Geological Investigations of the Coastal Plain of Southern New Jersey

Part 1: Field Guide

2nd Annual Meeting of the Geological Association of New Jersey

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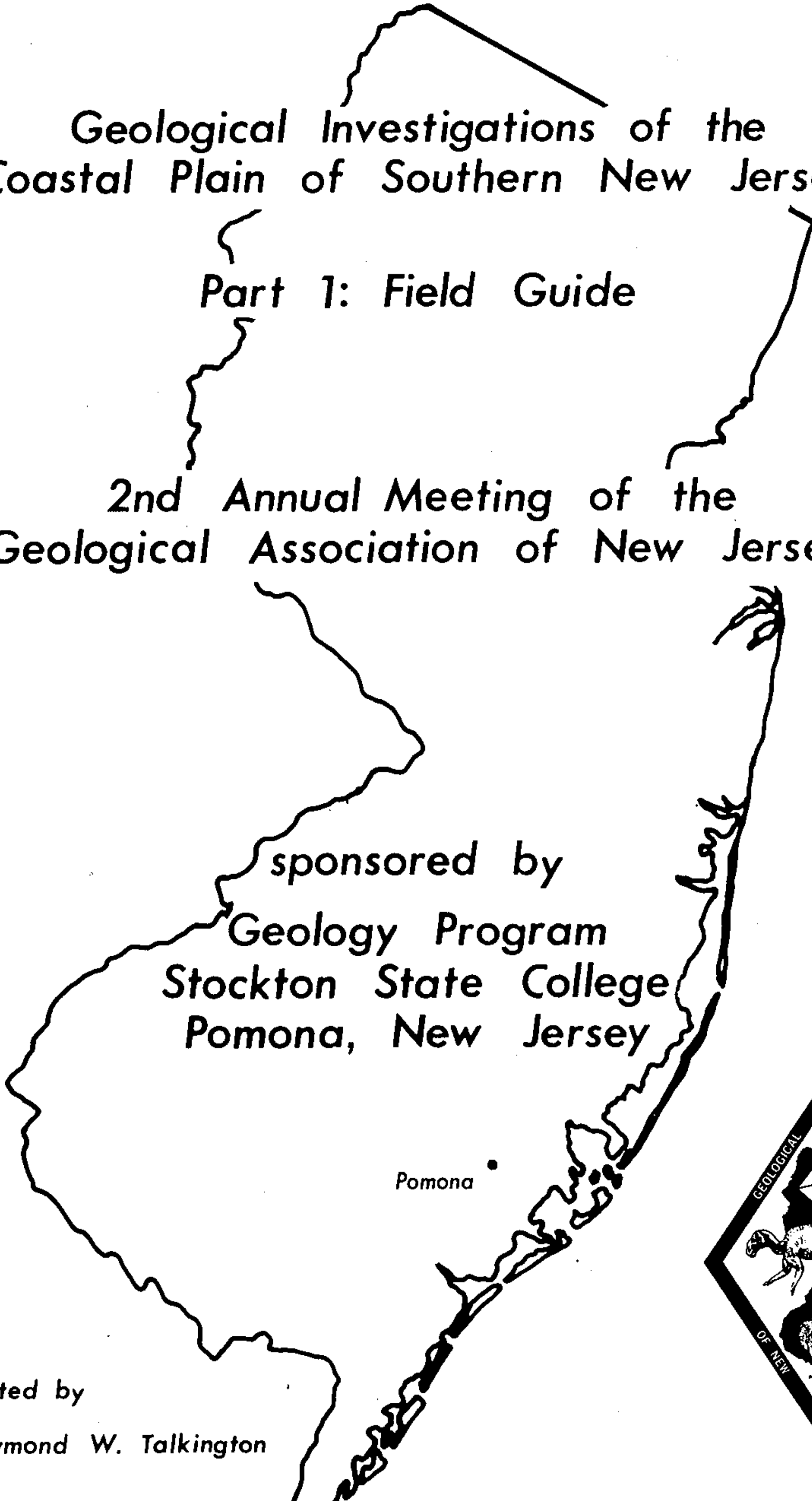
Stockton State College
Pomona, New Jersey



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Raymond W. Talkington

GEOLOGICAL INVESTIGATIONS OF THE COASTAL PLAIN OF SOUTHERN NEW JERSEY

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Stockton State College
Pomona, New Jersey

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FIELD TRIP A

PLEISTOCENE? BRAIDED STREAM DEPOSITS IN THE ATSION QUADRANGLE AREA NORTHWESTERN ATLANTIC COUNTY, NEW JERSEY

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A B S T R A C T

A two year sedimentological study of topographic features found in the Atsion 7 1/2' quadrangle has shown that: The pattern visible in aerial photographs is produced by multi-channel, shallow-depth stream flow unrelated to the present drainage. Channels and bars exhibit well defined elevations and a concave upward down-stream profile (1.0 m. per km.). First, second and third order stream channels can be defined and mapped on individual major bars.

The stratigraphy from 11, 2-2.5 m., 7.5 cm. dia. cores reveals a 1.5 m. thick veneer of coarse sand and fine gravel overlying fine sands and silty sands. The contact between the fine sands is always sharp and identified by a 0.5-0.75cm. sized gravel which fined vertically upward. In all ten cores in the drainage basin, the sediments above this contact exhibited at least three repeat cycles of coarse gravel to medium sand. Each cycle was about 0.3 m. thick.

Sediment analysis of 27 samples from excavations and the cores demonstrated a clear separation of sands into three sub-groups; the substrate, the bar top sands, and the channel gravels. The stream deposit material defined an excellent size parameter helix among the coarsest gravels, mixed gravels, gravelly-sand, and sand (Folk and Ward 1962).

Episodic meltwater overflow through several 90 ft. el.(27.5 m) gaps in the N.J.coastalplain cuesta ridge can be related to 2 to 6m. of sediment deposited over Cretaceous units on the Delaware River side of this divide. During extremes in discharge, excess water passing through these gaps and spreading southeastward, deposited a thin veneer of reworked sands and gravels as this braided stream system.

*Students in Geol 3231-2 who worked beyond the call of duty on the project are Keith Gagnon, Thomas Malinousky, Robert Colombo, Karen Mujica, Janet Mitrocsak, Andrew Cozzi, Edward Van Woudenberg, Thomas Weisbecker

<u>Introduction:</u> In 1977 while on a flight over the upper Mullica River estuary, the flight path was altered to see the results of a severe forest fire above Batsto, N.J. It was spring time and the water table was high throughout the state. While

passing over the region just south of U.S. route 206 at Atsion Lake in the northwesternmost portion of Atlantic County, a remarkable set of what looked like shallow stream channels and multiple bars came into view. Water reflecting sunlight made them look, now devoid of vegetation, as if they had just formed.

It wasn't until 1982 in December that a serious effort was made to study these features. In the winter of 1982-83 Farrell, Gagnon, and Malinousky mapped a down-stream profile and details of the topography visible in one of the large first-order bars. Excavations proved futile since the water table was at the surface. Shovel samples implied a significant difference between the grainsize of the sediment of the bar crests and the channel bottoms.

In the fall of 1983 the Sedimentation class worked on hand coring, sampling and size analysis of two selected sites; the bar previously mapped and a site of higher elevation to the northwest, upstream. The availability of a vibra-corer in the fall of 1984 allowed the recovery of 11, 7.5 cm. cores up to 3.0 m. long. In addition, a second fire in 1984 removed all vegetation from the area and allowed first class observation of the topographic features. The cores were described, measured and sampled to provide a series of sediment analyses of this unique field area.

Braided stream channels from many regions and environments have been studied in the last 25 years. The work by Fahnestock and Haushild in 1962 with flume studies on rapid flow and transport of cobbles on a sand bed, defined hydraulic parameters for flow rate, water depth, and gradient, which created a framework for critical analysis of field data. Doeglas (1962) defined bar, channel and grain orientation properties for the Ardeche and Durance Rivers, tributaries of the Rhone. His diagrams of bar shape compare well with topography found in the Mullica River Valley.

Other extensive reports on braided river morphology followed between 1962 and 1972; Ore (1964), Krigstrom (1962), Smith (1970), and Boothroyd (1972), being four that were reviewed in preparation for this paper.

Boothroyd's study of the Scott Glacier outwash in Alaska's southeast coast is of personal interest and relevance since the field work was experienced first hand in 1969-70. His description of the lower-gradient, mid-fan bar shapes most completely compare with the features herein described. The more recent papers cited deal with criteria useful in modeling braided stream behavior.

The Study Area: A forested, flat-floored valley, 2 km. wide is crossed by U.S. Route 206, 10 km. north of Hammonton, N.J. The Mullica River follows the northeast wall of this valley and is incised 2 meters into its surface. Tributary branches (Sleeper, and Nescochague) drain a larger area to the south and west. This drainage forms the southwest boundary of the research area and is about 0.5 m. higher than this lowest valley floor (see field trip map in road log). Numerous unnamed intermittent streams have incised themselves 0.4 to 1.0 m. into the 3.5 km. reach southeast of route 206. These are approximately located on figure 1 which was redrawn from the Atsion topographic quadrangle.

The valley floor studied is a 7 square km., flat-floor cross section which slopes southeastward at a decreasing gradient of from 1.2 to 0.7 meters/km. The gradient was surveyed with a theodolite in 1983 and is incorporated into the cross section diagram (Fig. 2). An aerial photograph (Fig. 3), taken in 1979, gives a dramatic map view of the northwest-most portion of this valley floor.

Topography: In the winter of 1982-83 extensive surveying of a large primary bar (Krigstrom, 1962) defined the topographic features visible on the ground. The resulting map (Fig. 4) is an example of a mid-fan, longitudinal bar described by Boothroyd on the outwash of the Scott Glacier. The only apparent post-depositional modification is the incising of an intermittent stream along its southwest margin and a 50-meter long bog-iron prospect pit which was omitted. The overall morphology is of a very gentle upstream nose dividing the stream channel into two branches. The unmodified northeast branch is between 20 and 35 m. wide, drops 43 cm. in elevation along a reach of 590 m., and possesses marked terraces at between 10 and 15 cm. above its bed. Several 10-15 cm. deep scours exist in the floor at confluences with secondary channels or at meander bends. The channel segments are straight, however, and sharply defined.

The bar itself is further dissected by shallow channels, all at least 20 cm. above the average depth of the primary channels. These secondary channels average 10 cm. deep and are short compared to the primary channels. Topographic crests are separated by either a poorly-defined 5-10 cm. lower saddle between them or a secondary channel. The former represents third order channels only occupied during high levels of discharge (Williams and Rust, 1969).

Major bar crests all fall within a 10-cm. envelope of elevation. Secondary channels are defined by arrows in figure 4. The crispness of channel margins, the detail preserved and the uniformity of gradients, slopes and shapes strongly imply a geologically recent origin. Their remarkable preservation here is perhaps due to a seasonal high water table at or above the surface and a tendency of channel floors to engulf vehicles in well sorted 0.5 to 2.0 cm. sandy gravels. Agricultural land uses on dryer parts of this valley floor up and down valley from here have obliterated all but a suggestion of major primary bar and channel topography.

The bar mapped is just one of a whole array of bar and channel features within this 7-km. square area. Special interest was shown in the bar just to the northwest of the one mapped and is the site of Stop One on the field trip. The site of the first stop is one of six in the field area with topography more than 50 cm. above a stream channel floor. It was mapped by Colombo, Van Woudenberg, and Albright in 1984 and its morphology is singularly different from the other bars in the area. Although it retains its elongate shape and is surrounded by channels, this bar is covered by small, random height, (0.5-1.5 m.) hills and grass. These six bars are mantled by wind-blown dunes built during low discharge or dry, zero-flow periods.

These features, then, summarize the topographic features preserved in this 2-km. wide zone of the Mullica Valley Floodplain.

Grainsize Distribution: While the high water table aided preservation of the surficial morphology, it hindered attempts to observe sediment distribution and structures using traditional trenches or auger holes. Early attempts at piston coring using a hand-driven, 5 cm. plastic tube resulted in several cores about 1.2 m. long. In the fall of 1984 a vibra-corer was obtained from the University of Maryland and 11, 2.5 to 3.0 m., 7.5 cm. diameter cores were drilled. Then, after a long dry period, it was finally possible to excavate a trench in a channel margin and bed in September 1985.

The cross sectional diagram (Fig. 2) was developed from most of the cores. The location map (Fig. 1) shows their relative positions. After each core was split, half was set aside for photography and description and the other half was used for sediment samples. A total of 27 samples were sieved at a 1/4 phi interval and graphically plotted. Both graphical (Folk, 1975) and method of moment statistics were generated.

Ten of the 11 cores were from the valley floor shown on the map (Fig. 1). They all revealed two distinct sub-divisions; a coarse sand and sandy gravel upper portion and a fine silty sand lower section. The upper section was between 0.9 and 1.5 m. thick and was always sharply in contact with the underlying material. In fact, while vibra-coring, this contact could be felt as a sudden reduction in the rate of penetration. The machine had a distinct difficulty driving any deeper than 3.0 meters, unlike much longer cores easily driven in Holocene lagoonal sands of similar size distribution near Brigantine, N.J.

All 27 cumulative percent curves were plotted on arithmetic probability paper and then the extremes of each of three sedimentary units was reproduced as figure 5. The channel gravels and river sands and bars come from the upper Mullica River sequence and the curves labeled "Substrate" represent an older pre-event basement, probably the upper Kirkwood Formation.

