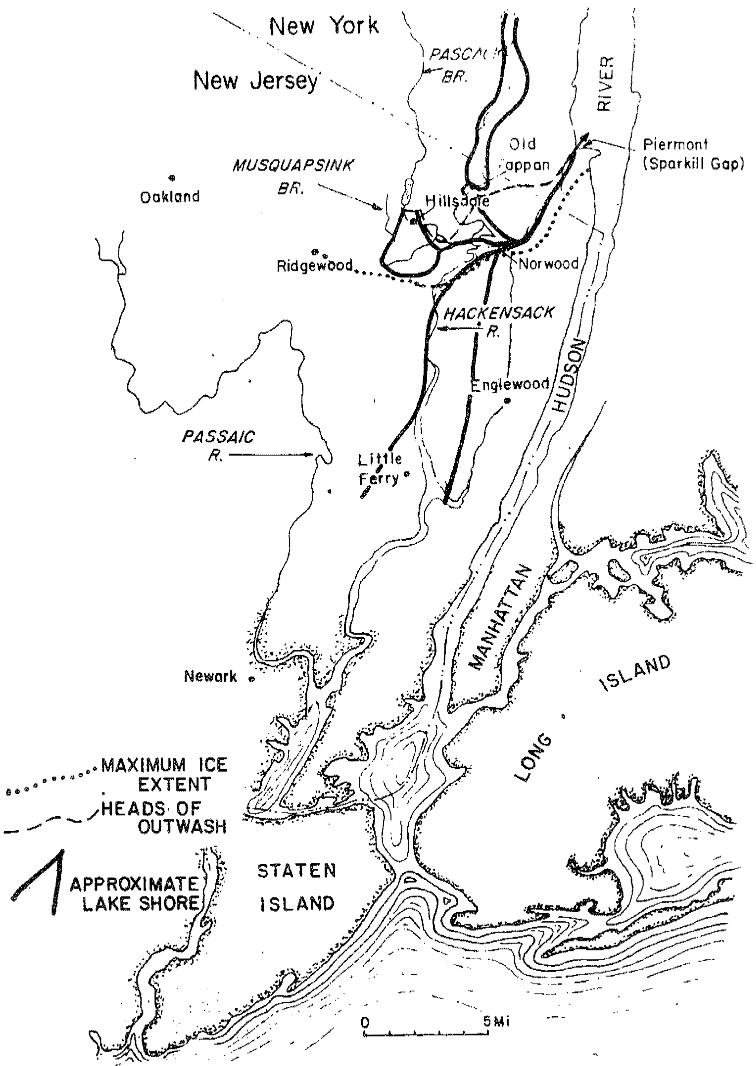

Fig. 12. Maximum extent of Tappan (yellow-brown till) glaciation and the line of Heads-of-outwash across the Hackensack Valley.

Arrow shows early post-glacial Hackensack River drainage through the Sparkill Gap. Proglacial Lake Sparkill is the largest. Pro- and post-glacial Lake Musquapsink is the smallest. Pro- and post-glacial Lake Tappan, twice the length shown extending to the northernmost end of the Hackensack Valley, was three times deeper than the other two.

outwash plain in Hillsdale, a collapsed moraine in River Vale and end moraines in Old Tappan and Franklin Lakes-Oakland. Outwash fans and valley trains extend south from these deposits for as much as 16 kilometers. These deposits are dissected by the present Hackensack River and its tributaries. Many kettles and kettle lakes dot the outwash deposits. Eskers, with a north-south alignment, are found in the Ramsey area as well as a single esker in Hillsdale (Salisbury, 1902).

This complex series of ice-contact deposits forms an undulating line just north of the approximate maximum penetration by the latest ice advance in the Hackensack Valley and is perpendicular to the general drumlin trend (Fig 12). They extend from Sparkill Gap to Woodcliff Lake, N.J., a distance of some 12 kilometers. Their nature and distribution indicate deposition as the result of ice-stagnation zone retreat (Koteff, 1974). Base level control for all but one of the deposits seems to have been the elevation of the then still isostatically higher land to the south of the ice sheet. Variations in slope are determined by the local elevation of each deposit and the local relief to the south.

From east to west these deposits are: the Sparkill moraine immediately north of the town of Sparkill, New York, the Old Tappan moraine and associated River Vale kames, the River Vale collapsed moraine and outwash, the Hillsdale-Westwood outwash plain with crevasse feeder and the Woodcliff Lake kame delta. All of these lie in the Hackensack River drainage basin (Fig. 12). The ice is believed to have penetrated several kilometers farther south in all the major valleys. Evidence is from the presence of scattered patches of thin yellow-brown till or from disrupted or missing older Lake Hackensack varves and ice-shove deformation in stratified drift.

Sparkill Moraine, Sparkill, New York:

Ice entered the Hackensack Valley in this region from two directions, from the north via the Haverstraw lowland and through Sparkill Gap (Fig. 12). Yellow-brown till and deformed varves are found as far south as the mastodon site (Norwood portion of the Oradell reservoir). At the Gap is an east-west morainic ridge across part of the valley immediately north of Sparkill Creek. Outwash was spread down the valley as a valley train at least as far south as Little Ferry. A proglacial lake, formed in front of the Sparkill ice tongue, and existed until the ice in the Hudson valley retreated north of the Sparkill Gap opening it to post-glacial Hackensack River drainage into the Hudson River. This early drainage and subsequent post-glacial events have altered the surface of this outwash plain (Fig. 13b).

Old Tappan Moraine, Old Tappan, New Jersey:

This east-west ridge, 2.3 km in length, lies across the path of the Hackensack River and stands some ten or more meters higher than the extensive and thick outwash plain to the south (Fig. 13c). The moraine consists of intercalated yellow-brown till and outwash indicating the presence of active ice. However, along its lateral margins, especially the western side, and in back of the moraine are found large kames and outwash deposits partially burying the moraine and indicating transition to a stagnant ice regime (Koteff, 1974). This is the only evidence of other than ice-stagnation zone retreat in the Hackensack drainage basin, probably because it is the major north-south valley in which ice flow was most ac-

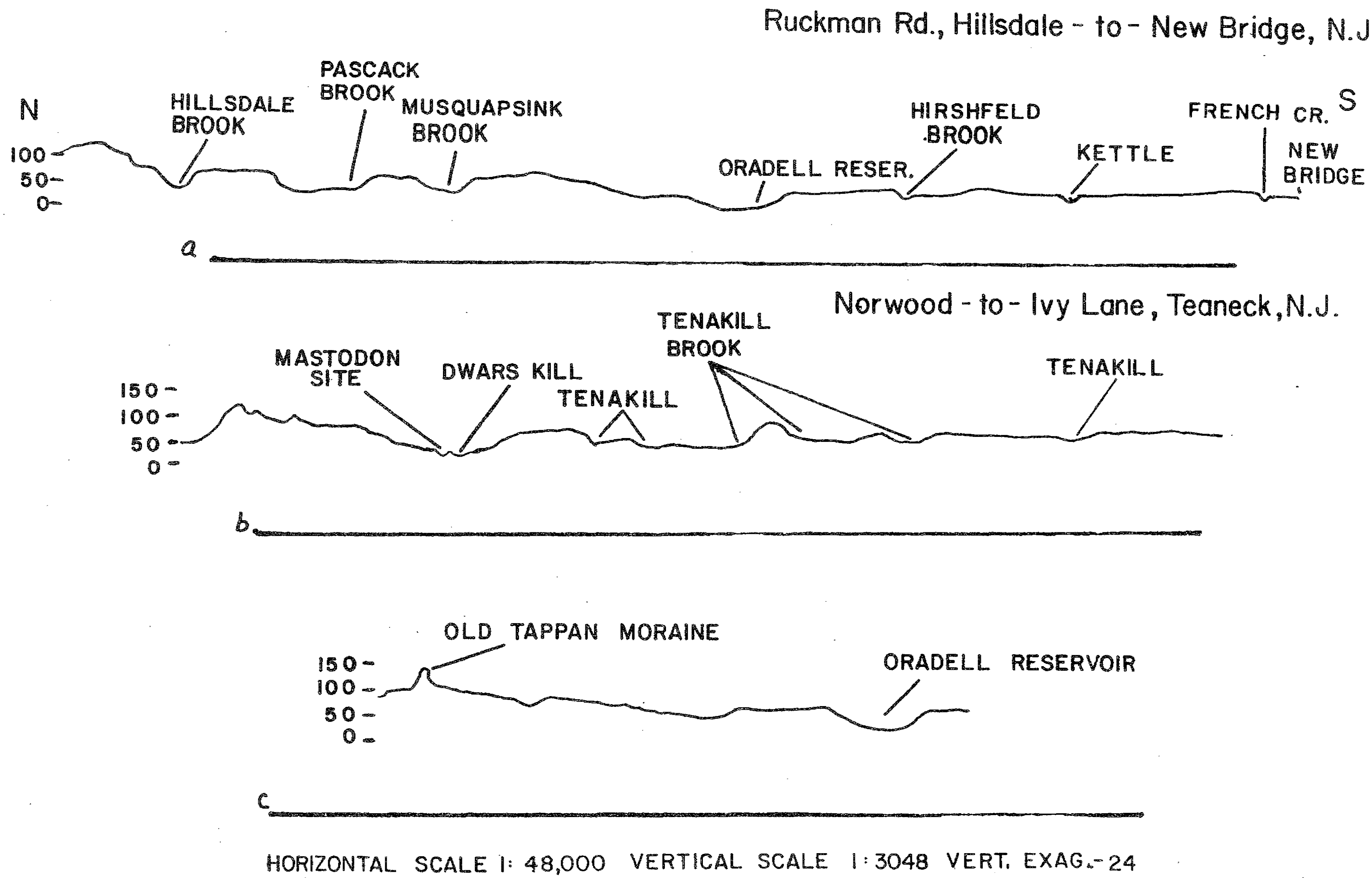

Fig. 13. Topographic Profiles from Heads-of-outwash
- a. Hillsdale-Westwood Outwash Plain from Ruckman Rd. crevasse feeder at the north
- b. Norwood Kame Group with dissected outwash to the south. Dwarskill and mastodon site in early post-glacial Hackensack River valley.
- c. Old Tappan moraine and outwash plain