Closer inspection of the upper section of each core showed between 3 and 5 fining-upwards sequences commencing with a sandy gravel with a coarsest grainsize of about 2.0 cm. The upper part of each fining upward sequence was sand with a mean size of between 0.25 and 0.18 mm. The eight "substrate" samples analyzed had a mean size of 0.125 mm. and a significant pan fraction (between 3% and 8%) less than 0.045 mm. (4.5 phi). A representative sample of each of the three sedimentation units is displayed as a frequency percent curve in figure 6. The gravel sample came from the base of a fining-upward sequence and the bar sample came from the middle part of a thick sequence. The many modes of the gravel curve may not be real, but reflect the influence of shape on the sieving process (Kennedy, Meloy, and Durney, 1985). However, there always appears to be a small amount of the gravel in the sand and a significant sand size mode always appears in the gravel samples (Folk and Ward, 1957). In fact, when one compares this sequence of gravels and sands to the data from the Brazos River there are striking similarities. Presently more samples from each of the three sub-sets are being run to get a statistically valid number of samples to make a direct comparison to the sedimentary "helix" derived for the gravel bars of the Brazos River.

The size parameters for the samples on hand were used to generate figure 7. The substrate samples are positively skewed, fine grained and tightly clustered. Most of the gravel samples are also positively skewed, but show a wide range of mean sizes. The bar sands are negatively skewed and intermediate in size and standard deviation. The complete separation of all 27 samples into the three clusters was a surprise. Tentative conclusions point to the sands and the gravels as being all from the same source and related to the same depositional conditions. The sand size making up the mode of the substrate is present in the sands above the contact, but none of the fine sizes in the substrate are present. This indicates that as the substrate was eroded, the fines were carried off.

Sedimentary Structures; The first seven vibra-cores obtained were drawn to scale and are shown in figure 8. Since only cores 7, 5, and 4 were in alignment with the surveyed valley gradient, cores 8, 9, and 10 were added later. The diagram shows the fining-upwards sequences, the contact with the substrate, and the sediment variation in the substrate (grainsize analysis was only done on sand, not the obvious clay rich layers). The core cross section was not large enough to define any sedimentary structures. Some hint of small scale ripples was observed in the sands of some fining-upwards units. These were in the form of heavy mineral laminations. Careful extraction of these minerals allowed a general picture to emerge as to source area. Comparison to the heavy minerals found in the Kirkwood sands elsewhere was far from conclusive, but was a close match. The presence of magnetite, garnet, ilmenite, zircon, and rutile in an otherwise quartz sand is not a conclusive match, but it is important to note that rock fragments and unique minerals from the Appalachian formations were not found.

As a result of a long dry period, in September 1985, it was found that the ever-present water table had dropped some 80 cm. under the channel bottoms. A 5.5 meter long, 80-90 cm. deep trench was dug in the primary channel margin at the "80 cm." contour symbol at the downstream point of the mapped bar (Fig.

4). The western end of the trench included a 12 cm. high terrace at the edge of the bar. The trench, illustrated in figures 9 and 10, became a compelling piece of evidence upon finding the sedimentary structures. The trench was dug to the substrate. Water came into the trench 5 cm. above the fine sands of the substrate through the gravels. Therefore, no substrate appears in the photographs (Fig. 10).

This channel was subjected to the following events in sedimentological order:
First, a rapid deposition on an erosional surface cut into the compact, fine, "substrate" sands. The sediment is cross bedded in large scale festoons with an alternation of gravel and sand laminations as the festoons migrated down channel. Individual sets of festoons are cut into each other indicating that the channel was transporting almost as much sediment as it was depositing. The bed was aggrading very slowly at this point. The festoon cross bedding dips at 22 degrees down channel and the individual festoon pits are about one meter in wave length.
Second, a truncation of all these bedforms by a very large-scale set of slightly-gravelly sand festoons shown in three dimensions in the photograph in figure 10. This set of bedforms thins to zero thickness at the channel margin. The sediment is deposited in well defined laminations dipping 15 degrees down channel. The festoons are large (1.4 m. wave length) and much better sorted as a whole. The flow rate was either less rapid or the water was deeper or, perhaps, both possibilities were true during full channel flow covering the bar crests.
Third, a truncation of the sandy festoons by a coarse basal layer of gravel, deposited in 80 to 100 cm. wave length flat festoon scour pits. The pits cut into the sandy crossbeds below and even cut down to the gravelly bedforms of the first unit. This is a very thin unit (7-10 cm.) and is not traceable past the large disturbed zone.
Fourth, this thin very coarse gravel is truncated by a wide spread fine gravel, which can be traced, rising up-section westward toward the terrace. The gravel layer is only 2-3 cm. thick and fines upward rapidly to a thick (35 cm.) ripple-laminated sand with few gravel-sized fragments. This layer also makes up the surface of the channel bottom and the terrace on the bar margin.

The preceding description, size relationships, bedforms and scale could be taken from any of the cited papers on braided stream morphology (Ore, 1964, Williams ans Rust, 1969, Boothroyd, 1972). One thing is certain, this trench eliminates any possibility that these deposits represent conditions or agents capable of producing them which are currently active in the Mullica valley floodplain today.

The largest clast size-slope gradient relationship data, while smaller and less steep than the mid-fan bars described by Boothroyd for the Scott Glacier, fall in the correct place on his graph (Fig. 11).

The width ratio, Wr, and the sinuosity, P, developed by Hong and Davies (1979) when applied to the aerial photograph (Fig. 2) yield values of 0.188 and 1.16 which fall with in their limits of Wr = 0.15 - 0.20 and P = 1.0 - 1.3.

If the morphological pattern, the sedimentology and the hydrology of these Mullica Valley stream deposits represents a high discharge, rapid flow rate braided stream system covering a 2 km. wide valley floor, where did the water come from, plus why and when did it happen?

The Origin of the Braided Stream Deposits: While the depositional history and the sedimentation mechanism seems clear, the solution to the origin of the water to create these deposits and the time period during which it occurred is still tentative. Clearly the water volume was at least three orders of magnitude greater than that which flows through the Mullica valley today. The sediments show that no minerals or rock fragments (in the coarsest sizes) are the least bit unusual from those to be found at an outcrop of the Cohansey or Kirkwood Formations. Therefore, the flow of water was reworking coastal plain sediments lying up-valley from the Atsion study site.

The Mullica River head waters presently begin in fresh water swamps in the Medford Lakes, N.J. area. Topographic maps show a ridge, trending southwest to northeast with hill tops at between 120 and 230 feet (40.3 and 83.5 meters). In the Medford Lakes region a series of three lower gaps exist in this ridge at an elevation of between 90 and 92 feet (32.7 and 33.4 meters) (Marsh, this volume). From these gaps, presently occupied by swampy ground, one large and two small valleys trend southeast toward Atsion. The streams presently occupying these valleys appear to be under-fit streams. Auger holes at one of the gaps (Flyat, N.J.) produce sediments in the silt range which are laminated dark gray to green. The banks of the valley at Flyat are composed of the same type of sand found as the "substrate".

The water responsible for creating the braided floodplain at Atsion had its origin at these gaps and was carrying nothing coarser than silt as it passed over the 90-foot (32.7 m.) divides between the Delaware drainage and the rest of southeast N.J.

Marsh feels that the Delaware River, forced by glacial melt and outwash sedimentation to aggrade its floodplain to about 55 to 60 feet (19.9 to 21.8 m.) above present sea level in Burlington County, N.J., needed only 30 feet (10.9 m.) of water at peak discharge to have water pass through these three and two other gaps in the ridge. Marsh also feels that the most likely mechanism would a ponding of meltwater in low-lying western Burlington County to form a glacial lake trapped behind a temporary barrier such as a delta fan produced by the glacial Schuylkill River.

The evidence for fluvial reworking of Cretaceous coastal plain formations can be found at several gravel pits in Burlington County, N.J. and was also seen during excavation for an extension of New Jersey state route 55 in Deptford N.J. in 1983 (Farrell, 1984). The gravel pits in Crosswicks, N.J. and Lumberton, N.J., shown on the field trip each have several meters of sand and gravelly sand overlying an unconformity with the Cretaceous units below. The sedimentary features are totally unlike those found in the unit upon which they lie. The cut and fill coarse sand and gravelly sand is repeated several times as a fining upward sequence. The pit at Lumberton (STOP 3) contains over 6.0 m. of material over the Marshalltown Formation and the pit at Crosswicks has 2.5 m. of coarse sand and gravelly sand overlying the Merchantville Formation (STOP 4).

The excavation work in Deptford revealed 1.5 m. of sand with scattered cobbles and gravel overlying the Marshalltown, Wenonah and Mt Laurel Formations along 2.5 km. of roadway. One excavation was done in one of three circular depressions. The stratigraphy was as follows: The Marshalltown was in contact with a fluvial sand with festoon and small ripple cross bedding (up to 0.7 m wavelength). This was 1.75 m. thick at the margins of the depression. In the center a cobble gravel with a chaotic surface was found about .4 to 1.0 m. in thickness. The fluvial sands which both underlay and covered the margins of this deposit were deformed by it. The depression itself was filled by black, green and limonitic yellow silts and very fine sands. The trench yielded evidence for standing water and a lacustrine shoreline. The pond was also the location of a pre-woodlands Indian dwelling site (Mounier, 1984).

The Deptford discovery tentatively points to an ice-carrying, Pleistocene Delaware river, spread out on a floodplain from the bedrock of the Piedmont to the cuesta of the coastal plain, aggradded to an elevation of 60 feet at Crosswicks, N.J., sloping down to about 45 feet at Deptford, N.J. The choice of Pleistocene time is obviously for the large volumes of water present during the periods glacial melting. The Deptford pond cobbles were composed in part of non-coastal plain fragments. Gneisses, quartzites, and sandstones were the significant indication of ice rafted non-coastal plain origin debris (Farrell, 1984).

During peak discharges the Delaware, swollen beyond valley capacity, sent water over the low places in the cuesta to rush down the initially steeper southeast slope of the coastal plain, carving shallow gorges. By the time the flow reached Atsion from three separate gaps the gradient had lessened to the point where deposition exceeded erosion and braided deposition of the Atsion floodplain began. The sediment was exclusively that eroded from immediately up valley toward Medford Lakes, N.J. Further down valley toward the sea, the braided stream was joined by two other braided streams which started near Tabernacle, N.J. The rest of the journey to the sea was not done as a braided stream since most of the coarse sediment had been deposited and the gradient was too gentle (0.6 m/km.) to support the rapid erosion and channel migration needed to sustain braiding of the stream system. A pre-Holocene deposit profile across the Mullica River Estuary between Mystic Islands, N.J. on the north bank and Leeds Point, N.J. on the south bank was taken several years ago by Goddard (1976). This profile has shown a gravelly sand surface about 2.8 m. below present mean high water, below the Spartina marsh which is continuous to the present banks of the Mullica River. The 15 meter depth and 270 meter width of the estuary channel is probably the fossil channel of this once vigorous river.

The work on the Atsion study site needs to be expanded to cover the entire system to help interpret a history of this river basin and its brief connection with the Delaware River waters which is based on detailed research throughout the drainage basin. Most definitely, more work needs to be done.

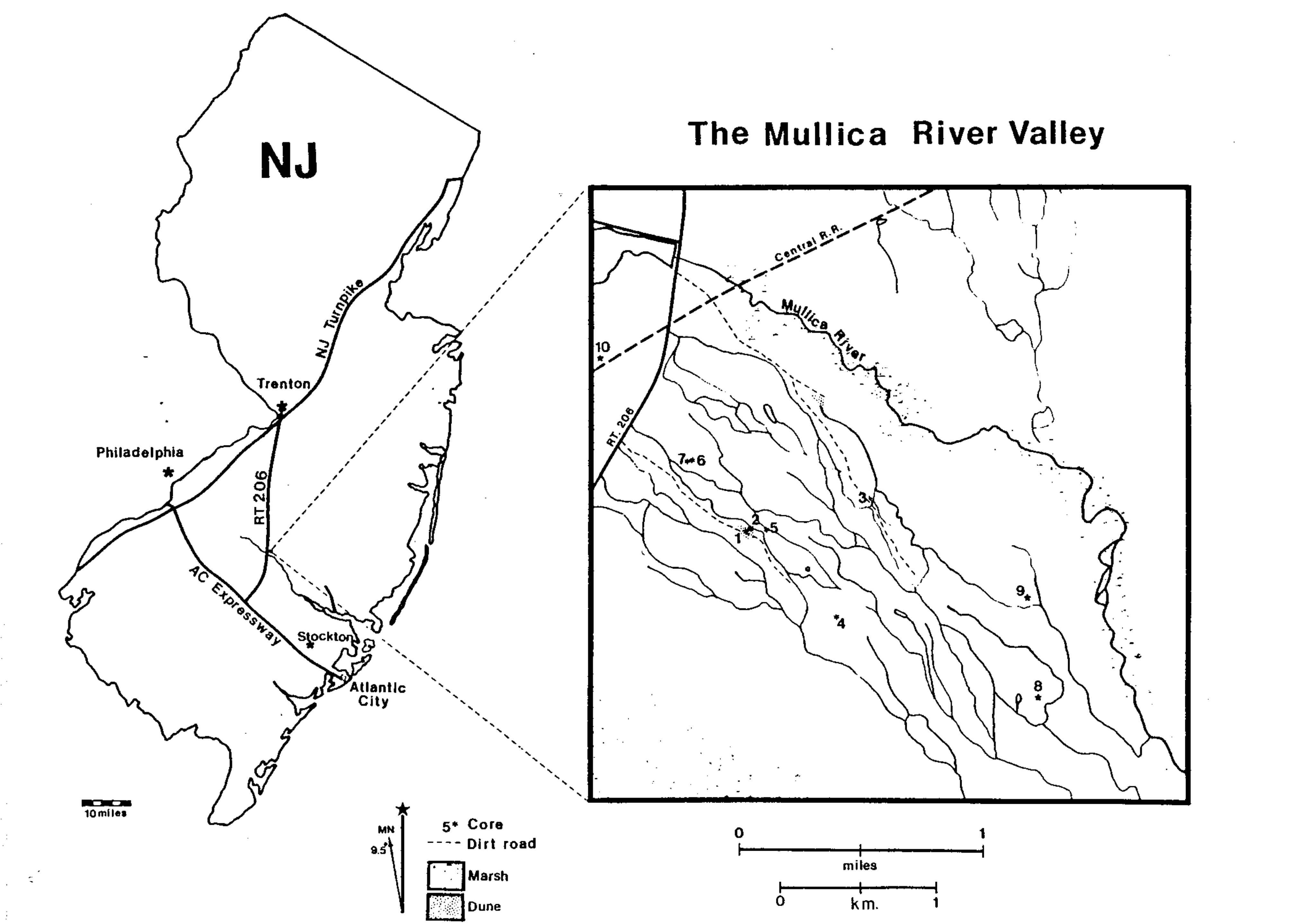
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FIGURE 1. Location diagram for the Mullica Valley study area. The research was conducted southeast of U.S. Route 206 in a 2.0-km. wide pine-forested floodplain. The streams shown on the inset map are intermittent and have excavated small channels with the wide, shallow channels visible in one of the aerial photograph in figure 3. The numbers are the vibra-core locations.