tive. The surface between the Sparkill and Old Tappan moraines is of subdued morainic habit or covered by outwash and the ice front position is difficult to trace. A series of large kames, referred to as the River Vale kames, curve northward from the eastern end of the Old Tappan moraine.

River Vale collapsed moraine, River Vale, New Jersey:

This area, immediately east and a little south of the Old Tappan moraine and about 1 kilometer wide, is more complex. A stagnant ice mass head-of-outwash front formed parallel to Cleveland Avenue. The moraine and overwash collapsed when the stagnant ice melted. It formed the low hummocky terrain north of Cleveland Avenue to Piermont Avenue where it is overlapped by outwash from the River Vale kames that formed along the western margin of the main Hackensack valley ice lobe. South of the collapsed zone at Cleveland Avenue is found an outwash plain which has been dissected by Pascack Brook and which grades into a valley train in the Hackensack Valley near the Oradell reservoir.

Hillsdale-Westwood Outwash Plain, Hillsdale, New Jersey:

East of Cedar Lane, River Vale-Hillsdale, and fed near its eastern margin from a north-south crevasse about 1 kilometer in length (Ruckman Rd.-Everdell Ave. ridge) the ice constructed a massive ice-contact outwash plain. The sequence illustrated here is typical of Jahns' prototype and Koteff's fluvial ice-contact sequence (Koteff, 1974) with the ice channel filling, kames, outwash plains and a valley train (Fig. 13a). The margin of the ice stood along Washington Avenue, Hillsdale and farther west along the line just north of the present northwest-southeast course of Pascack Brook (Fig. 12). The head-of-outwash is not as well defined in parts of the western segment.

Kame delta, Woodcliff Lake, New Jersey:

This sequence is a lacustrine ice-contact sequence with the stand of ice at the present site of the Woodcliff Lake dam. Base level in this sequence was different from all others. It was the level of the proglacial lake which lay to the south in the valley of the present Musquapsink Brook (Fig. 12). The earlier deposited Lake Hackensack kame delta in Westwood (Fig. 11) formed a dam at about 70 feet above present sea level across its present drainage just west of Kinderkamack Rd. at Old Hook Rd. in Westwood. Forset beds are found at the dam site (Salisbury, 1902) and thin yellow-brown till overlies the stratified drift to the north on the islands of the reservoir.

This series of deposits ends at the steep east-facing sandstone ridge at the western side of the Hackensack River drainage basin. Yellow-brown till is found only as a thin veneer on top of the ridge this far south and no distinct marginal deposit was located. The yellow-brown till thickens rapidly northward along the ridge and completely blankets the red drift beneath.

North of the Border:

North of this drift border, as at Park Ridge in the Pascack Brook and in the Hackensack River valley at Nauraushaun, New York (both at Convent Avenue and 5th Avenue) are some of the larger outwash deposits found north of the glacial readvance limit. Most are of the fluvial ice-contact sequence type.

Till Fabric Analysis

In the Saddle River valley, immediately west of the Hackensack River divide, a large excavation into the side of a drumlin has exposed the yellow-brown till in north-south and east-west walls (Stop 8 Fig. 16). Gully erosion has removed the finer particles and allows easy measurement of elongate cobbles. As of late April 1980, excavation has revealed more of the same. More than fifty of these clasts were measured. The majority of clasts have a bimodal compass orientation of S.20°E and S. 20°-40°W. The majority have the westerly trend (S20°-40°W) and a few large cobbles are oriented almost east-west. One steep-faced exposure shows a strongly fissile fabric to the till matrix. This fissility, even more strongly developed, was also observed in Park Ridge in the excavation for the Howard Savings Bank on Kinderkamack Rd.

The large clast till fabric supports the flow direction as indicated by the drumlin axis alignment. However, the major purpose here is to demonstrate that this yellow-brown till is a lodgement till and not an ablation till as suggested by Salisbury (1902) and also demonstrate that this "two tills" problem is not one of ablation till over lodgement till. Such a strong large clast lineation in the till indicates strong directional motion not achieved in an ablation till. Furthermore, the fissility of the till indicates a lodgement type till as well (Muller, 1974).

Palynology

Samples for pollen analysis were taken and analyzed from two stratigraphic levels; interstadial and post-glacial (Fig. 10). Both levels were found at the two sampling sites. The mastodon site area, in the Norwood section of the Oradell reservoir, yielded interstadial pollen from gray Lake Hackensack varves as well as from a partial but very significant post-glacial section.

Beechwood Park in Hillsdale yielded pollen from a thin clayey peat layer in interstadial lacustrine gray clay. The clay was beneath the sand and gravel that was coextensive with the adjacent kame. The large fairly shallow kettle bog, set in sandy outwash against kames constructed at the distal end of a very large yellow-brown till drumlin, has yielded an apparently continuous post-glacial vegetational record.

A series of C-14 dates was obtained from the two sites. Four of the dates are substantiated by stratigraphy and pollen data and are considered valid. They are used to reconstruct the late and post-glacial events in a partial absolute chronologic framework. The C-14 dates are discussed in the next section.

The pollen data is summarized in this paper because of its field trip orientation and space limitation. A forthcoming paper will present the data in some detail.

Interstadial pollen

Light gray Lake Hackensack varves, that conformably overlie virtually identical red varves (except for color), were sampled in Norwood. They yielded a small amount of pollen. Two slides were made and each contained about 75 grains, two-thirds of which was arboreal pollen (AP). Pine, birch, spruce and popular were the predominant species. Grasses, sedge, heath and compositae comprised the majority of the non-arboreal pollen (NAP) type. Some aquatic species were in the sample. Sufficient NAP was found to indicate local derivation and demonstrates that the vegetation grew in and around the lake.

The Beechwood Park, Hillsdale sample was removed by drilling with a large truck-mounted rig. Sixty-five grains were counted. the NAP and AP percentages were the same as in the varves and the vegetation was similar. Birch, pine and alder were the predominant species with small pollen forms of the birch and pine much more abundant. Spruce and alder are present at both localities but have reverse percentage values. Grass, aquatics, lilaceae and sedge are the most abundant NAP with some subordinate heath and Typha tetrads. They both indicate the presence of an open boreal forest and the associated subarctic climate.

Post-glacial pollen

The Beechwood Park stratigraphy is summarized in Fig. 10. It is notable for an unusually long tundra (T-zone) sequence. Following the "textbook" pattern, it begins with a low pollen sum that increases upward. As is the case with virtually all bogs in the area, the pollen sum increases dramatically in the Spruce-Pine (A-zone) portion of the section. The transition to cool climate mixed-forest types (B-zone) is indicated by the disappearance of spruce and small pollen pine with replacement by large pollen pine and a doubling of oak pollen sum. Later increases in oak are at the expense of the compositae (ragweed) and pine. Compositae grains and other NAP make up an unusually high proportion of the pollen sum in most of the section. This is probably due to the high permeability of the underlying medium to coarse sand which blankets the area and which apparently prevented establishment of a closed forest. It presumably delayed the establishment of the invading forest as well. The bog was virtually filled by the end of B pollen zone time, for only about one meter of peat belonging to the C-zone is present at the top of the sequence.

The mastodon site in Norwood has only a partial post-glacial record but it is this which permits us to decipher much of the post-glacial history of the Hackensack River (Fig. 10). The post-glacial pollen record here begins abruptly when fluvial sediments change to lake clays. A thin layer of tan clay at the base was barren of pollen except for one "ghost" of Picea (spruce). Gray clays above contain much pollen with 55% spruce in the next decimeter. There is a sudden drop in spruce and a concomitant increase in pine pollen at that level. It is clearly the A2-A3 pollen subzone boundary. The gray clay grades rapidly upward into dense black peat and yields A3 zone type pollen (pine, alder, poplar and subordinate spruce) to its top. The upper 10 cm were leached of clay and the pollen showed signs of oxidation. The overlying dark brown, "fluffy when dry", peat contained C zone pollen and clearly demonstrates the presence of an unconformity.

Radiocarbon Dates

A total of eight radiocarbon dates were obtained on various materials. Four of them, all obtained on large amounts of peat, are considered consistant with the other data and are themselves internally consistent. They are also in agreement with similar dated sequences in the surrounding region. An attempt was made to date the remains of the mastodon, heavily impregnated with shellac, but all three dates, two on bone and one on tusk dentine, yielded ages that were far too young. Further, there was a date spread of some 1,200 radiocarbon years between the bones and the dentine. The fourth rejected date is on a small sample from interstadial peat at the Beechwood Park site. This previously reported date of 9,125 ± 150 B.P. (I-6286) (Averill, 1975) has been rejected as too young as the result of the establishment of a complete post-glacial pollen sequence and the above mentioned acceptable C-14 dates.

All four acceptable dates are from post-glacial peat. Two dates were obtained on the black peat in the lacustrine sequence at Norwood in which lay the mastodon remains. The basal peat, some 10 cm higher than the A2-A3 pollen subzone boundary, dates at 12,870±200 B.P. (QC-296). A sample some 15 cm higher produced a date of 12,150±210 B.P. (QC-297). At Beechwood Park, Hillsdale, in borehold #2 (B.P.-2), a date on the lowest peat 2.0-2.1 meters deep, near the B1-A4 pollen boundary, was 10,135±180 B.P (QC-507). Subsequent investigation of the bog located the deepest portion of the bog about 30 meters east of the B.P.-2 site. The deepest peat of B.P.-3 was at 3.75 m, some 1.7 m deeper than B.P.-2. The kettle has a total depth of 6.95 m at the B.P.-3 site. The date on the lowest peat from 3.5 to 3.75 m is 10,575±250 (QC-700). As both dates are on the lowest peat encountered, it appears as if they date the transition from an ideally eutrophic lake to a strongly eutrophic condition with the onset of the formation of peat. The two dates closely mark the A-B pollen zone transition.

Bog-bottom Sedimentation

The C-14 dates obtained tell us glacial ice abandoned the area more than 12,870 YBP. The question is how much more? Sedimentation rates of 0.08 cm/yr (Davis, 1969), and 0.036 cm/yr (Davis and Deevey, 1964) have been used in an attempt to estimate the time of glacial recession. The sites here indicate that Davis' revised rate of 0.08 cm/yr is more accurate at the Hillsdale Beechwood Park kettle bog.

Site B.P.-2 is 5.9 meters deep. The lowest peat occurs at 2.1 m. The C-14 date at 2.0 to 2.1 m is 10,135±180 B.P. (QC-507). The age of the silty clay sediment beneath the peat is determined by the following arithmetic: 5.9 m - 2.1 m = 380 cm ÷ 0.08 cm/year = 4,750 years + 10,135 years = 14,885 B.P. for the time of the onset of bog sedimentation.

Site B.P.-3 is 6.95 meters deep. The lowest peat is at 3.75 m. The C-14 date at 3.5 to 3.75 m is 10,575±250 B.P. (QC-700) as the peat had begun to accumulate a little earlier in the deepest part of the lake. The age of the silty clay sediment beneath the peat is: 6.95 m — 3.75 m = 320 cm ÷ 0.08 cm/year = 4,000 years +10,575 years = 14,575 B.P. for the time of the onset of bog sedimentation.

As both bore sites are near the center of the bog, we have assumed sedimentation began at the same time and that the rate was the same at both sites. The difference between these two dates is only 310 years and is well within one standard deviation of the two C-14 dates (430 years). It indicates the probability that they date the same event. Use of the 0.036 cm/year sedimentation rate places the date range well outside of two standard deviations for the C-14 dates (860 years) making this sedimentation rate unrealistic. It also places final ice recession from the lower Hudson Valley at about 20,000 YBP which is much earlier than any present data indicates.

The low pollen sum in the lowest 1.5 meters of the Beechwood Park bog supports either very slow encroachment of vegetation following glaciation or a rapid sedimentation rate. As vegetation existed in the area prior to the readvance, it probably existed just to the south of the ice margin and so very slow encroachment by vegetation seems unlikely. The alternative must be a high rate of sedimentation. In fact, correlation of the A2-3 pollen subzone boundary and the date of 12,870 B.P. in Norwood with the same pollen level in the Hillsdale section infers a slightly more rapid rate of sedimentation than 0.08 cm/year, at least in the lower portion of the bog.

With this in mind, it is probably safe to say that glacial ice began its retreat from the Hillsdale head-of-outwash within a few centuries of 15,000 YBP.

THE PIERMONT TIDAL MARSH

The Piermont estuarine tidal marsh fringe abuts the Palisades ridge along the west shore of the Hudson Estuary between the Piermont Pier on the north and Sneden Landing on the south (Fig. 2a). The marsh exactly spans the 3 kilometer wide Sparkill Gap of Johnson (1931). The marsh is about 0.6 kilometers wide at its northern end and tapers to a feather edge at its southern terminus. Although examination of the Nyack 7½-minute Quadrangle Sheet suggests that the marsh developed as the delta of Sparkill Creek in the apex bounded by the Palisades Ridge on the west and the Piermont Pier on the north, our boring program within the marsh indicates that a portion of the marsh has been in existence for at least several thousand years. The Piermont Pier was built as the eastern terminus of the Erie Railroad in 1841. An 1882 map of the area, when compared with the most recent topographic map of the area, indicates that the marsh has gained about 25% in area during a 73 year interval.

According to Lehr (1967), the Piermont tidal marsh contains the most northerly concentration of true halophytes in the Hudson Estuary. Adjacent to the road at the base of the Palisades escarpment, the marsh is dominated by cattail *(Typha sp.)* while the marsh adjacent to the estuary is covered with *Spartina spp.* with minor amounts of other salt marsh halophytes. Leveling from a Palisades Interstate Park bench mark adjacent to the swimming pool complex indicates that most of the marsh surface is within 30 centimeters of Mean High Water. Therefore, the marsh surface appears essentially in equilibrium with contemporary sea level and forms a convenient reference datum.

We have sunk numerous bores through the marsh to refusal since 1966. Our initial boring instrument was the Davis (U.S.G.S.) Peat and Marl Sampler, later a one inch I.D. Davis-type sampler fabricated in the Queens College Machine Shop, and for the past two years, the "Dutch-type" Gouge Auger which secures a continuous sample up to six centimeters in diameter in one meter flights. Most of these samples were mixtures of estuarine organic silt and peat composed for the most part of phreatophytic culms and roots. With the exception of the two oldest samples, we did not encounter basal peat nor sedge peat at any point just above refusal. The two deepest and oldest samples are true basal peats. Refusal, encountered at increasing depths toward the east, appeared to be a stratum that included sand and gravel but could not otherwise be identified. All our basal samples contained specimens of either brackish water diatoms or the foraminifer *Trochammina cf. inflata* or both of these taxa.

We assume that the first peaty material to accumulate on the refusal substrate marks the level of the sea at that time. We further presume that the radiocarbon date obtained on these basal materials when plotted on a time-depth plot yields a reasonable plot of the late Holocene relative marine transgress at this locality. Indeed, the plot of our data (Fig. 14) yields a transgression rate of close to 2.0 meters over the past 7,000 millennia radiocarbon years which appreciably decelerates in the most recent millennia. Our plot also displays considerable noise. Some portion of this noise is undoubtedly due to operator and instrument errors of various kinds. In addition, neotectonics and sea level fluctuations may be a source of some of the variability. Finally, it may well be that some of our presumed basal peat is allochthonous and has moved to another level from its point of original accumulation.

Concluding this section, the sea level data obtained from the Piermont Marsh demonstrates that the Hudson Estuary has been in existence for at least 7,000 radiocarbon years and has witnessed a generally transgressive mode for much of this interval. Paradoxically, our micropaleontological data suggest that the estuary is perhaps less saline today than it was during mid-Holocene times. We believe that the valley has been shoaling more rapidly than the sea has been rising thus reducing the cross-sectional area of the estuary and attenuating the penetration of the salt-water wedge instrusion upstream.

Description of Woodfordian Deglacial Events

At a point in time, not yet determined precisely, the Hudson lobe of the Woodfordian ice sheet began its retreat from the Harbor Hill terminal moraine in western Long Island and Staten Island, New York and Perth Amboy, New Jersey. Our story begins with the formation of the large proglacial lakes (Hackensack, et al.) trapped between the Harbor Hill moraine dam at the south and the northward retreating ice front. We will not speculate here on the original flow direction of the late Woodfordian ice sheet and the source of the ice (Sanders, 1974; Sanders and Rampino, 1978; Salisbury, et al; 1902; Reeds, 1930, 1933; Gager, 1932) or the relationship of the lakes to the Harbor Hill and Roslyn tills (Connally and Sirkin, 1975).