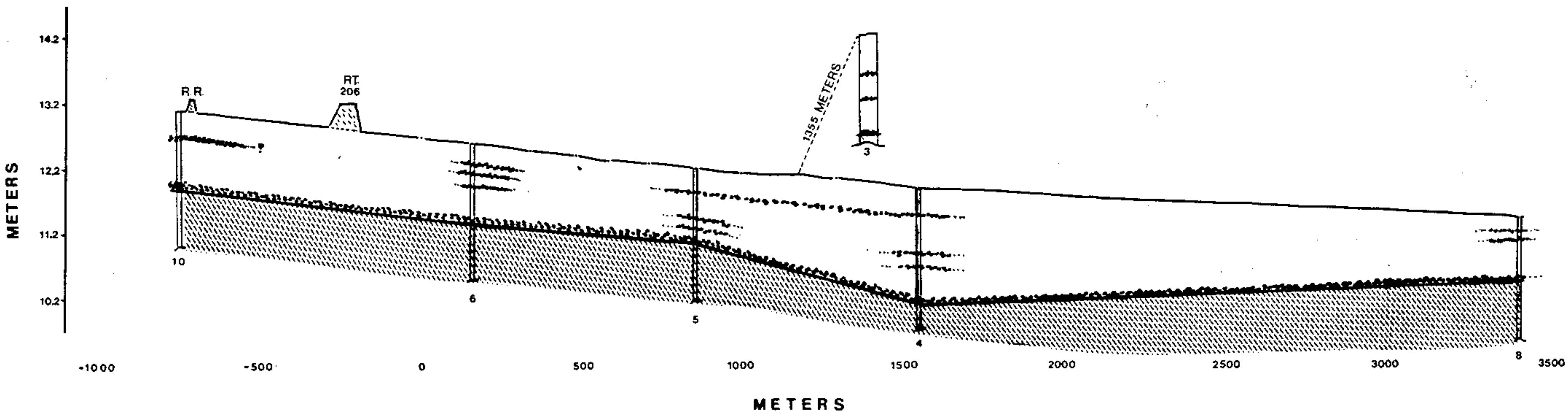

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FIGURE 2. Cross section of the Mullica Valley deposits revealed by vibra-coring. Six of the 10 cores taken in the study area were used to illustrate the repetitive nature of the upper sand and gravel sediments. The literature discusses the difficulty of correlating the gravel layers over any distance and the trench excavation confirmed this. The dashed lines represent the pre-existing coastal plain sediments, probably the uppermost Kirkwood Formation. The surface of the cross section is a survey line parallel with flow down valley. Core three was drilled on the northeast side of the valley 1335 m. from the profile line. The braided stream complex deposit is consistent in thickness and sedimentology throughout the 7 square km.

FIGURE 3. Aerial photograph taken June 26, 1979 by the U.S. Dept. of the Interior. The upper left corner is Route 206. Stop One on the field trip is located on a large bar, mantled by dunes rising 1.5 m. higher than a typical bar crest. The large bar mapped (Fig. 4) is outlined by dashed lines. Vibra-core #5 is located in the upstream end of this bar, and the trench shown in figures 9 and 10 was dug northeastward from its downstream end into the unmodified channel. The dark, irregular feature is a series of bog-iron prospect pits.

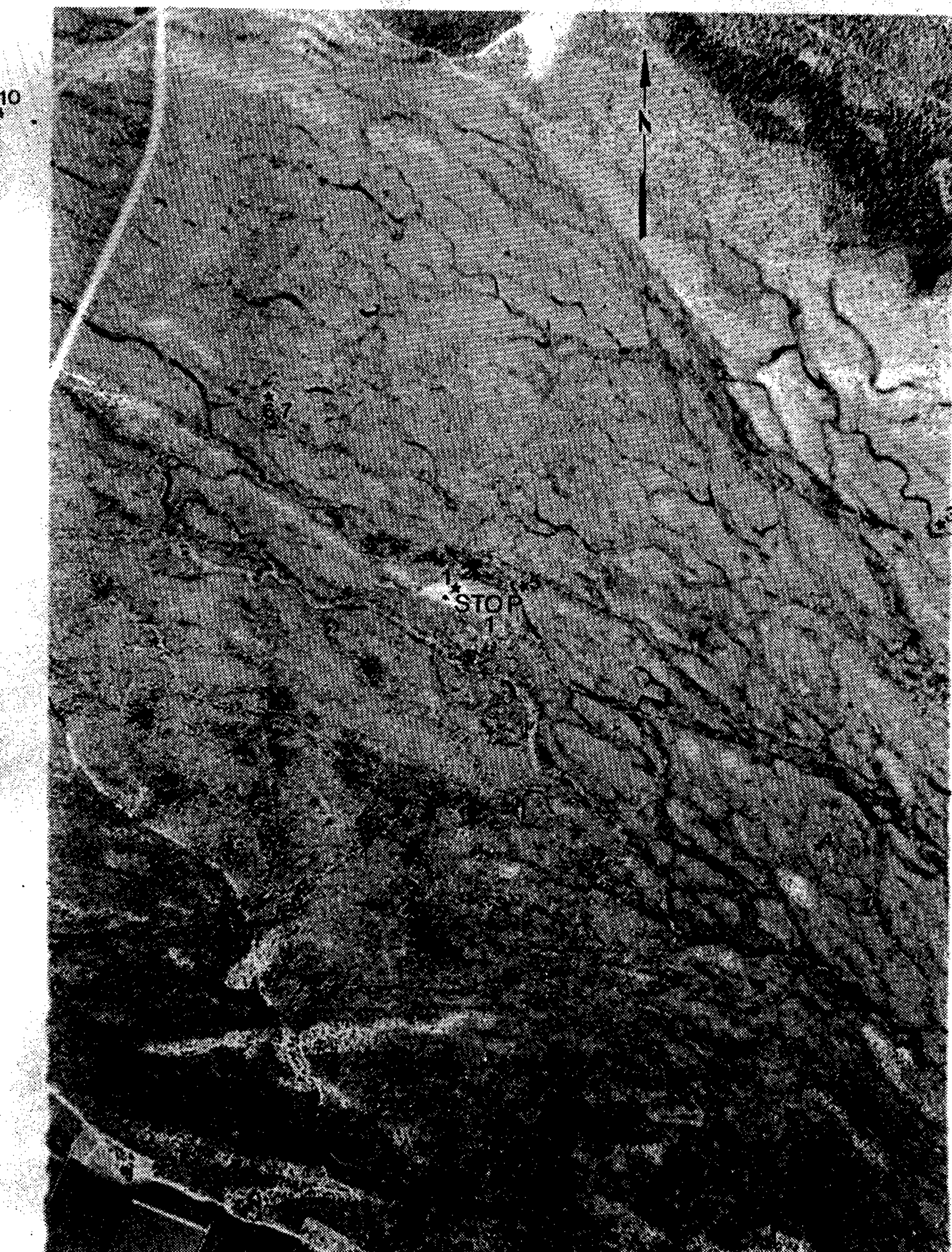
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FIGURE 4. Topography of a primary bar in the Mullica Valley. The map, based on 3ØØ data points shot with a theodolite in the winter of 1982-83, shows the sharp boundaries of the bar. The primary channels are outlined in shading, while arrows show the paths taken by secondary channels. The bar crests are further divided by very shallow, 5-1Ø cm. deep, third order channels occupied during high levels of discharge. The total relief is 55 cm. between the primary channel bed and an adjacent bar crest. The southwest primary channel has been incised by one of the modern intermittent streams to a depth of 5Ø-9Ø cm. below the original channel bed.

The Mullica River Valley

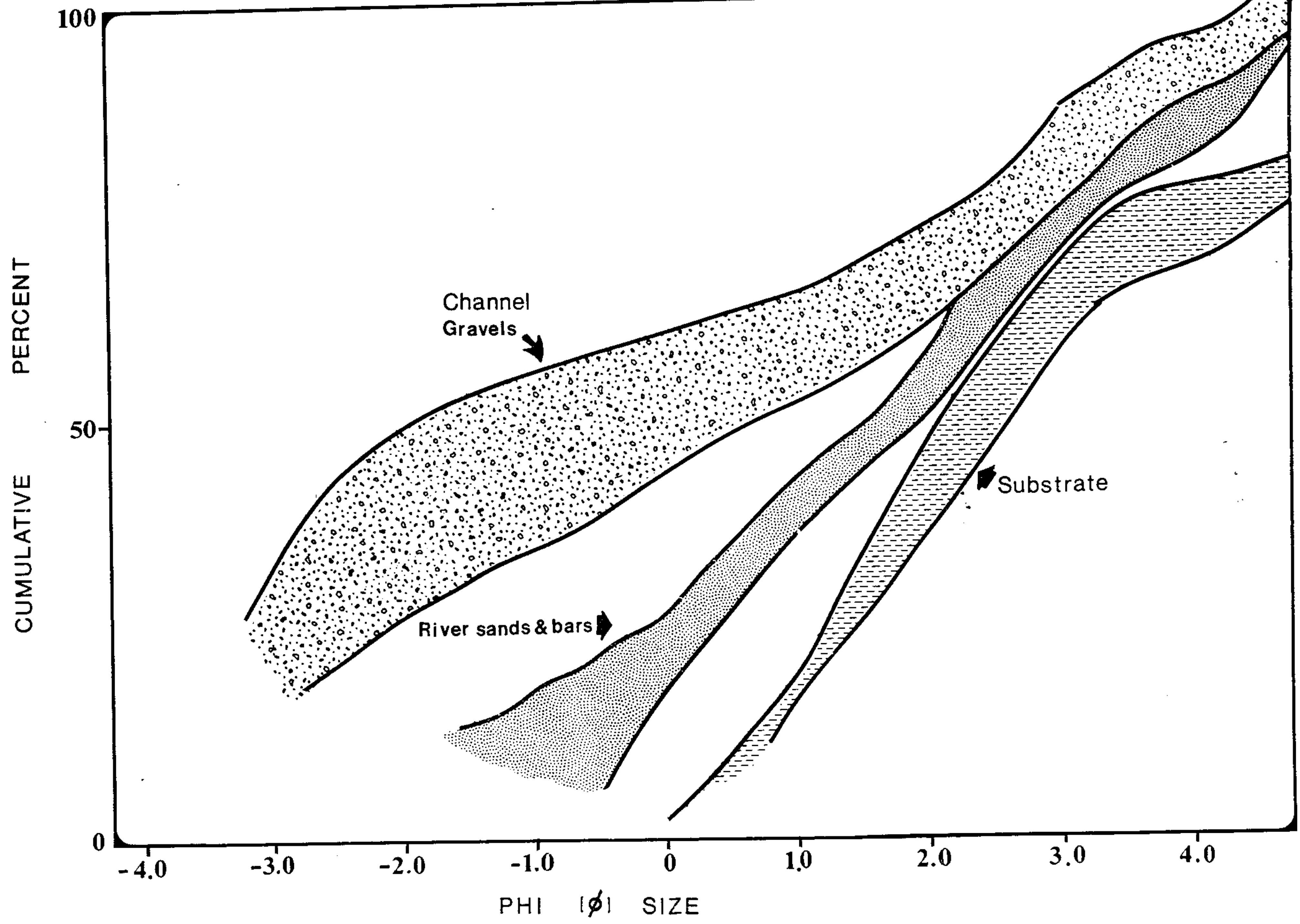
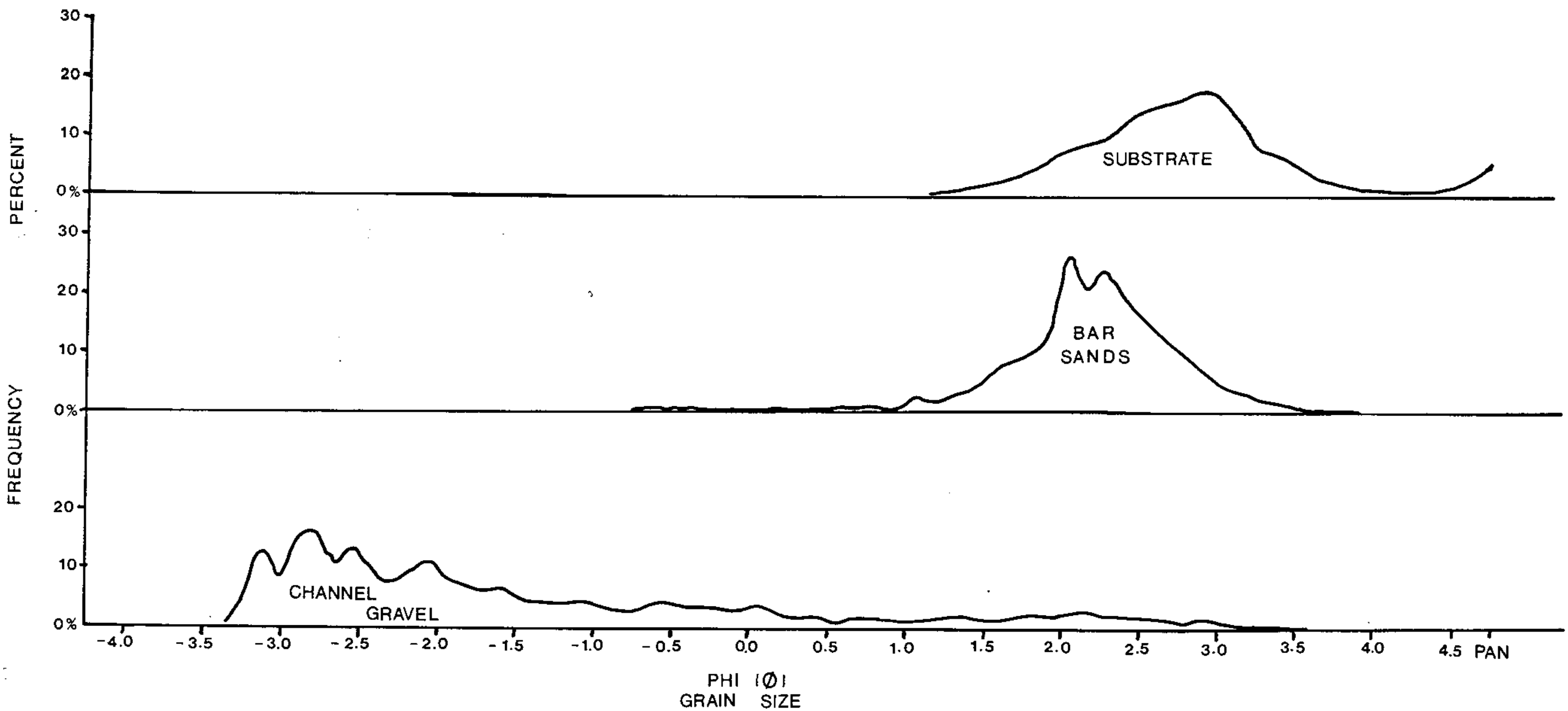