The melting ice deposited a thick carpet of sediments over the irregular bottom of the expanding Lake Hackensack (Lovegreen, 1974). Pauses in the retreat of the ice are marked by kame deltas (Salisbury, 1902). After an unknown length of time, the ice front stood north of Little Ferry. Using modern retreatal rates for Alaskan glaciers, where the ice front terminates in water (Goldthwait, 1974) and extrapolating that rate to the late Woodfordian glacier in the Hackensack Valley, the retreating ice would have required about 500 years to reach the Little Ferry position. Reeds (1926) estimated the retreat rate at 100 feet/year, which would require some 1,200 years for the ice front to retreat to Little Ferry. Neither value allows any time necessary for possible minor readvances of the ice during this interval. At Little Ferry, Reeds (1926) counted 2,550 red varves and indicated that some of the upper varves had been removed by erosion. In Norwood, Averill (1980) found some 300 gray varves containing pollen. The use of the minimum figures indicates that glacial Lake Hackensack, from its small beginning to its maximum extent surrounded by a spruce-park forest, existed for over 3,350 calendar years.

Glacial ice was gone, temporarily, from the Lower Hudson. Lakes Hackensack, Flushing and Hudson remained as its legacy, the latter as Lake Hudson-Albany probably still growing larger somewhere up the Hudson Valley. The interstade was already some three centuries old.

The moraine dam was breached and the lakes drained, exposing the lake floors to erosion, carbonate leaching, dessication, invasion by vegetation and lacustrine deposition in isolated basins. One can only speculate as to the cause of the breach. However, it was almost certainly not due to isostatic rebound as is generally believed. As only about one-half of the differential rebound had occurred by about 13,000 Y.B.P., we suspect very little rebound had occurred by the time of drainage which was about 3,000 years earlier. Further, if the isostatic bulge concept of rebound is correct, then the southern end of the lake may have been close to its maximum differential elevation.

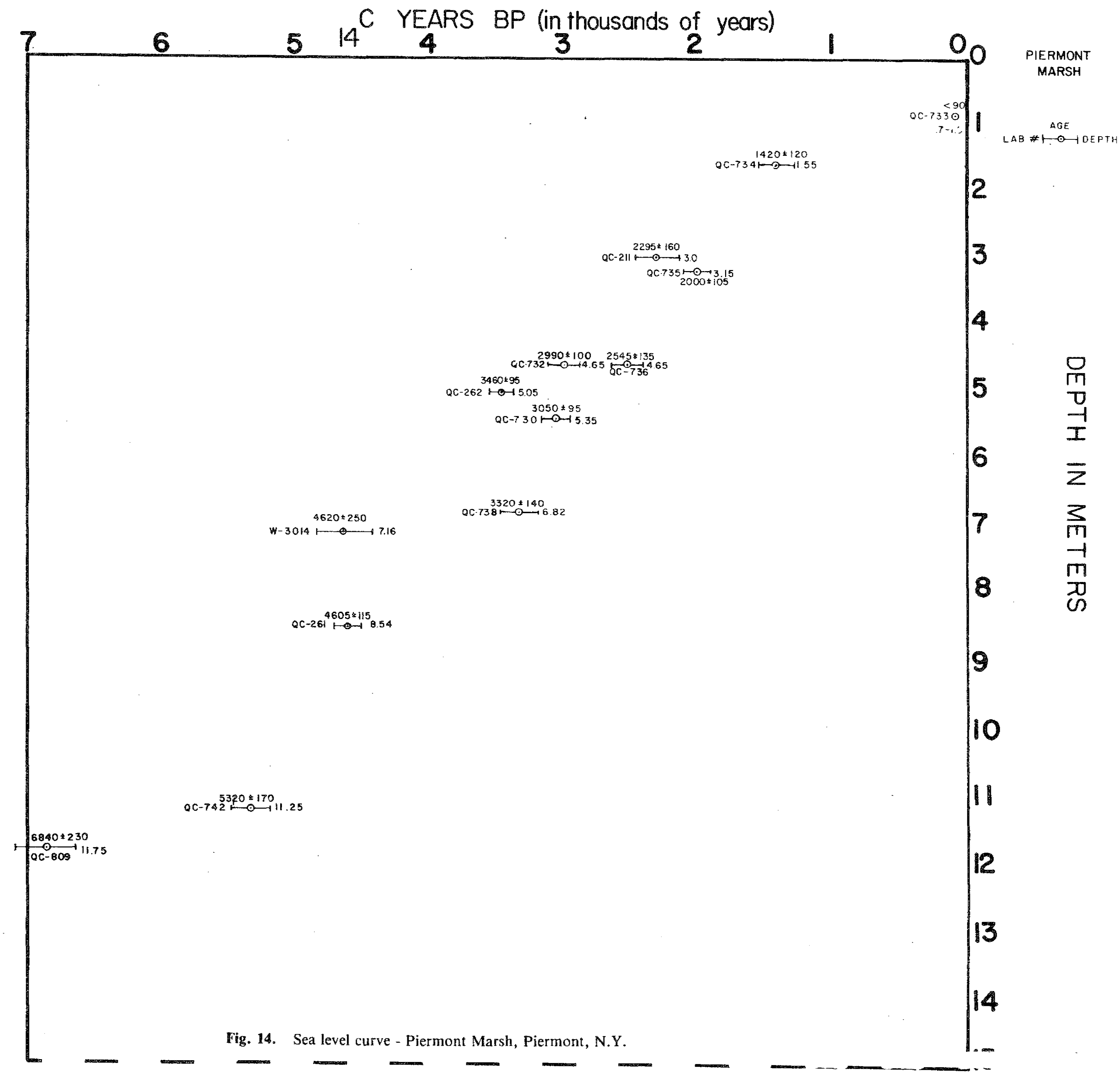

Fig. 14. Sea level curve - Piermont Marsh, Piermont, N.Y.

Thawing of the moraine dam, perhaps aided by melting of large buried ice blocks at the Narrows and Arthur Kill, supported by ground water sapping from the hydrostatic head of the lakes behind the dam are the more likely cause of the breach. A sudden increase of hydrostatic head might have been a precipitating factor. This could have been caused by the catastrophic drainage of Lake Passaic into Lake Hackensack, or readvance of glacial ice (a glacial surge?) down the Hudson Valley. Both would have raised the level of the lakes, either providing the extra pressure to break the dam or causing the water to overflow at a low point where recently melted ice blocks had lowered the crest of the ridge. Drainage of Lake Hackensack was through the lowlands near Jersey City and through the Sparkill Gap. Because of the northward isostatic tilt of the surface, most of the later lake drainage was through the Gap. The flow of water cut a broad valley across the outwash fan at the eastern margin of the Norwood kame group. The Dwarskill and Sparkill Creeks now lie in this valley. (Figs. 12, 13, 15).

Interstadial Hackensack River drainage was through the Sparkill Gap where it joined the Hudson River as a hanging falls. Streams flowed from the south and north through the Gap. It is likely that a large lake existed in the upper Hackensack Valley because of isostatic tilt.

The duration of the interstade is subject to conjecture. The meter of massive (unvarved) gray lacustrine clay and the 0.8 m of overlying silt and thin peat layers at the Beechwood Park site (Fig. 10) are interstadial and presumably deposited after Lake Hackensack drained. A conservative estimate of 700 years is proposed (Averill) for the time to deposit these sediments. Such an extended period of time is supported by the extensive erosion of the lake bed by interstadial streams. Further, the buried red glacial drift has been leached of carbonates to a depth of 30 cm. The 300 gray varves plus these estimated 700 years give an interstade of one millenia duration.

Readvance ice thrust down the Hudson Valley penetrating into the Hackensack Valley at Haverstraw, New York and at the Sparkill Gap. Just north of the line of maximum ice penetration, the glacier built a series of ice-contact deposits from Sparkill, New York across the Hackensack Valley to Woodcliff Lake, New Jersey. These deposits have been described earlier. Their outwash deposits have covered most of the till that would show the maximum spread of the ice. These ice-contact deposits indicate that the mode of deglaciation was ice-front stagnation zone retreat (Koteff, 1974).

The glacier apparently pushed farther south in the main Hudson Valley, as meltwater continued to pour through Sparkill Gap into the Hackensack Valley when the ice front was north of the Sparkill Moraine in the Hackensack Valley. The meltwater formed pro-glacial Lake Sparkill that headed at the Gap, covered the area of the present Oradell reservoir and apparently extended at least as far south as Little Ferry (Reeds, 1926) (Fig. 12). The baselevel dam was probably the still isostatically higher land to the south. For a time the flow of water into the lake must have been small because a black clay layer was deposited in the middle of the outwash and valley train sequence. Fine sand deposited over the clay tells us the ice began to melt more rapidly or had readvanced and penetrated through the Gap again to supply this upper sand. Certainly the periglacial involutions formed in the clay and sand tell us the ice was not far away. (Fig. 5)

After the ice began its retreat up the Hackensack River valley, sedimentation began in the kettle bog at Beechwood Park in Hillsdale. The extrapolated bog bottom date of 14,800 YBP discussed earlier in this paper is suggested also as the approximate time that the ice in the Hudson Valley retreated north of the Sparkill Gap. This allowed the proglacial lake to cascade into the Hudson from its hanging valley at Sparkill Gap.