FIGURE 5. A series of cumulative weight percent curves for 28 samples from the braided stream sediments. Each pair of curves represents the grainsize extremes for the sedimentary sub-units. The sand curves merge with those for the gravel layers at 2.Ø phi (1/4 mm.) and finer since the sand sizes in the gravel are identical with the size distribution in an all-sand sample. In fact, if one selects a coarsest gravel, a sandy gravel, a gravelly sand, and a sand, one can reproduce the mean size, standard deviation, skewness helix discussed in Folk and Ward (1962).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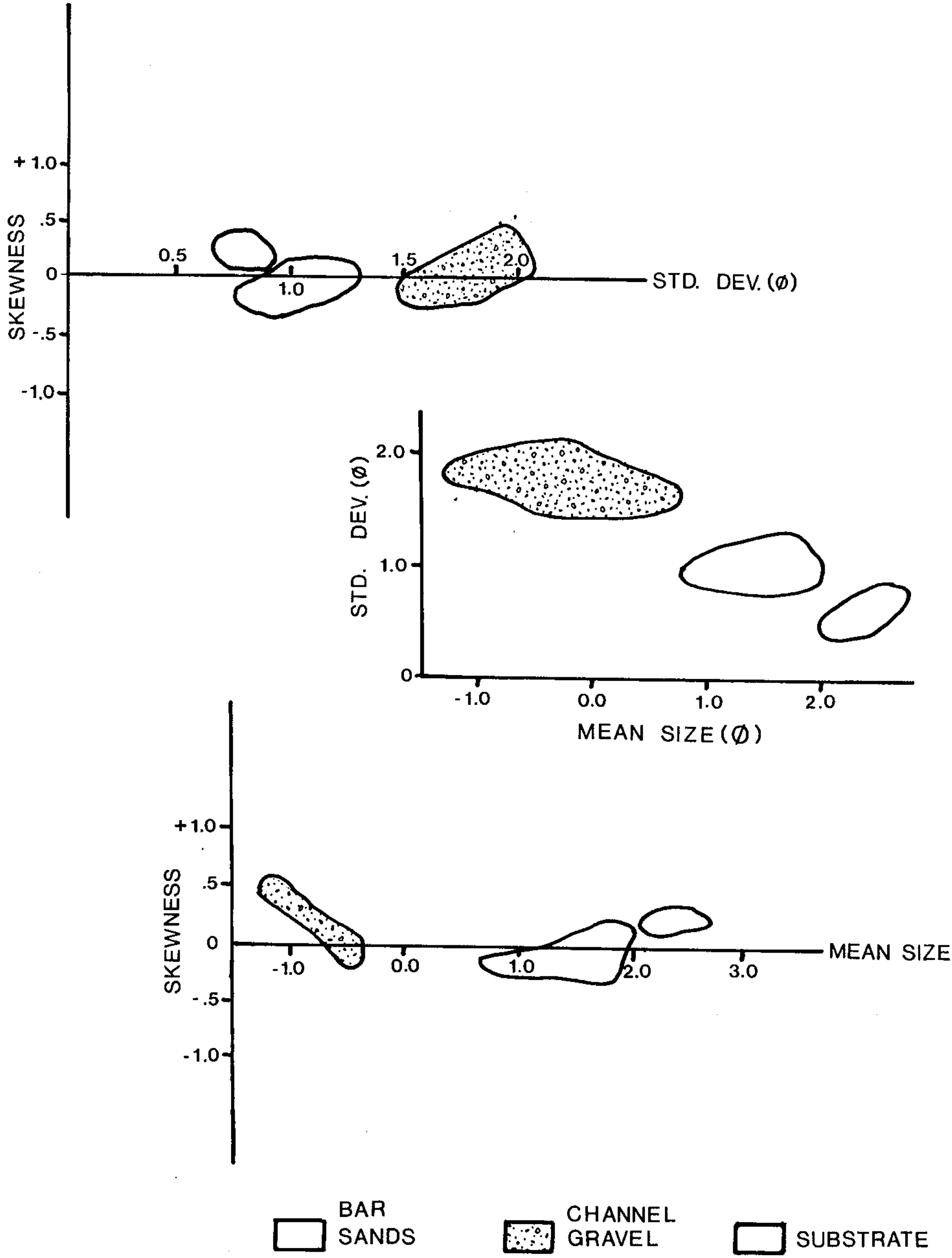
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
PAN
PHI (Ø)
GRAIN SIZE

FIGURE 6. Frequency percent curves for the three end member sediment types found in the cores and surface samples. All gravel samples contain some sand and all sands (except the dunes) contain from a few percent gravel to just occasional clasts. None of the non-substrate samples contained any silt or even 4.0 phi (0.062 mm.) sand, while a sievable substrate sand had at least 7% finer than 4.5 phi (0.045 mm.).

FIGURE 7. Statistical parameter plots for 28 samples from the Mullica Valley. The substrate (8 samples) form a tight cluster. Only sands were analyzed since the silt content often exceeded 50% in some layers. The skewness of the gravel samples decreases and becomes negative as the mean size decreases. The bar sands continue a trend which reverses as the mean size gets still smaller. This continuous change in size and skewness is typical of low gradient, mid-fan bars where the gravels are dropped out as the flow passes up onto the bar crest (Folk and Ward (1962); Williams and Rust (1969)).



SKEWNESS
+1.0
.5
0
-.5
-1.0
0.5
1.0
1.5
2.0
STD. DEV. (Ø)
STD. DEV. (Ø)
2.0
1.0
0
-1.0
0.0
1.0
2.0
MEAN SIZE (Ø)
SKEWNESS
+1.0
.5
0
-.5
-1.0
-1.0
0.0
1.0
2.0
3.0
MEAN SIZE
BAR SANDS
CHANNEL GRAVEL
SUBSTRATE

Mullica River Valley Stratigraphic Columns

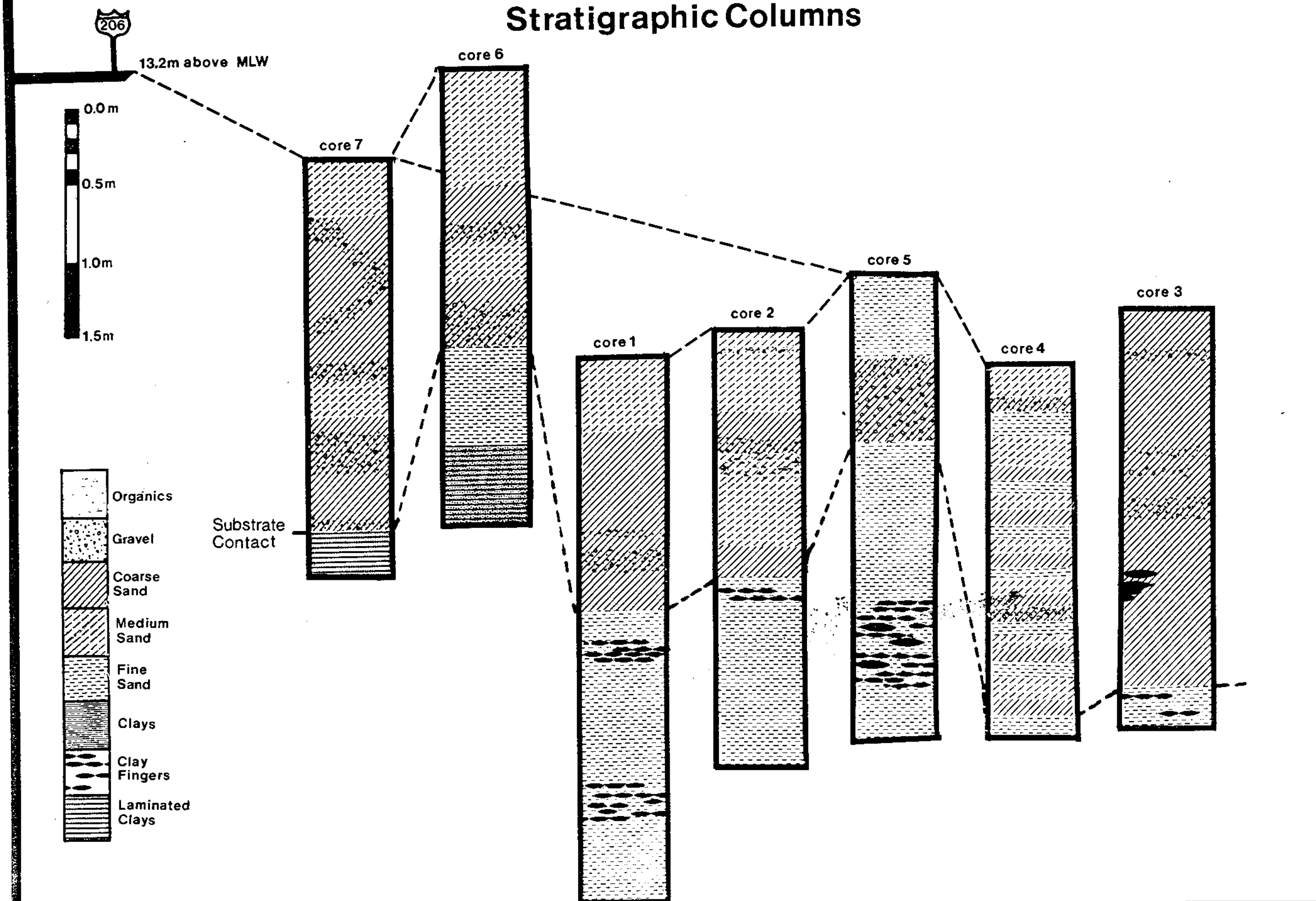


FIGURE 8. Correlation of vibra-cores 1 through 7 within the Mullica Valley. The contact with the substrate defines the base of the braided stream deposits from the older coastal plain sediments. The substrate is not as uniform as the grain size analysis would indicate simply because it was impossible to sieve the clay-silt layers. Each core contained at least 3 fining upwards sequences, not all of which began as a gravel.