Early post-glacial Hackensack River drainage was established through the Gap. A stream drained northward from the isostatically induced baselevel dam south of Little Ferry while another flowed southward from the proglacial lake impounded behind the Old Tappan moraine and the River Vale kames (Fig. 12). The course of the Pascack Brook was established just south of the line of the heads-of-outwash by meltwater after the construction of those great sheets of outwash. Note that the stream's angle of insertion into the Hackensack River is towards Sparkill Gap. The present valley of the Musquapsink Brook was dammed near its southern-most segment by outwash associated with the earlier glaciation. An interstadial lake presumably existed there and drained north and east into the Hackensack River. If the lake did not exist, there certainly was a proglacial Lake Musquapsink (Fig. 12) that occupied the shallow basin, for the Woodcliff Lake kame delta built into the lake. The lake drained northward into Pascack Brook in Hillsdale for some time until isostatic rebound raised its northern end slightly and the dam at the south was sluiced away.

The previously mentioned proglacial lake behind the Old Tappan moraine, herein called Lake Tappan, had remained as a post-glacial lake that extended well up the valley, probably to its northern-most limit at the recurved arm of the Palisades at Haverstraw. The isostatic rebound referred to earlier was tilting the land surface southward in the upper Hackensack Valley. Lake Tappan's dam was higher relative to its water surface and so it lasted for a longer time than Musquapsink Lake.

About 13,000 YBP the dam burst draining the lake catastrophically. The torrent of water poured through the Norwood portion of the Oradell Reservoir on its way to the Hudson through Sparkill Gap. This catastrophic outpouring could not be drained through the narrow rock-walled gorge quickly enough and it became choked with sediment. As a result, a sandy divide was constructed across the old drainage course at the New York-New Jersey border. The crest of the divide is presently 40 ft. ASL (above sea level).

The evidence for this story was found in the Norwood section of the Oradell reservoir where a reverse-graded coarse sand to boulder sequence lies directly beneath lacustrine clay (Fig. 6). The flow direction is clearly indicated by the boulders in the lee of the 3 meter diabase boulder (Fig. 6). The sandy divide dammed the drainage and formed a large lake, herein called Lake Norwood, that extended south along the river valley to River Edge and northward up the valley to the vicinity of West Nyack, New York. It included the area of the present Oradell Reservoir but was at least three times as large (Fig. 15).

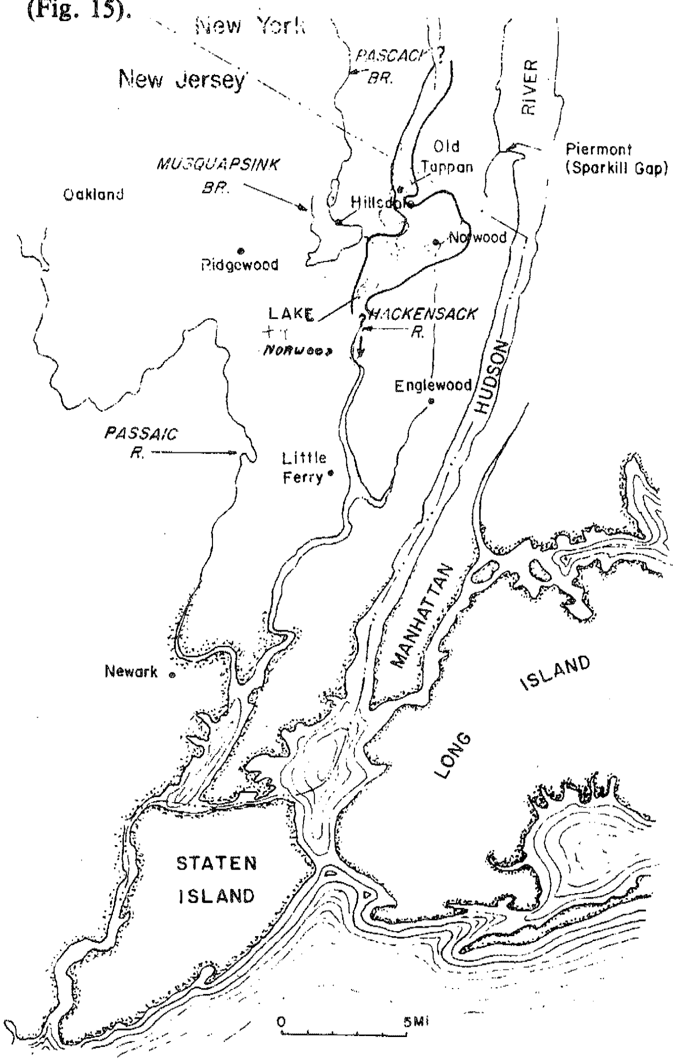

Fig. 15. Post-glacial Lake Norwood

The Lake Norwood sequence stratigraphy of coarse sand, tan clay, gray to black clay and black peat in Norwood (Fig. 6) is repeated at Fifth Avenue near Nauraushaun, New York at about 30 ft. ASL. The same stratigraphy repeats itself, but in an off-lapped sequence at 40 ft. ASL at Westwood Avenue in River Vale. As the dam top is at the same elevation it must mark the former shoreline. The elevation of the bottom of the lake sequence in Norwood is at about 5 ft. ASL. Therefore, the depth of the lake at Norwood, where the mastodon apparently fell through the ice and drowned, was about 10.7 m (35 ft.) deep (40 ft. ASL-5 ft. ASL). Assuming an original isostatic tilt of .426 m/Km (2.25 ft./mile) (Reeds, 1933), the 64 Km (40 miles) distance from the terminal moraine would place the Norwood area 27 meters (90 ft.) lower than today. This is in approximate agreement with the present elevation of the uppermost varves at opposite ends of the basin (Salisbury, 1902, Reeds, 1926). An interstadial stream channel is cut at least 9 m (30 ft.) into the varves below the bottom of the post-glacial lake at + 5 ft. ASL. This post-glacial lake was 10.7 m (35 ft.) deep at the same site so a rough estimate of somewhat more than one-half (perhaps two-thirds) of the rebound had occurred by the time of the catastrophic flood.

The basal peat in the lake sequence has been dated at 12,870±200 B.P. (QC-297) and is the basis for establishing the 13,000 YBP date as the approximate time of the catastrophic flood and resulting lake.

Establishment of modern south-flowing through drainage occurred sometime after 11,000 YBP. The peat sequence deposited on the lake bottom was partially eroded after the lake drained and the modern Hackensack River began its history. The remaining peat is all of upper A pollen zone. Extrapolated peat sedimentation rates on the two C-14 dates at Norwood (Figs. 6 & 10), together with the pollen indicate the lake existed until at least 11,000 YBP.

The vegetation history of the area in post-glacial time is clearly shown at Norwood and the Beechwood Park kettle bog. Each of the pollen zones T, A, B, and C, C are clearly represented (Fig. 6). The T zone of tundra is unusually well represented. The A2-3 pollen subzone boundary is also very clearly marked and closely dated with C-14 at about 13,000 YBP. The two dates of 10,135±180 B.P. and 10,575±250 B.P. (QC-507 & 700) are close to the A-B pollen zone boundary, bracketing it. This is somewhat earlier than indicated by most other workers in the surrounding areas. Finally something that does not show on the pollen summation diagram is a *very* high birch pollen sum in A3 pollen subzone time. This last is a puzzlement and something to say on another day.

Summary of Late Woodfordian Hudson Ice Lobe Deglacial History.