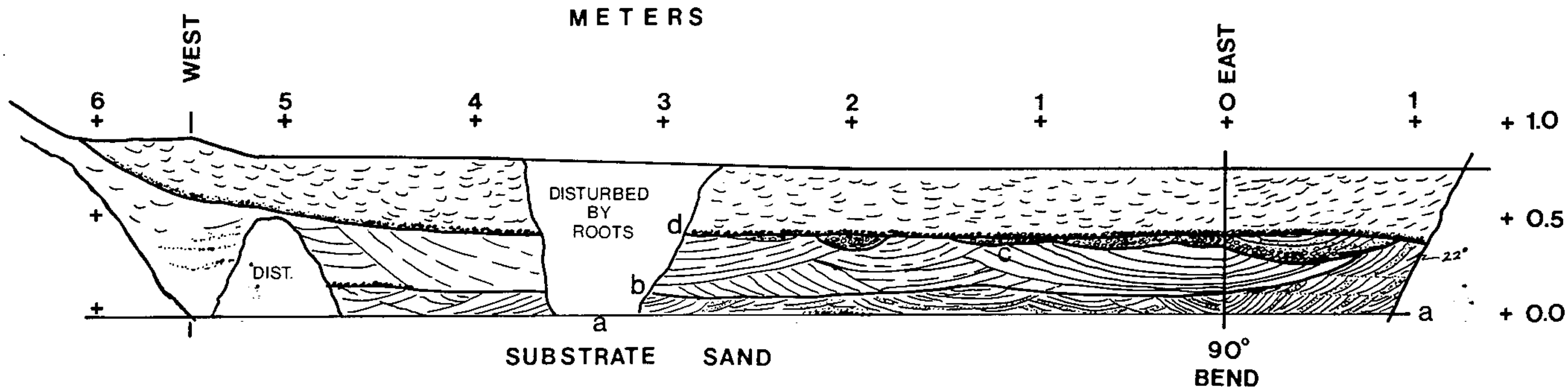

METERS
WEST
EAST
6
5
4
3
2
1
O
1
+ 1.0
+ 0.5
+ 0.0
DISTURBED
BY
ROOTS
DIST.
a
b
c
d
22°
SUBSTRATE SAND
90°
BEND

FIGURE 9. Scaled drawing of a 5.5 meter long, 9Ø cm. deep trench excavated perpendicular to the northeast margin of the downstream end of the bar, mapped in figure 4. This trench was dug during a period of extremely low water table (the surface is normally wet) in Sept. 1985. This allowed, for the first time, a large scale observation of sedimentary structures within the stream deposits. Positions of growth of Holocene-to-modern trees has destroyed some of the bedding features, but otherwise it shows four distinct sequences of erosion and deposition. A 1.Ø meter long current-parallel trench was dug in the channel (east end).

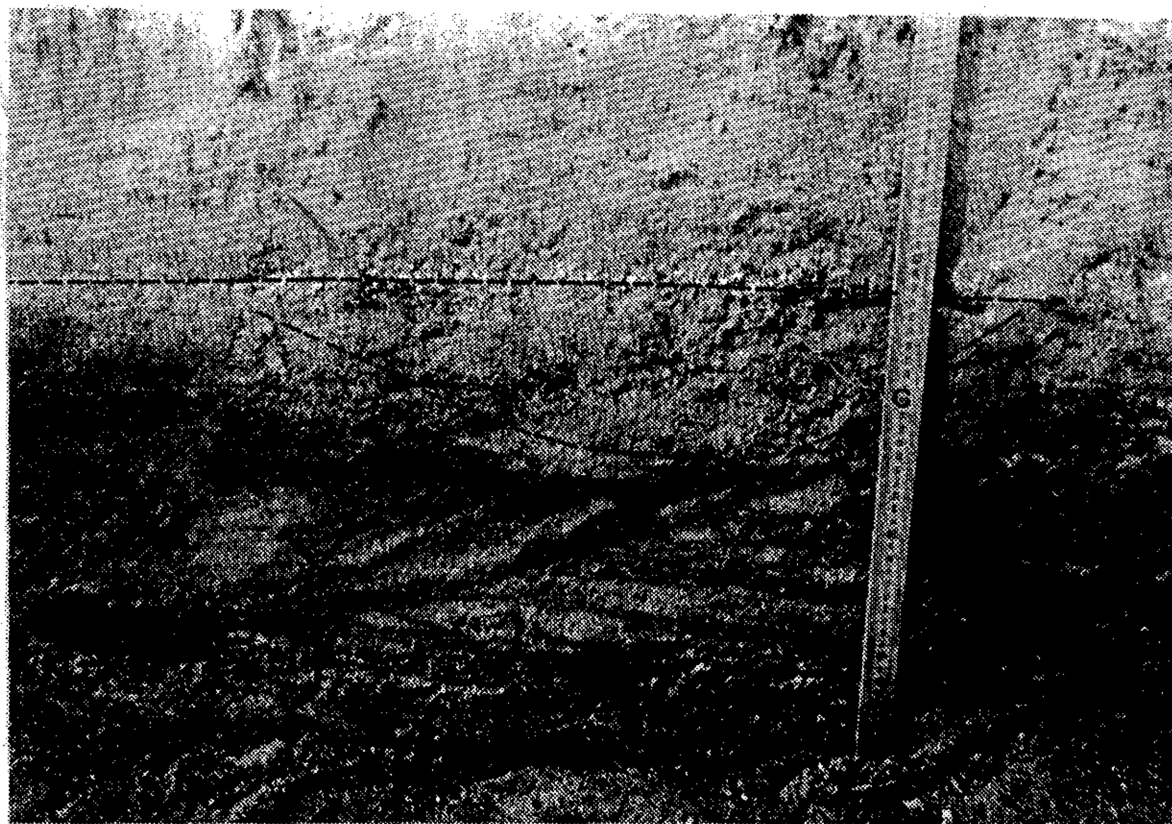
The trench shows:

a. Initial erosion of the substrate; Ø.5-Ø.8 m. wave length, steeply dipping (22 degrees) cross bedded festoon bedforms deposited.
b. Truncation of these by large scale, low angle festoons (1.2 m. wave length) which are 99% sand laminations.
c. Thin layer of Ø.8 m. wavelength, gravel-filled, festoon scour mega-ripples.
d. Truncation and or removal of these by a fine gravel basal layer, quickly grading upward into small scale ripples. The gravel layer traces into the bar and under the 1Ø-15 cm. channel terrace (west end).

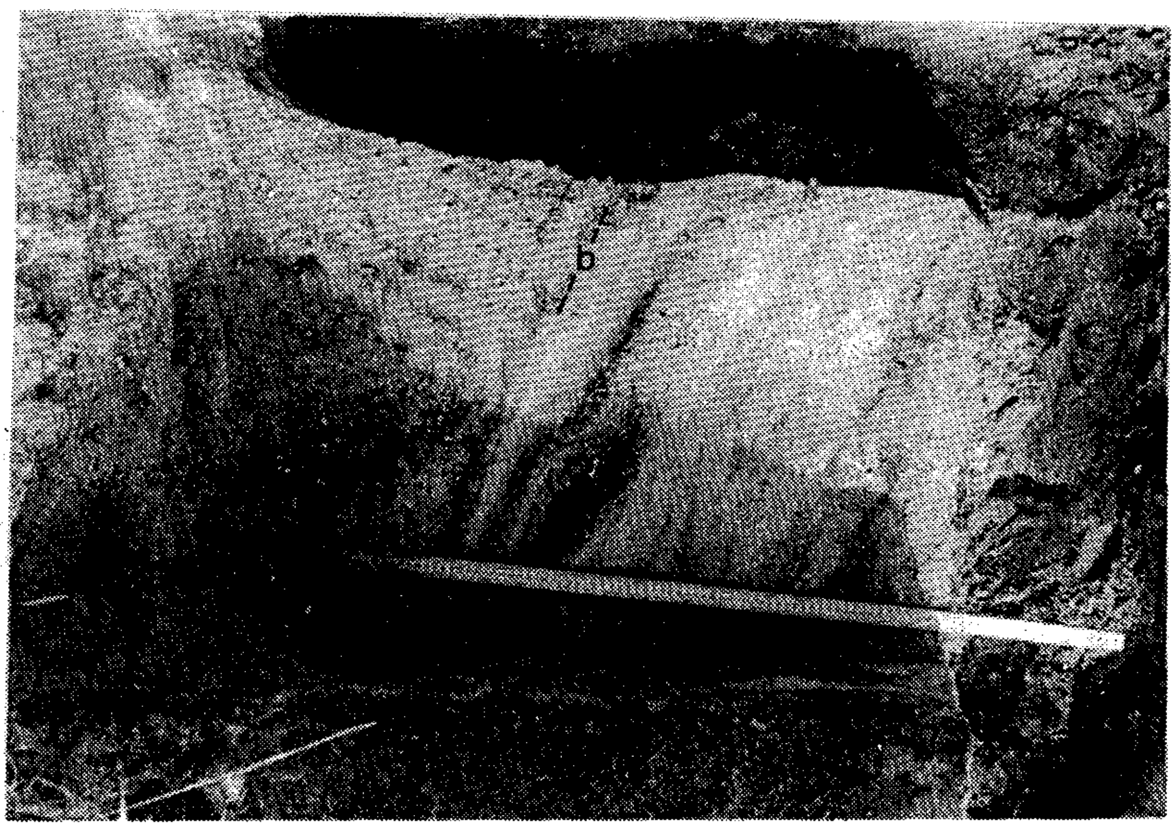
FIGURE 1Ø. Photographs of the trench excavated across the primary channel margin sketched to scale in figure 9.

A. Photograph of crosscutting sand festoons above disconformity b (Fig. 9). The gravel lens above the darker laminations has an upper contact at 37 cm. with the small scale ripple bedforms which make up the unit above the erosional contact d.(dashed lines)

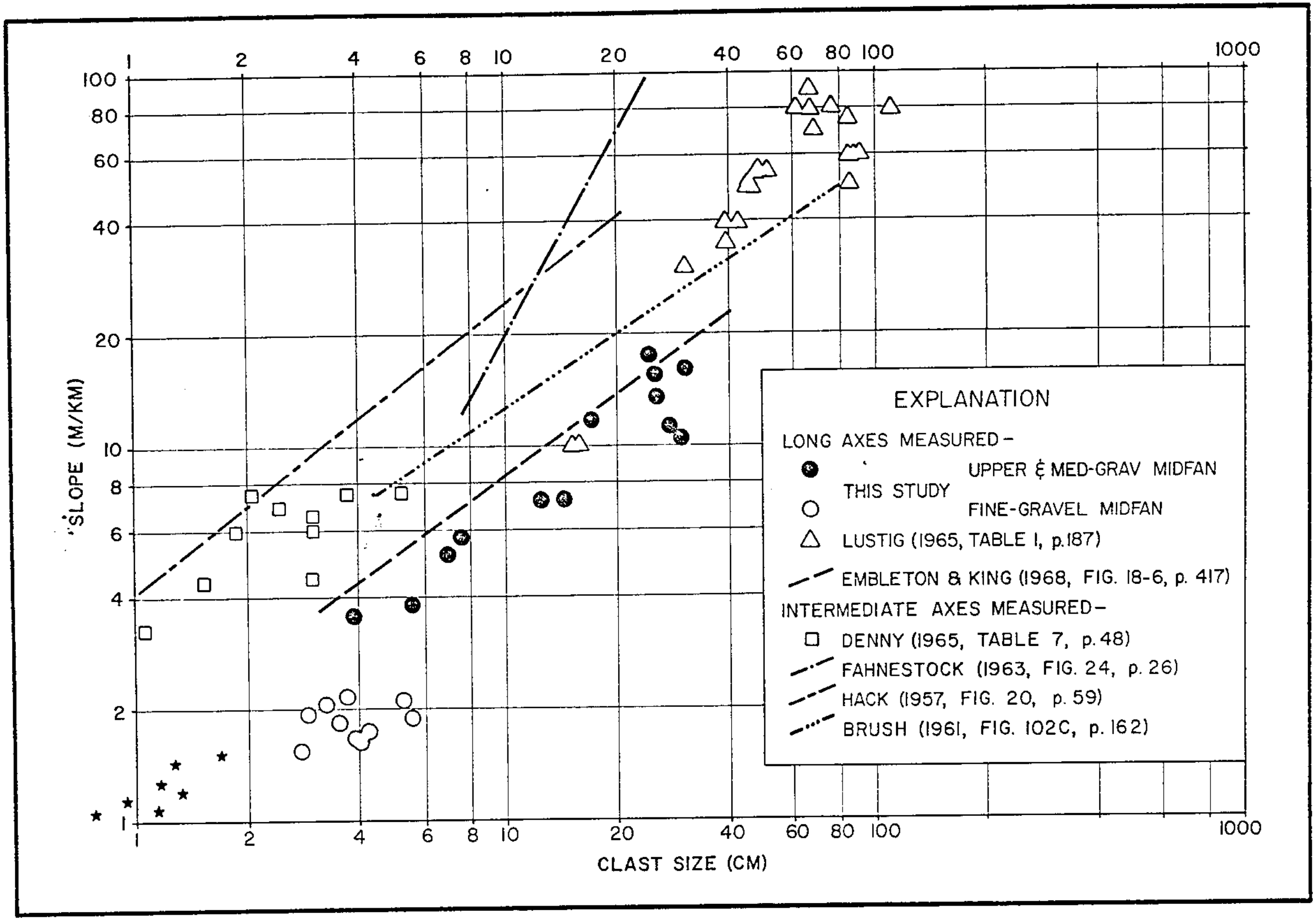
B. Photograph of a horizontal surface cut at 25 cm. above the substrate's erosional surface. To the left are the gravel/sand interlaminated festoons, to the right, the lower angle, larger scale, sand festoons. Flow is from left to right.



A



B



SLOPE (M/KM)
CLAST SIZE (CM)
EXPLANATION
LONG AXES MEASURED–
THIS STUDY
UPPER & MED-GRAV MIDFAN
FINE-GRAVEL MIDFAN
LUSTIG (1965, TABLE 1, p.187)
EMBLETON & KING (1968, FIG. 18-6, p. 417)
INTERMEDIATE AXES MEASURED–
DENNY (1965, TABLE 7, p.48)
FAHNESTOCK (1963, FIG. 24, p. 26)
HACK (1957, FIG. 20, p. 59)
BRUSH (1961, FIG. 102C, p. 162)

FIGURE 11. Figure 9 from Boothroyd's 1972 paper on the Scott Glacier. The stars represent the seven samples from the cores with large clast-size gravel in them. The slope-gradient/clast size data from the Mullica places the data points to the left of the lowest gradients Boothroyd studied, but nonetheless on the same line when extended.

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A Pleistocene Lake in Central New Jersey

Elizabeth Redfield Marsh[1]

Abstract: There appear to have been one or more episodes during the Pleistocene in which the Delaware River was obstructed while the glacier was melting, creating a large, temporary lake in the Delaware Valley and over part of Burlington County in central New Jersey. This lake may have excavated itself into the fine sands of the Inner Coastal Plain by a process of underwater slumping and flow until it was 25 miles in extent north and south and about 15 miles east and west. In at least one episode, in the Wisconsinan glaciation, the water apparently found spillways in an earlier valley, parallel to the Delaware, and overflowed to the Mullica River valley and the Atlantic Ocean. Evidences include: a series of shoreline features at 140', 100', and 60' elevation; the extent and shape of the depression which contained the lake; the sediments within the presumed lake; the configuration of the spillway valley and fan; and deposition downstream from the Wisconsinan event.

Introduction:

The geomorphological evidence presented here suggests that, from time to time during the Wisconsinan glaciation and possibly earlier, floodwaters created a large, temporary lake over western Burlington County in central New Jersey and that in at least one episode this water body overflowed down the valley of the Mullica. Further examination of sediments and landforms is required to confirm this hypothesis and to understand where the lake fits into geologic history.

Present Geomorphology:

The Inner Coastal Plain in New Jersey slopes from an elevation of about 130 feet south of New Brunswick to a depression east of Mount Holly with interfluve elevations of 40 feet. This lowland is bounded by the Delaware River's Pennsylvania bank on the west and, to the east, by a distinct escarpment and a plateau over 200' high between it and the ocean. A low ridge separates the interior of this lowland from the Delaware River Valley. (See map, Figure 1.)

At the south end of the lowland and 10 miles east of the present Delaware is a wide, subtle valley extending southward through the Pine Barrens toward the Atlantic Ocean. This valley contains both the upper tributaries of the Mullica River flowing southeastward and those of the Rancocas which flows northwest, down to the lowland and to the Delaware. Both headwaters rise from several bogs at the divides. The Mullica headwaters descend through narrow valleys at their sources; the small modern streams cross a broad alluvial fan on their way south, and then merge into the present Mullica River. On that fan are the meander scars of earlier fluvial events.

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Evidences:

The morphological evidences suggesting the presence of a sequence of lakes in the Inner Coastal Plain lowlands include, first, the profiles and sediments of the lakes themselves and, second, the remains of a lake overflow episode by way of a spillway well above the presumed lake floor. Supporting the hypothesis that the lakes existed, there is a series of shore features with repeated features including a beach rim, a declivity just off-shore, and surfaces on which lake-bottom sediments remain. The redeposited sands and sediments within the lake basin include, almost everywhere, characteristic laminae in the C horizon with evidence of deposition in fluviatile and still water environments.

Further evidence of a large body of relatively still water appears in the series of spillways and downstream waterways, by which water overflowed from time to time. The sills of these spillways, at about 95', are 25' above the bottom of the presumed lake from which the water flowed. As for the obstruction or dam which created the lake itself, the present study can only give evidence that such an obstruction developed. However some suggestions of how the Delaware might have been blocked downstream are given in the next paragraphs.

The Lake: Origins:

If there was, intermittently, a relatively quiet body of water upstream of Philadelphia, in the Delaware Valley, there must have been a mechanism which could raise the water level about 30' and keep it there. In an episode of rapid glacial melting a combination of bedload deposition, jams of ice floes and timber, and a modest delta fan from the Schuylkill River at Philadelphia could, by itself, create the necessary temporary rise to back up the river for periods of days or weeks. The evidence of the lake suggests, however, that the obstruction downstream was a significant dam and that it recurred from time to time in unusual circumstances.

For example, the Schuylkill could build a delta across the Delaware at any time when the larger river was backed up and in flood if the smaller river were carrying an unusual load of water and sediment. Such an unusual flow might occur if the Delaware were blocked by a glacier tongue at Lehigh so that meltwaters backed up in the Great Valley and joined the Schuylkill or else if there were breakouts of ice in the upper Schuylkill, allowing backed up water to carry loads of periglacial colluvium out of the mountains toward Philadelphia. Or there may have been a different process; the evidences that the lake was present require that a mechanism existed to create it.

Lake: Shorelines:

The first piece of evidence suggesting that a lake created some of the landscape features of central New Jersey is seen in the traces of its successive levels. A series of traverses at the rim of the lowlands, taken at the interfluves between small modern streams, shows a recurrent profile with shore features occurring at several elevations, as follows:

200' level: This surface is earlier than those being studied for the lake hypothesis. It is included because it includes the features found in the later and lower levels. There seems to be a little wave-cut cliff on some uplands at about 200' and then, on the level uplands at Fort Dix, at about 180' there is a thick deposit of the characteristic, laminated soil also found at the two

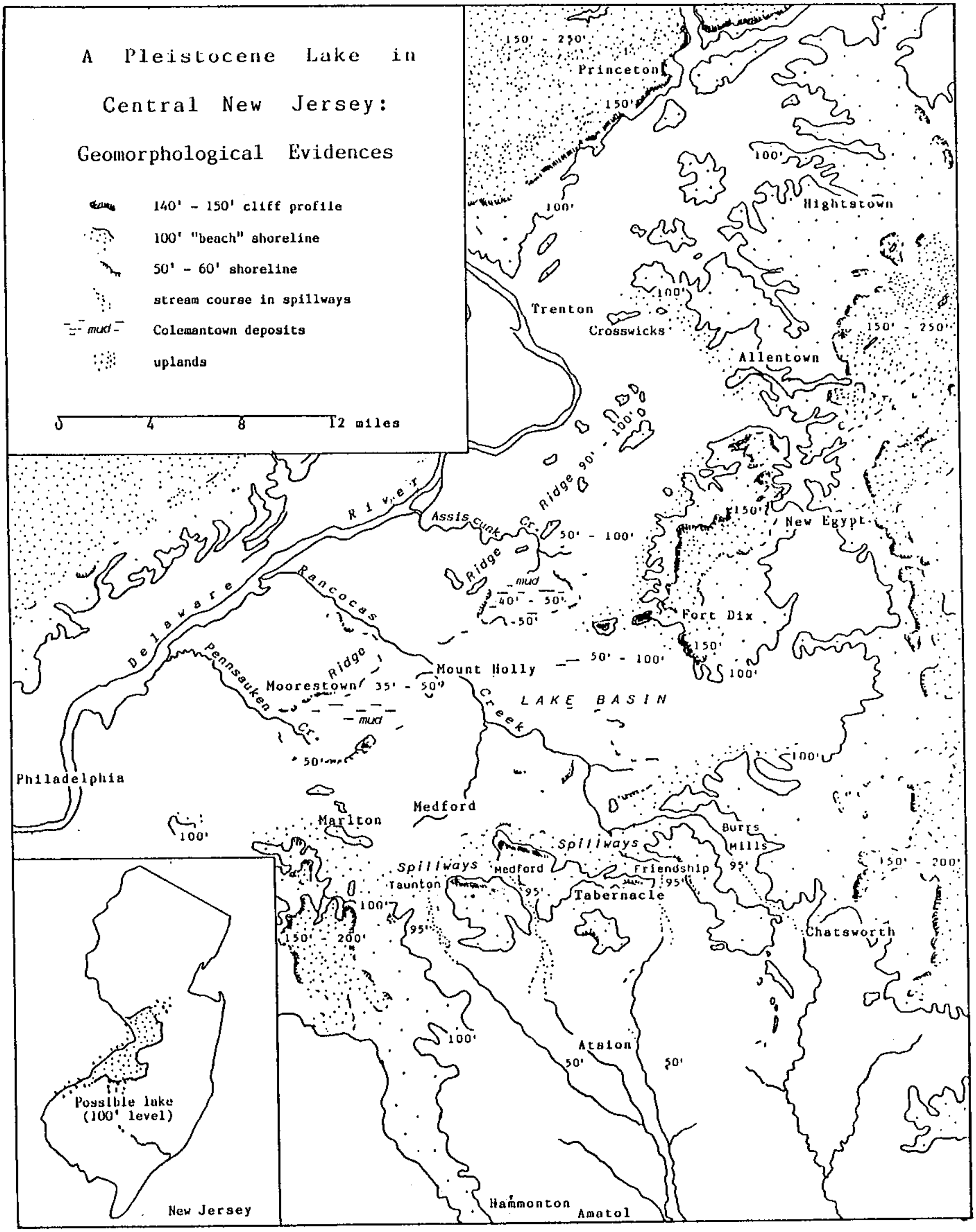
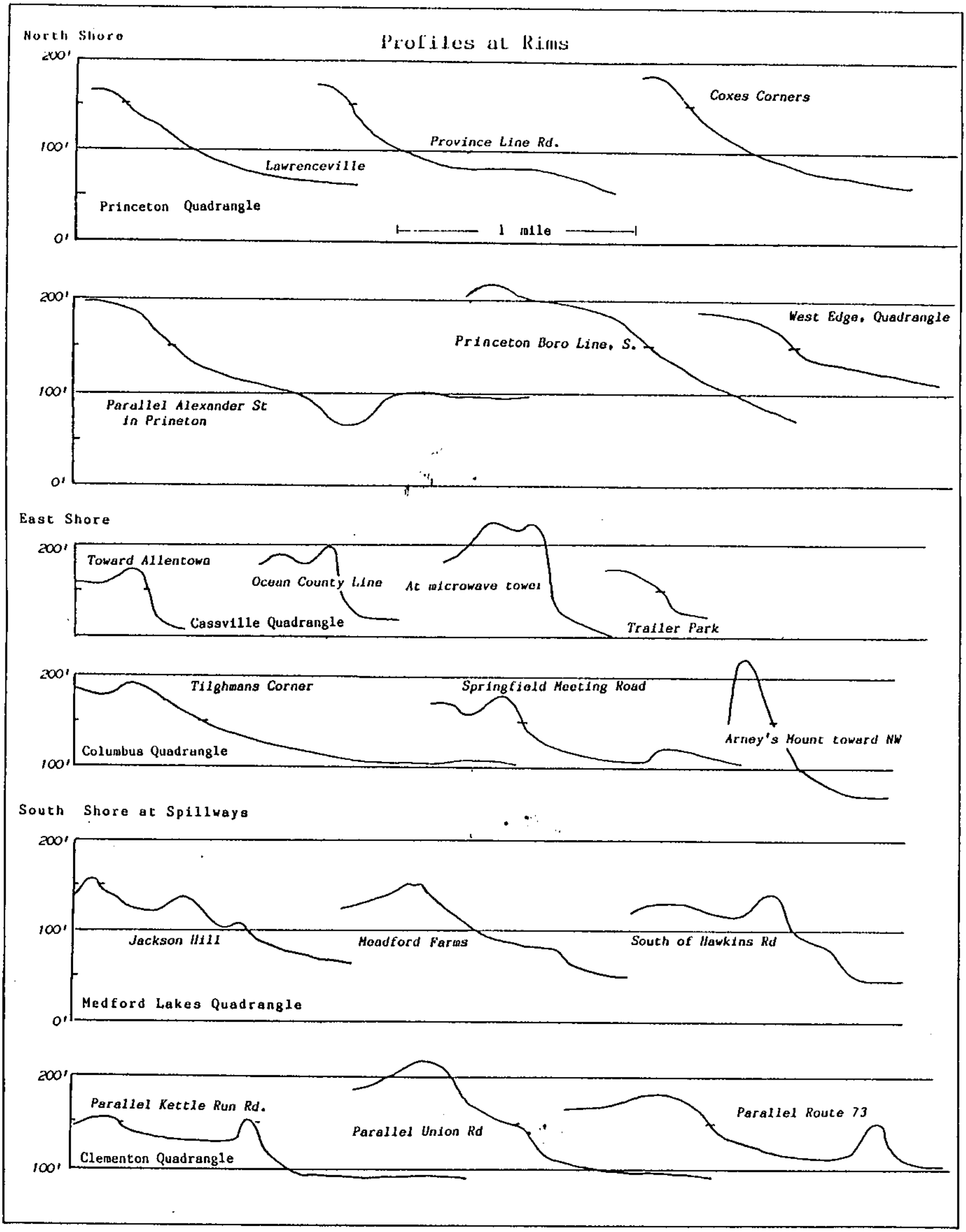

A Pleistocene Lake in
Central New Jersey:
Geomorphological Evidences
140' - 150' cliff profile
100' "beach" shoreline
50' - 60' shoreline
stream course in spillways
mud
Colemantown deposits
uplands
0 4 8 12 miles
Princeton
Hightstown
Trenton
Crosswicks
Allentown
New Egypt
Fort Dix
Delaware River
Assiscunk Cr.
Rancocas
Ridge
Pennsauken Cr.
Moorestown
Mount Holly
Creek
LAKE BASIN
Philadelphia
Marlton
Medford
Spillways
Taunton
Tabernacle
Friendship
Burrs Mills
Chatsworth
Atsion
Hammonton
Amatol
Possible lake (100' level)
New Jersey

Figure 1



North Shore
Profiles at Rims
200'
100'
0'
Lawrenceville
Province Line Rd.
Coxes Corners
Princeton Quadrangle
1 mile
Parallel Alexander St in Prineton
Princeton Boro Line, S.
West Edge, Quadrangle
East Shore
Toward Allentown
Ocean County Line
At microwave towe
Cassville Quadrangle
Trailer Park
Tilghmans Corner
Springfield Meeting Road
Arney's Mount toward NW
Columbus Quadrangle
South Shore at Spillways
Jackson Hill
Medford Farms
South of Hawkins Rd
Medford Lakes Quadrangle
Parallel Kettle Run Rd.
Parallel Union Rd
Parallel Route 73
Clementon Quadrangle

Figure 2

lower levels. Between 190' and 130' there is a declivity to a lower surface.