All figures used here to calculate the dates of deglacial events are minimal figures. C-14 dates placing constraints upon these events are the Long Island date sequence of Sirkin and Struckenrath (1975) of 22,800 YBP for the emplacement of the Harbor Hill terminal moraine till and the oldest closely controlled postglacial date in the lower Hudson region of 12,870 ± 200 B.P. (QC-297) (Averill, 1980)

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DATE	EVENTS
22,800 YBP	Emplacement of the Harbor Hill till (date approximate)
?YBP	Retreat with the formation of a proglacial lake and lake bottom sediments
?YBP	Readvance to western Long Island & emplacement of thin Roslyn till over lake sediments
19,250 YBP	Date of initial retreat of Lake Hackensack glacier from Roslyn till contact with Harbor Hill moraine.
19,250 to 18,750 YBP	Retreat with the formation of proglacial lakes Flushing, Hudson and Hackensack to the Little Ferry ice front position across the Hackensack Valley.
18,750 to 16,200 YBP	Deposition of red drift by Lake Hackensack glacier continues during retreat to the Highlands at the northern edge of the lower Hudson Region. During this time there was one known readvance of at least several kilometers. It is not calculated in the figures at the left.
16,200 to 15,900 YBP	Beginning of interstade: Lake Hudson-Albany expands with the retreating ice front. During this time some 300 gray varves were deposited in Lake Hackensack.
15,900 YBP	Catastrophic drainage of Lake Hackensack, et al, with the breaching of the terminal moraine at the Narrows and Arthur Kill.
15,900 to 15,200 YBP	Interstadial Hackensack River Valley drainage through Sparkill Gap. Erosion, dessication and reforestation of lake bed. Deposition of 1.8 meters of interstadial clay and silt lake deposits at Beechwood Park site.
15,200 to 15,000 YBP	Tappan (Yellow-Brown till glaciation) Readvance of the Hudson Valley ice lobe into the Hackensack Valley and lower Hudson Valley. Duration of active glacial ice in the Hackensack and lower Hudson Valleys is a rough approximation based on till and outwash thicknesses present in the Hackensack Valley by extrapolating modern sedimentation rates of temperate Alaskan coastal glaciers (Goldthwait, 1974). Figures are minimal values.
15,000 YBP	Retreat from the Sparkill-Old Tappan - Hillsdale-Woodcliff Lake heads-of-outwash. Formation of various temporary proglacial lakes (ie. Lake Musquapsink, Lake Tappan, Lake Sparkill).
14,800 YBP	Advent of sedimentation in Beechwood Park kettle bog. Return of vegetation. Stagnant ice mass remnant in Ramsey area. Drainage of Lake Sparkill.
13,000 YBP	Lake Tappan, behind the Old Tappan moraine, had

remained as a long-lived post-glacial lake. Its dam burst and catastrophically flooded the drainage through Sparkill Gap. Formation of a new post-glacial lake in the mid-Hackensack Valley, referred to here as Lake Norwood.

12,870 YBP Date on basal peat in Lake Norwood. Spruce to pine forest sudden change recorded in dark gray clay 10 cm below; and just 5 cm above the bottom of the lacustrine clay.

12,000 to 11,000 YBP? Drowning of the mastodon.

11,000 YBP (maximum date, possibly several millenia later) Final drainage of post-glacial Lake Norwood, largely the result of differential isostatic rebound and establishment of through-flowing southward Hackensack River drainage. Erosion predominates throughout the valley.

2000 YBP Rise of sea level and advent of estuarine conditions in the Hackensack Valley penetrating north into River Vale. Tidal marsh sedimentation begins.

1915 A.D. Construction of the Oradell Reservior dam.

MAPS Topographic maps of the study area are all U.S.G.S. 7½ minute quadrangles. The first five listed at the left cover the area of more detailed study. The latter five are the areas of reconnaissance examination. Those wishing to examine the area closely will find them invaluable.

Weehawken, NJ-NY	Haverstraw, NY
Hackensack, NJ	Thiells, NY
Park Ridge, NJ-NY	Central Park, NY -NJ
Nyack, NY-NJ	Jersey City, NJ-NY
Yonkers, NJ-NY	Brooklyn, NY

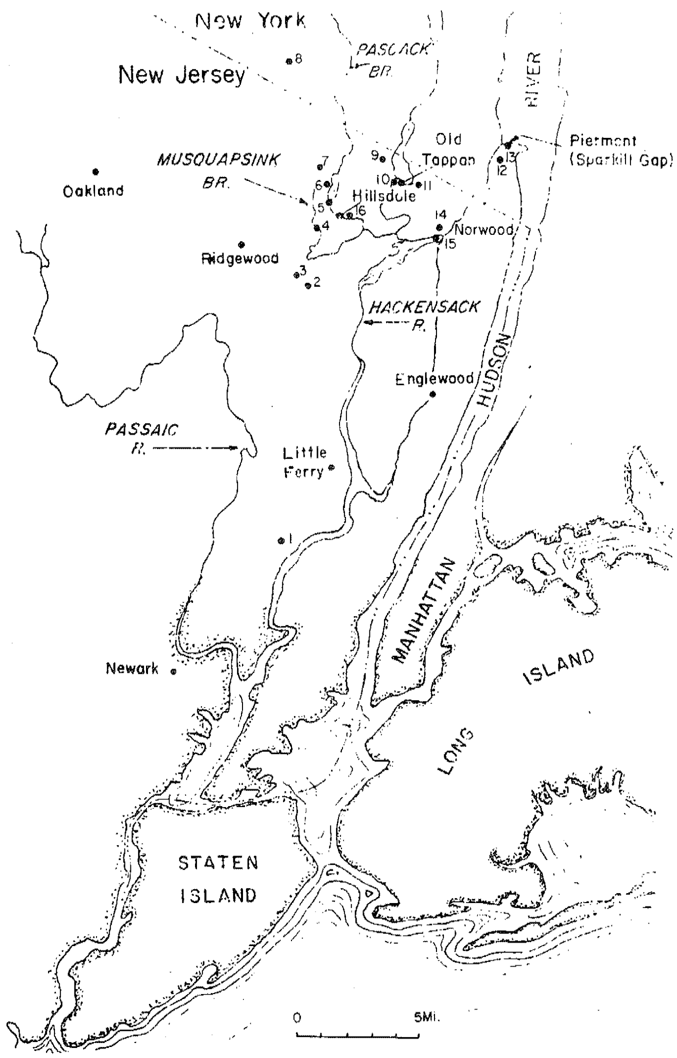

Fig. 16. Stop locations for field trip

FIELD TRIP ROAD LOG

MILEAGE

0.0 Rutgers-Newark parking lot; turn LEFT onto Warren St.

0.1 LEFT turn at 2nd traffic light onto Washington Ave.

0.5 Bear RIGHT onto Bridge St. (crossing Broad St.)

0.7 Take bridge over Passaic River. Continue STRAIGHT onto Harrison St. to the New Jersey Turnpike.

2.9 LEFT onto Turnpike Entrance. Proceed to Exit 16E and leave Turnpike. Mileage will restart at 0.0 at the toll plaza.

0.0 Toll Plaza: Exit 16E; Keep to left. Take Rt. 3, Secaucus; Proceed to light.

0.6 Turn LEFT. Proceed straight ahead. (at 0.8 mile, at County Rd., we may turn left if exposures are available). We are crossing the Secaucus drumlin. It is aligned with its long axis N-S. A relatively thin red till overlies this red and gray rock-cored drumlin. Contact metamorphism of the sandstone was observed throughout most of a very large excavation. The Palisade Sill cannot be far below.

1.1 At light bear RIGHT toward Rt. 3

1.4 Make RIGHT onto Rt. 3. We are crossing the old Lake Hackensack floor now covered by a 3 to 6 meter sheet of sand with the tidal marsh over the sand. The lake covered the "Meadowlands" as far as one can see. The ridges to the east and west formed the shores.

4.6 Turn onto Rt. 17 South (signs). Proceed to light (Polito Ave.). (at Holiday Inn)

5.5 Turn LEFT onto Polito Ave. Proceed to dead end road on right at 5.7 miles.

5.7 Turn in road (unnamed) and park.

5.8 **STOP 1** This is the Rutherford rock-cored drumlin. The Upper Triassic Brunswick formation sandstones and shales are exposed here at the side of the drumlin. Note the copper mineralization. Red drift, sometimes till, sometimes sand and gravel, blanket the drumlin. Some yellow "loam" may be exposed (if we're lucky). The "loam" here is about 15'

cm thick and is loess. This drumlin was at the western edge of Lk. Hackensack.
Leave Stop 1

5.9 Turn RIGHT onto Polito Rd. Proceed to Stop sign.

6.1 Turn RIGHT onto Valley Brook Rd. Proceed to light on Orient Way.

6.3 RIGHT turn on Orient Way. Proceed to traffic light.

6.9 RIGHT turn onto Rt. 17 North. We are leaving the drumlin and proceeding onto the old lake bed surface. As you drive north on Rt. 17, note what was the steep western shoreline of the lake. A deep preglacial valley exists under Rt. 17. The varves are by far the thickest here along the western side of the Hackensack Valley (Lovegreen, 1974).

8.5 At the center of the valley close to the Hackensack River are the former brick yard clay pits from which Reeds' extracted and counted 2550 varves. Mileage approx.

Intersection of I-80 and Rt. 17. We are now crossing one of the sandstone ridges that form the low divide between the Hackensack and Passaic valleys.

Intersection of Rts. 17 & 4, Paramus. We have just passed through the divide between the Hackensack and Saddle Rivers and are near the distal end of the outwash fan associated with the Ridgewood kame group. As we proceed north on Rt. 17, notice the slope of the outwash plain.

18.2 Turn RIGHT on Midland Ave. This is the northern-most known location of Lk. Hackensack red varves in the Saddle River valley. (G.S. Pkwy boring records.) Proceed on Midland to light.

19.0 Turn LEFT onto Farview. Proceed on Farview to fork.

19.6 Turn RIGHT onto Ridgewood Ave. Proceed .1 mile.

19.7 Turn LEFT into Parking Lot of Bergen Community Museum.

STOP 2 Mastodon display and rest stop.

19.9 RIGHT turn from parking lot onto Ridgewood Ave.

20.0 RIGHT turn at stop sign onto Farview Ave. Proceed to traffic light.

21.3 LEFT turn on Oradell Ave. (East Ridgewood Rd.) Proceed to Garden State Parkway Entrance.

21.5 RIGHT turn, NORTH on G.S. Pkwy. We are at the crest of the Ridgewood kame group. Travel almost to main G.S. Pkwy roadway. Do NOT enter.

21.9 **STOP 3** PARK ON MACADAM APRON ON FAR RIGHT.

Walk back to kame. South side of kame shows stratified drift. This used to be a gravel pit. We are told that much coarser gravel was removed from here than is presently exposed. Return to north side of kame. Clean off the face and note the vertical sand layers with minor asymmetrical folds. At the top of the exposure is a layer of fine to medium sand capped with yellow loess under the top soil and vegetation. Return to bus.

21.9 Enter G.S. Pkwy North; Toll Plaza at 22.8 miles. Proceed to Exit 168 on the right.

24.0 Bear RIGHT off the Parkway, Exit 168 to Stop sign.

24.1 RIGHT TURN onto Washington Ave. Proceed short distance to small bridge on Musquapsink Brook.

24.2 **STOP 4** Musquapsink Brook; exposure of red till in the banks to the south. Bedrock in stream to the north. Leave Stop 4.

24.2 Proceed along Washington Ave. (East) to light.

24.7 Turn LEFT onto Pascack Rd. (North) Proceed to Church Rd.

25.8 Turn RIGHT onto Church Rd. (Dam Rd.)

25.9 Park in church lot.

STOP 5 We will have to walk along the causeway. Please watch the traffic. This is the Woodcliff Lake kame delta that built into the proglacial lake in the Musquapsink Valley. Note the very sharp drop in elevation below the dam.

25.9 Return to Church Rd. and proceed to Stop sign.

26.0 Turn RIGHT onto Pascack Rd. and proceed to light. As we ride, note the till capping outwash on the island in the lake. It forms a small dark slightly overhanging layer at the top.

26.5 RIGHT turn onto Woodcliff Ave. Follow road to fork and bear LEFT (STRAIGHT) onto Mill Rd. Proceed on Mill Rd. to gate.

26.9 **STOP 6** Enter the Woodcliff Lake reservoir of the Hackensack Water Co. NO TRASH DROPS PLEASE. We will examine the wave-cut cliff exposure of yellow-brown till over readvance outwash. There is less than 1 meter of till here. One-tenth of a mile west, immediately west of Pascack Rd., the tightly packed red cobble till of the Lake Hackensack glaciation lies below the readvance outwash.

26.9 Proceed along Mill Rd. to Stop sign.

27.0 Turn RIGHT onto Pascack Rd. and proceed to Ridge Rd.

27.6 Turn LEFT onto Ridge Rd. Proceed to Wortendyke Rd.

27.9 Turn LEFT onto Wortendyke Rd. into Atkins Glen Park. At the "T" turn RIGHT into Park Ave.

STOP 7 This lovely glen is a preglacial valley (at least pre-Woodfordian) cut across the Brunswick fm. strata at right angles to the bedrock strike. This valley contains red till and near the top is overlain by the yellow-brown till. It is very close to the farthest north natural exposure of the red till. The valley was exhumed in post-glacial time when a large and deep lake left by the ice, in what is now the Bear Swamp section (Park Ridge 7½ minute Quadrangle), was drained by downcutting.

Leave Atkins Glen Park via Wortendyke Rd.

28.1 Turn LEFT and proceed on Ridge Rd.

28.6 Turn RIGHT onto Spring Valley Rd. Proceed to light.

29.6 Turn LEFT (West) onto Grand Ave. Proceed through light and down hill to 2nd light. We have crossed into the Saddle River basin.

32.0 Turn RIGHT (North) onto E. Saddle River Rd. Proceed into New York State. (@33.4 miles)

33.8 **STOP 8** Turn RIGHT into gravel surfaced area of pit. It is across the street from the *Cemetery of the Ascension.* The exposure is in the side of a drumlin. The yellow-brown till is well exposed here. A strong bimodal till fabric can be measured here and fissility of the till was noted in two steep-faced exposures.

33.8 Return south on E. Saddle River Dr. to light on Grand Ave.

35.7 Turn LEFT on Grand Ave. Proceed until road ends at a "T".

40.4 Turn RIGHT (South) on Middletown Rd. (River Vale Rd.) and proceed to Barr Ct.

41.1 Turn RIGHT up hill along Barr Ct.

STOP 9 The Yellow-Brown till is 2.7-4 meters thick here. Red till is below. This is the River Vale Rd. drumlin. View to the east (over golf course) is the line of River Vale kames that form a north-south ridge to the east of River Vale Rd. until they join the Old Tappan moraine at their southern end. The west slope of the Palisades is across the Hackensack Valley in the distance.

Return to River Vale Rd.

42.0 Turn RIGHT onto River Vale Rd. and proceed to Poplar Rd.

43.0 Turn LEFT onto Poplar Rd. We travel through some kettle bog areas before reaching the old (landscaped) kame crest line. The Old Tappan moraine is ahead of us (south). The present reservoir is the location of post-glacial Lake Tappan. Note the ice-pressed terrain on the back-side of the moraine dam. Many large kames were removed from here during construction of the reservoir. Ultimate drainage, resulting in that catastrophic flood, was through the present Hackensack River drainage exit at the dam.

As we drive up the back slope of the moraine ridge, we can see a steep-sided kettle to the left of the road and just north of the small cemetery. This road is now Washington Ave. North. Proceed to intersection, (Stop sign)

44.3 Turn RIGHT onto Old Tappan Rd. Proceed to Ledson Pkwy.

45.0 Turn RIGHT onto Ledson Parkway. Proceed to dead-end.

45.2 **STOP 10** Old Tappan Rd. and Ledson Parkway are on the sandy outwash plain. Erosion has cut a gully here and has revealed the yellow-brown till of the moraine at the base of the ravine.

Turn around and return to Old Tappan Rd.

45.3 Turn LEFT (east). Proceed to Bi-State Plaza shopping center. Park in the lot of the Plaza.

46.0 **STOP 11** Observe excavated end of moraine. It is mostly stratified drift here.

46.1 Leave lot. Turn LEFT onto Old Tappan Rd. Proceed into Tappan, New York. Go to light by the Town Green.

48.6 At light, proceed STRAIGHT through onto Washington St. (This town is where Major Andre, of Revolutionary War infamy, was imprisoned, tried, hanged and buried.) Proceed along Washington St. to the town of Sparkill.

51.7 Turn RIGHT (immediately before RR crossing) and park at entrance to sand pit.

STOP 12 This is a great sequence of outwash capped by a thin layer of yellow-brown Tappan till. The owner has suddenly died and at this writing we are not sure whether we will be able to enter legally. Return to Washington St.

51.75 Turn RIGHT, cross RR tracks and proceed to light in center of town.

52.2 At light, road becomes Main St. Proceed STRAIGHT on Main St. to next light.

52.4 Turn RIGHT toward 9W South.

52.5 Take LEFT fork onto 9W South. Proceed to Tallman State Pk.

52.9 Enter Tallman Mt. State Park.

Follow signs to picnic area for lunch. After lunch Dineen will discuss the geology of the adjacent Sparkill Gap. Averill will discuss the importance of the Gap to the Woodfordian history of the Hackensack Valley. Newman will discuss the origin of the Piermont salt marsh below and the rise of sea level. For the uninitiated, Dineen and Newman will demonstrate their seismic and coring procedures.

Leave Tallman State Park.

55.0 Because of the variable distances one may drive within the Park, I have arbitrarally set 55 miles as the exit mileage number. Proceed past brown toll house to fork.

55.02 Turn RIGHT, road will take us into the Sparkill Gap. Go to "T".

55.45 Turn LEFT on Ferdon Ave., Sparkill Creek will be on your right. Proceed straight across Rt. 340 at 56.0 miles. You are on William St. Proceed to fork.

56.15 Take LEFT fork. Proceed to Washington St.

56.25 Turn LEFT on Washington St. Proceed to Main St.

57.4 Turn LEFT on Main St. to fork. Take RIGHT fork at 57.45. The road enters New Jersey & beoomes Tappan Rd. It begins to increase in elevation at the Norwood kame grouping and generally runs along the crest. Proceed to Broadway.

59.1 Turn RIGHT on Broadway, proceed to crest of rise (kame).

The Norwood kames were constructed into glacial Lk. Hackensack and were later buried by the readvance Tappan till glacier.

59.2 Park off side of road. **STOP 14** Enter new development on north side of road. Walk up hill to top.

Kame is constructed of red coarse cobble outwash and has patches of overlying yellow-brown till.

Return to Tappan Road.

59.4 Turn RIGHT on Tappan Rd. Proceed to Blanche Ave.

59.7 Turn LEFT on Blanche Ave. Proceed down hill to light.

The first slope is the outwash plain. There is then a break in the slope and the slope increases. This is the erosional slope first cut during the drainage of glacial Lk. Hackensack.