140' "cliff": At about 140' of elevation there appears to be a wave-cut cliff encircling the lake lowland on three sides. The location and profile of this feature are shown in Figures 1 and 2. This cliff is cut into the Mesozooic shales for about 20 miles north-east from Trenton; it runs across the Princeton campus. The same cliff or one which is accordant is also cut into the sediments of the Coastal Plain, as shown in Figures 1 and 2. This little cliff is well displayed near New Egypt, where it runs south for 15 miles, just west of Route 539; it appears again rimming the promentory on which Fort Dix stands. To the south the cliff cuts an upland south of Marlton and another east of Medford.

This prominent feature may have had its beginnings as the underwater extension of the 200' level described above; it may be the rim of an early stage of the 100' level listed below. Or it may be a separate phenomenon. This shoreline may be a relict of a marine embayment; there is a similar break in slope, less well displayed, on the seaward side of the coastal uplands.

100' level: This beach and off-shore feature appears as broad expanses of sand along the southern rim of the lake lowland, at about 100' elevation, and as declivities from 90' down to 80' and to broad surfaces at 70 to 80', on the north, east, and south of the basin. The 90' depression begins near Marlton on the southern rim, just below the Fort Dix upland on the east, and south of Allentown on the north.

The wide beach on the south rim appears to be reworked sands of the underlying Cenozoic marine deposits; in a series of analyses (Table 1) the sand from these beaches resembled marine deposits and only one sample, that from a presumed beach spit, showed the grain size distribution characteristic of beaches.

The elevations of the four presumed spillways southward are at about the level of these beaches, at 95' for most of the passages. There are spit-shaped features at 100' along the spillway entrances.

The farm fields at Tabernacle, to the south, lie at the level of this shore, at about 95', with a slight cliff cut into the uplands at the end of this surface, one mile south of Tabernacle. The village of Marlton is just above this shore, on the south rim of the lake. There is a ridge along the east side of the Delaware River, with surfaces which may be wave cut at about 100 feet elevation and some possible islands wave-cut to 95' within the lowland.

The deepening slope offshore, at 90', will be described later as a possible underwater excavation.

60' level: The lowest distinct shore feature is at 60'. The 70' - 80' surface slopes to a declivity from 60' down to 50', bottoming out to flat expanses of fine sediments at about 45' average elevation. This too appears to be a subaqueous erosion feature.

Lake excavation:

This paper will discuss the 100' and 50' levels of the lake and mention the surface which lies below the 140' cliff, into which the lower levels are excavated.

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Table 1

Sediments analysis

Sample	Location	Graphic mean Description	Variance Sorting	Skewness Beach/dune	Diagnosis
1	70' ridge Egg Harbor City (Taylors, Heidelberg Ave.)	0.076 Coarse sand (river sand?)	1.44 poorly sorted (glacial?)	-1.13 beach	Possible beach in river sand
2	100' sand N of Tabernacle (Mill Chase Rd.)	1.26 Medium sand (flood plain or beach?)	1.40 poorly sorted (glacial, river, lagoon, offshore?)	0.15 dune	Outcrop of Kirkwood sand windblown
3	100' sand South end (Wards Pit)	1.19 Medium sand (river?)	1.15 poorly sorted (glacial, river, lagoon, offshore?)	0.18 dune	Unclear
4	100' linear sand at spillway (Burrs Mill Brook, Johnson Place)	1.77 Medium sand (beach?)	1.21 poorly sorted (see above)	-0.25 beach	Beach spit at spillway
5	100' sand South end (Rt. 72, Green Lane)	2.46 Fine sand (offshore marine?)	1.08 poorly sorted	-0.35 beach	Outcrop of Kirkwood sand
6	50'surface (Bear Swamp Rt. 70)	3.00 Fine sand (offshore or dune)	1.41 poorly sorted	0.86 dune	Dune of glauconitic sediments

Note: Analyses from Wellesley College' programmed computer print-out by Ann Grunow. Sediment size on Wentworth Scale.

The upper surface of the Inner Coastal Plain lowland, below 140' and to the 100' rim of the lake, is floored with the "Bridgeton" yellow sands and gravels. These gravels are believed, by Owens and Minard (1979) and others to have been left by the ancestral Hudson as it flowed along the Piedmont rim to join the Delaware. Such gravels mantle much of the southern counties of New Jersey, and also may occur on uplands in the old valley through which the 100' lake later drained.

These gravels stretch to the north, from the lake rim, in a level ramp 110 to 130' in elevation around Hightstown and toward New Brunswick. This surface continues south of Trenton in a few upland patches on the escarpment which

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parallels the Delaware; the New Jersey Turnpike lies on this surface for much of its route south of New Brunswick.

The 100' level lake lay in a depression about 25 miles long, reaching from Allentown in the north to Marlton in the south and excavated beneath the Bridgeton gravels and into the Cenozoic sands of the Inner Coastal Plain.

The 60' level lake was in a depression about 10 miles long, from north of Mount Holly to near Marlton. This lowland is drained by the Pensauken, Rancocas, and Assiscunk Creeks which cut through the ridge to reach the Delaware.

The lake-bottom lowlands at 70' to 80' and those at 45' are flat and slightly affected by recent stream valleys. Their arcuate shapes have the appearance of being excavated or scooped into the sands rather than eroded by rivers. William Von Arx at Woods Hole, in discussing this erosion, noted that while sand in banks has a steep angle of repose, when fine sand is under water it flows to an angle of near zero. Any child who has tried to maintain a moat while building sand castles knows how rapidly beach sand saps away at the banks and slides to a flat surface under water.

Hence, a possible mechanism at work in this system may be a sapping and flow, in which, as water rises into the fine sand substrate, the sand enters flow and spreads for some distance. It is hard to think of a modern analogy of this process on a larger scale than the moat around the sandcastle; however the sapping and flow hypothesis seems to fit the evidence in the landscape and the deposition found here.

Lake bottom soils:

Some of the evidences for the lake and for its means of excavation are in the sediments and soils of the former lake bottom. The Soil Survey maps for Burlington County give a similar description for most of the fourteen or so soils for the area presumed to have underlain the lake. In each of these soils, except for those which developed on dunes and the Colemantown muds discussed later, the C hozizon, from about 3 feet down, is described as containing sand and clay laminae. The Freehold series, a common soil which is moderately rich in the local glauconite is described with "alternating layers of light, olive-brown, loamy sand and olive brown, fine sandy loam; loamy sand layers are single grain, loose; sandy loam layers are massive, friable or slightly firm; glauconite content low; mass speckled by unweathered dark glauconite grains," in the C horizon.

Other soils differ in the sand-glauconite ratio, but each soil included the same alternating layers. The glauconite comes from the deeper marine sediments of the area, the Manasquan, Hornerstown and Navesink Marls and the Merchantville Clay (Lewis and Kummel, 1912; Owens and Sohl, 1969).

Minard and Rhodehamel (1969) describe this deposit also, calling it the "glauconitic alluvium," writing "(The sediments) are nearly everywhere characterized by conspicuous, thin horizontal layers of sand. The stratification is emphasized by the marked alternation of fine and course layers and layers rich in green glauconite as compared with layers less rich in that mineral." They say that " the uniform stratification and narrow range of sediment size...suggest a fluviatile depositional environment of remarkable uniformity" (1969, p. 292, 293).

8 In exposure some of these layers are clearly fluviatile. It is the uniformity, the extensitiveness, and the landscape configuration which suggest the possiblity of a subaqueous, slump and flow deposition in other places. The sand, it is postulated, was deposited in periods of high energy erosion, as under waves; the clay settled in times of calm.

Owens and Minard classify these laminated sediments into useful units in their "Geologic Map of the Surficial Deposits in the Trenton Area" (1975). Their differentiation, by materials, shows their "Greensand 2," which are the glauconitic deposits lying at 60' to 100' in the main basin, below the 100' rim, as being from a more energetic environment, with up to 6' of gravel at the base and with a good deal of glauconite mixed into the sediments. In contrast their "Greensand 1," lying mostly at lower elevations within the 60' rim is less glauconitic and more prodominantly fine and medium sand; it does not contain the thick gravels. Owens and Minard suggest the Sangamon as the age of these deposits because of the higher sealevel at that time. They also describe "Greensand 3," the deposits of the 200' level found at 150 to 180' on top of the Fort Dix upland, as similar in composition to the others.

Both Greensand 1 and Greensand 2 filled former stream valleys; Greensand 1 is up to 40 thick in the Rancocos Valley; on the flatlands the depth of both these deposits is around 10', according to the Owens and Minard map.

Above the lamella in the C horizon the Soil Survey describes the A and B horizons for each soil as consisting of 10 to 16 inches of "fine sandy loam" in the A horizon over sandy clay loam or sandy loam in the B horizon. Certain soils which are high in "marl" or glauconite have clay loam in the B horizon. These homogenous layers may have been deposited by heavily laden floodwaters on top of the sands.

If the glacial lake had persisted over the winter there would be fine sediments with varves on the bottom. It is proposed that the lake under discussion would not have survived once the floodwaters fell; however there are areas of what appear to be lake bottom sediments on the 70 to 80' surfaces and again at about 45'. Many of the deposits in the 70' range are fragmentary, resting on the middle terraces of small streams, but there is a more or less intact expanse of the 45' sediments just north of Mount Holly, within a flat depression four miles wide and two or three miles north and south. The fine sediment covering these areas is named the Colemantown soil in the Soils Survey. It is described as rich in glauconite with its top 10 inches of "dark, greenish-grey heavy loam... sticky and plastic when wet" (1971, p. 16). Some exposures in the field are, however, several feet thick.

It is the pervasiveness of the laminae all over the area, and their depth, along with the evidence of the channel overflow at 100', which suggest a subaqueous excavation of the lake depression rather than the streambank sapping which is an alternate hypothesis.

Material in several of the old wetland deposits have been carbon dated for the late Wisconsinan: a sample of wood in the 80' level, off Route 537 near Fort Dix, was dated at 10,770, +300 B.P.; a sample just east of Crosswicks at the north end of the depression, at the basal layer of the lake excavation was dated at 26,800, +1000 years B.P. (Minard and Rhodehamel, 1969, p.309, and Sirkin _et. al_., 1970).

9

A final interesting deposit occurs at Trenton, where the Delaware leaves its Piedmont gorge. The city there lies on a platform of a different sediment made up of materials whose provenance is up the Delaware to the north, This fan has a level surface at 50 to 55' and has the appearance of a river-mouth delta into the lake. Owens and Minard who describe this deposit as the Graywacke 2 give it a date, based on field relationships, of not later than early Pleistocene.

Boundaries of Lake:

The processes of erosion, including the sapping away of fine sand deposits, appear to have extended the shores of the lake levels, in intermittent flooding events, until the water reached a more resistent formation.

The Inner Coastal Plain is underlain by a succession of clay beds interspersed with fine sand deposits, all dipping to the east and lapping up onto the Piedmont to the west. In the sapping process the fine sands would have been carried away, expanding the excavation until a clay formation intersected the surface. Thus the resistent Merchantville and Woodbury Clays remained as an upland to the west, creating the low ridge along the Delaware River. The Hornerstown and Navasink Marl formations outcropping on the other side of the lowland created the eastward shore and the 140' to 180' escarpment on which Fort Dix stands. The soft Englishtown and Mount Laurel sands in between were easily carried away along with some less resistent clays. Beyond and to the south the Vincentown and Kirkwood sands were also more easily transported, leaving the partly indurated. coarser Cohansey sands to remain as the uplands plateau of the Pine Barrens.

The Spillways:

The sills of the spillways leading south to the Mullica River are at about 95', placing them high above the 60' level of the lake floor in the late Wisconsin when the last overflow occurred. The older valley it which the spillways developed runs south from Medford and Chatsworth; it is 20 miles wide and cut 100 feet down into the sediments of the Pine Barrens.

To the west this valley is separated from the present Delaware river by an upland promentory rising south of Medford. This upland continues south as the bluff above the Delaware; it is over 200' in elevation at its highest points. To the east the valley is bounded by the Pine Barrens plateau of the old surface of the Cohansey sand. The plateau rises just east of Chatsworth also to an elevation of 200' in places. State routes 70 and 72 pass across the head of this valley, just north of the spillways. US Route 206 travels down its center and state routes 73 and 563 descend its west and east sides. The little streams feeding the Mullica River flow in the valley today.