60.3 Light at Livingston Ave. Cross intersection and park in the open area on the right.

STOP 15 This is the Norwood portion of the Oradell Reservoir. This is where the mastodon remains were found. The large (3 meter) diabase boulder can be seen. Discussion....

Leave mastodon site and return up Blanche Ave. to Tappan Rd.

61.0 Turn LEFT on Tappan Rd. and proceed to "T" (Schralenburg Rd.).

61.7 Turn RIGHT, onto Schralenburg Rd. (NEXT TURN IS QUICK)

61.71 Turn LEFT onto Harriot Ave. Proceed on Harriot Ave. Follow road into River Vale where it becomes River Vale Rd. Proceed to light.

You are on the outwash plain of the Old Tappan moraine.

63.8 Turn LEFT on Westwood Ave. Proceed to Fondiller St.

To the immediate left is the 40 ft. ASL contour line and the shoreline of post-glacial Lake Norwood.

64.2 Turn RIGHT and proceed on Fondiller St. to end at "T". We have been ascending the River Vale collapsed moraine outwash plain.

64.6 Turn RIGHT onto Cedar Lane. Proceed north to Cleveland Ave.

Note the flood plain of Pascack Brook to the left (West). It cut deeply into the outwash plain south of the Hillsdale heads-of-outwash.

64.8 At YIELD sign, follow bend in Cedar Lane and proceed STRAIGHT ahead. Proceed to "T".

We have crossed Cleveland Ave. head-of-outwash and are going down hill into the area of collapsed moraine. At the end of Cedar Lane at the "T", is a new Condominium complex. These five story pre-cast concrete structures were built directly on glacial Lk. Hackensack red varves. No pre-construction preparation was necessary as they (the varves) were already in a preconsolidated state.

65.4 Turn LEFT onto Piermont Rd. (a right turn would take you to the Old Tappan moraine). Proceed west to Everdell Ave.

The 1st street on the right (Ruckman Ave.) is the crevasse channel outwash feeder. It can be seen on the left (south) across from Ruckman Ave. It is composed of medium clean sand with occasional large boulders. Piermont Rd. cuts through the crevasse filling in a small stream valley (more on that later).

66.3 Turn LEFT on Everdell Ave. along the crevasse filling. Proceed to East Liberty Ave.

66.5 Turn RIGHT (west) onto E. Liberty Ave. Proceed to Holdrum St.

We proceed down the hill to the flat valley floor. Ahead of us is the Kinderkamack Rd. drumlin, one of the largest in the area.

66.8 LEFT turn onto Holdrum St. Proceed almost to end of street and park in open area on the left.

66.9 **STOP 16** Beechwood Park, Hillsdale, N.J.

Walk into park. Note the kame on the west and the large kettle bog. The bog is also found south of Hillsdale Ave. beyond the confines of the Park. B.P.1 boring was made on the southeast side of the bog and penetrated to the bedrock floor of a deep valley 55 ft. down. Surface elevation of the bog is 50 ft. ASL. B.P.-2 was sited 10 m south of Hillsdale Ave. almost due south of B.P.-1. B.P.-3 was sited east of B.P.-2 just east of the sewer cut in the deepest part of the kettle.

Note the stratigraphy as shown in Fig. 10. Discussion.

The Hillsdale head-of-outwash is immediately south of us. A small, apparently very short-lived, proglacial lake formed behind the dam and between the drumlin on the west and the crevasse filling on the east. As the ice retreated, the eastern ridge was breached at Piermont Rd.

66.95 Turn RIGHT onto Hillsdale Ave. Proceed to Kinderkamack Rd. at first light.

67.0 Turn LEFT (south) onto Kinderkamack Rd. We will stay on this road until we reach Rt. 4.
Proceed south on the outwash plain of the Hillsdale heads-of-outwash. The 1st valley we cross is the Pascack Brook.

67.2 Farther south, after we pass through "5 Corners" in Westwood, we drop into a very large valley drained by the now tiny Musquapsink Brook. This is the valley cut by the draining of proglacial Lk. Musquapsink. The Woodcliff Lk. kame delta was constructed into this lake.
Proceeding south in Emerson we are still on the outwash plain. In Oradell, near the Xerox building, more of the same but on the west is the large Oradell drumlin; rock-cored and coated with red till. Lk. Hackensack red varves were encountered at the Xerox site under the outwash sand. Yellow "loam" loess as much as 30 cm thick overlies the area to the south. Man's activity has removed much of the loess.

END OF OFFICIAL TRIP.

Continue south of Kinderkamack Rd. At the southern end you will pass under the Rt. 4 overpass. Follow the sign to Rt. 4 East-New York. Turn RIGHT and proceed to Stop sign. Turn RIGHT onto entrance to Rt. 4 East. Proceed to Teaneck Rd. Turn RIGHT (south). Proceed to I-80, follow signs to I-80 East Local Lane. Proceed the short distance to the N.J. Turnpike South and proceed to Newark Exit. Reverse directions on page 1 of road log to campus.

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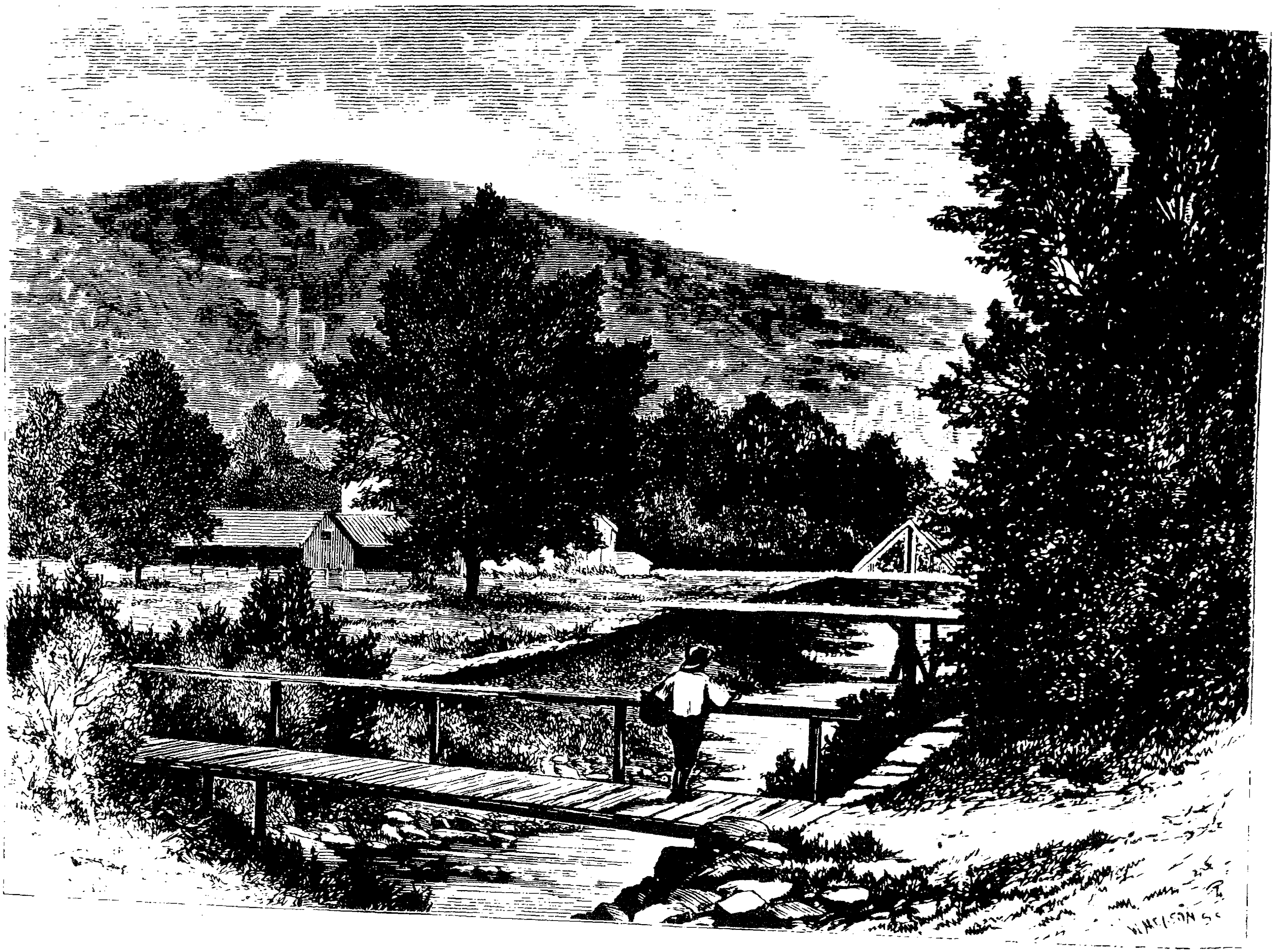

Near Greenwood Lake.

NEAR GREENWOOD LAKE by Jules Travernier

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