Within the valley, particularly at the upper end, there appear to be relict upland surfaces of an earlier valley floor. The gravel on these "islands" and similar hillocks downstream grades from 140' elevation at the upper end, near Medford, down to 100' twenty miles downstream, at Amatol near Hammonton. There, on the lowlands east of Hammonton the gravels seem to merge as a train on the upper bluff on the south side of the present Mullica River. These gravels, known locally as the "river stones," contain deeply weathered cobbles, some of which are crystalline, suggesting that they came from a distance, carried by a river, not a lake. The gravels slope on down from 100' south of Hammonton to

50' as they approach the sea. There appears to be the remnant of a high beach at 70' elevation just west of Egg Harbor City on Heidelberg Avenue. (See sand analysis, Table 1, sample 1.) South of that beach is a sandy plain at about 60' lined with other beach-shape features all trending east-west; the present coast trends northeast-southwest.

At the spillways at the head of this valley, between the upland islands, are low-relief gorges containing bogs, now used for cranberries. The headwater streams, which now flow from these bogs either north to the Rancocas or south to the Mullica began in these gorges, but the valley widens a few miles downstream into a depositional surface.

At Atsion this depositional slope spreads into a smooth, classic fan. Across this surface wander the traces of braided stream channels, which are easily recognised from the air due to a recent fire. These channels were left, apparently, when the final glacial meltwater overflowed down the spillways; they are fresh and visible today. Stewart Farrell at Stockton State College had noted the similarity of this stream pattern to glacial outwash features he had seen in Alaska. His students are now studying these channel traces in detail. Dr. Farrell's report on this feature appears elsewhere in this volume.

Below the fan at Atsion the stream channels gather together to enter the lower valley of the Mullica on the way to the sea. However on the farm fields above the lower valley, at about 60', occasional sandstone boulders turn up each spring in farmers' fields, as if ice floes had run aground up there in the summer floods, leaving Pennsylvania stones in the sands of New Jersey.

It appears that when the lake rose in Burlington County it found a spillway somewhere downstream of the present divide. Water overflowed and began cutting the gorges at the present headwater, the relatively clean water carrying only the local sand and spreading it downstream. These episodes were intermittent and soon over; otherwise the gorge would be far deeper. In between overflows the Kirkwood and other sands at the headwaters were worked back and forth by lake waves, blocking one spillway to permit another to be used later. A sand sample taken at a spit at one spillway appears to be of beach sand. (Table 1, sample 4.)

Of the four apparent spillways, each has a level stretch of stream-valley or bog for several miles at about 95' or a little lower, so that it is hard to define the sill; there is evidence of successions of spits across some of these spillways.

The four spillways lie, from east to west: at **Burrs Mills,** at **Friendship** near at Tabernacle, south of **Medford Lakes** toward Flyat, and south of **Taunton.** The Burrs Mills spillway is crossed by the Sooy Place Road; the road travels along a beach spit at 100' elevation and crosses a little stream, the trace of the former spillway, at a cranberry bog. There are also traces of earlier, higher spillways and of stream gravels at higher levels than the present surface.

History:

Where does this sequence of lakes fit into geological history? Except for noting that the upper levels of the spillway valley to the Mullica appear to have been cut during the time when the Hudson-Delaware River was moving back and forth across the Coastal Plain, the confusing record of those rivers, of sealevel changes, and of the first glaciations does not permit much speculation about the higher shorelines and the old valley, beyond noting that they are there. The early shoreline was important to the later lake in that the embayment provided a space; the shape of the 140' embayment might well have had the same genesis as did the 100' lake.

As for the lake excavation and the 100' beaches, they cut into the remnants of the gravels left by the Hudson and so developed long after the Hudson had left its earlier route. The excavation of the lake lowlands may have been part of a process repeated in earlier glaciations, but it seems possible that the entire sequence happened during the Wisconsinan glaciation; the freshness of the braided stream traces downstream of the spillway suggest an event occurring at the very end of the Wisconsinan glaciation.

The evidences for the lake and the overflow seem to be strong, given the geomorphology of the area. However until more detailed work is done on sediments, especially on the Colemantown lake bottom deposits and on the origins of the laminae, and on the obstruction which dammed the water, the description of the lake remains an hypothesis requiring further testing.

Acknowledgements: Anne Grunow, now a graduate student at Lamont-Dougherty, provided field assistance and sand analysis, supported by an AMEX Foundation grant to Wellesley College. Christopher Smith, Soil Conservation Service, pointed out the Colemantown soils. Stewart Farrell at Stockton State College and Ben Marsh at Bucknell University raised questions and made suggestions.

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Tour guide: Pleistocene Features in the New Jersey Coastal Plain.

USGS Quadrangles covered: Atsion, Columbus, Indian Mills, Mount Holly, Pemberton, Trenton East.

Summary: This tour will show features resulting from events during the Pleistocene when, it is suggested, the Delaware River rose in times of rapid glacial melting. The floodwaters created a large, temporary lake over the lowlands in central New Jersey; the waters excavated the fine sand formations there by a process of slumping and flowing, expanding the lake basin. There appear to have been several stands of this lake, marked by declivities where the sand slumped into the depression and floored by bottom sediment surfaces. The declivities are at 140' with the old surface missing, at 90' with fine sediment deposits at 70 to 80', and at 60' with the fine deposits at 45'. At the 90' stand the river flood or lake apparently overflowed near Medford, Tabernacle, and Chatsworth to leave an alluvial fan at Atsion and to follow the Mullica River to the sea.

Start: Intersection of US 30 and Rt. 206. On Rt. 206 6.5 miles north to a sand road to the right. Use four-wheel drive only for 0.7 miles on sand road to a remnant sand dune.

Route description: The Routes 206 and 30 intersection is on the upland Bridgeton gravels overlain in places by dunes. The general surface at Hammonton is at 100 to 150 feet; at the intersection the elevation is 90. Overbank flooding in the Pleistocene may have contributed to the fertility which supports peach orchards and other crops along 206. In 2 miles, at the edge of the cultivated fields, the land descends to the former surface of the braided stream channel which carried the overflow meltwaters from the Delaware south. This alluvial fan surface, which the road will traverse for the next four miles, is at about 50 feet elevation. Rising sea level is pressing the water-table into this surface. The modern Mullica River is incised about six feet into this fan.

Stop 1, The Pleistocene fan. (Atsion Quadrangle, Rt. 206, sand road south just within Burlington County.) Due to a recent, 1983, fire the landscape is bare of shrubs and most trees. The local relief is about 0.5 meters, but the relict channels apparently left at the end of the Wisconsin glaciation may be clearly recognised by vegetation differences, with grasses in the channels, and by their topography. A view from the air shows that these channels traverse the entire lowland in braided stream fashion. There are also some shovel excavations from early bog iron prospecting. The dunes are about 1.5 meters high and occupy one of six bar crests on this floodplain surface.

A core taken into a the relict braided stream bed shows typical shallow, braided stream bar and channel stratigraphy about 1.4 meters thick. The stream-carried sands and gravels are apparently eroded from a few miles upstream and appear to contain the same mineralology (quartz, magnetite, illmenite, zircon) as the Cohansey and Kirkwood formations.

Beneath the stream deposits there is an abrupt unconformity with an indurated, older substrate composed of fine sand and laminated silts and sands.

Drive: Return to Rt. 206 for 4.7 miles. Look for Y on right before coming intersection. Take Old Tuckerton Road right 1.9 miles. then left where paved road ends, 0.4 miles, and left again to Tabernacle, 2.3 miles.

At Tabernacle graveyard go right (east) 0.8 miles on Rt. 532, the Chatsworth Road, past a sand-mining operation, take Zimmerman Road left 1 mile. Bear left for 0.5 miles on Patty Bowker Road to Fox Chase-Friendship Road. Turn right 0.7 miles to Powell Place Road. Turn right, cross Friendship Creek, and stop.

Route Description: Route 206 north of Atsion is running on the upper surfaces of the braided streams which apparently overflowed from the north. There are abandoned cranberry bogs; the fertility of the sandy crop fields may be due to a dressing of glauconitic muds which were carried by the floodwaters.

After the turn from 206 to the old cross-state route, the Tuckerton Road, the road passes and climbs a hill 150' in elevation above the general 90' surface. This upland is a relict "island" in the braided stream; it is made of the Cohansey formation and may be capped by gravels left by an earlier, higher river.

Approaching Tabernacle the road comes into the open to a view across broad fields to the village a mile away. This point may be a shoreline worked into the upland just described. This flat surface has a relief of between 96 and 100 feet and may have been a lagoon enclosed by the sand strip on which Tabernacle sits.

Stop 2, Spillway: (Indian Mills Quadrangle, Bridge over Friendship Creek.) This stop shows features of the spillway passages through which waters overflowed from the north, from time to time, to the Mullica River. A relict sandspit and part of the underlying Cohansey sand sill are visible.

Friendship Creek runs north to the Delaware at this point; this stop is not at the overflow point of the spillway, though it displays some spillway features. The stream rises in bogs to the south, about a mile away. At their south end these same bogs drain to the Mullica. The divide between the northward and southward drainage is at 85' elevation and is three miles upstream and not easily accessible. This sand spit and earlier stream bed appear to be remnants of the 60' stand of the lake which did not overflow.

The modern stream is incised into the earlier stream bed. A short distance to the east, on the north side of the road, a pit into a sand bank shows the deposits of a beach bar across the streamway; an excavation there shows coursening sand a couple of meters from the upper surface, merging into 1" quartzose yellow gravels. To the east, further down the road, the course gravels of the Cohansey appear at the surface.

The sand-bank here is at 55' elevation. A mile or two away, to the east and the west are the northernmost escarpment headlands between which the spillways flowed south. These uplands are 130' to 160' high. Apparently the northern gap of the spillway occurred at this point but the overflow point is a couple of miles to the south. There is a well-displayed spillway at 90' on the Sooy Place Road, about five miles to the east.

Drive: Turn around and continue straight, to the north, on the Powell Place Road for 1 mile. Bear right, to the north, on New Road (Vincentown Road) and continue 3 miles, crossing Route 70, to an intersection with Route 206. Continue north on 206 1.2 miles and turn left, west, to Vincentown, on Main Street (also Retreat Road). Follow Main Street through Vincentown for 0.6 miles, bearing right in town. Turn left on Church Road and bear right in 0.3 miles on the Lumberton Road. Continue for 3.4 miles, bearing left to cross a stream, into Lumberton. Turn left on Mount Holly Road, the main street, for 0.3 miles,crossing Rancocas South Branch. Turn right on Creek Road. Continue 1.2 miles, cross a small stream, and turn into a gravel pit on the right.

Route description; During this drive the road first travels over the outcrop of the fine Kirkwood Sands, Pliocene, which leave beach-like terrain. After crossing Route 70 the road lies along a low ridge which may be the inverse topography left from a former stream channel. At 206 the route descends into the presumed 60' lake bottom. The surface is flat and below 50'.

Stop 3, Sand pit at low elevation. (Mount Holly Quadrangle, mile northeast of Lumberton on Creek Road.)

In this large excavation are displayed the sequence of many thin laminae of sand and clays. Similar fluvial depositional features are found in most soil profiles below 90' elevation, all over the Burlington County lowland, with variations in the amount of glauconite present and in the energy-level of the depositional environment.

This sand pit is dug into an area where river erosion and slumping into a lake had excavated to about 20' above sea-level. The place had then been covered with reworked material, mostly sand and some gravels. This close to the river the bedding shows definite stream-flow features such as small scale festoon bedforms and cut-and-fill channels. There are intrusions of deformed mud into the lower beds where the weight of the sand forced wet sediments upward. Most of the pit is excavated into the Mount Laurel Sands though actual deposits may have come from further away. To the northwest, at the far end of the pit, are outcrops of the Marshalltown Formation, glauconitic marl and clay, with the Englishtown Sands beneath, in place.

Drive: Return 1.2 miles to Lumberton. Turn left, north back onto the main street for 1.7 miles to Route 38, near Mount Holly. Turn right, east, on 38 for 5.8 miles, crossing Route 206, to turn left on Birmingham Road which is a little more than a mile from 206. Descend into Birmingham village, cross the North Branch of the Rancocas, and look for the Arneys Mount Road to the right, 0.8 miles from Route 38.

Follow the Arneys Mount Road for 2 miles, up and over Arneys Mount, and turn left or north on the Pemberton Road for 0.3 miles to the intersection below a Quaker meeting house. Turn right at this intersection to skirt the Juliustown Mount to Juliustown in 1.6 miles. In Juliustown turn left or north to go straight for 2 miles on the Juliustown-Georgetown Road to dead-end at Meetinghouse Road. Turn right on Meetinghouse Road for 1.6 miles. crossing the Fort Dix Access Highway and climbing up the plateau on which Fort Dix stands. Go left, north, on Highland Road which follows the brow of the plateau. At

Tilghmans Corners turn left on Rt. 537, the Monmouth Road. Descending from the plateau, continue west 2 miles, crossing the Fort Dix Access Highway again. Look for a sharp turn right on the Gaunts Bridge Road (Juliustown-Georgetown Road). Take this turn north for 2 miles to the Fort Dix Access highway.

Take the Access Highway to the left, north 3.4 miles to Route 206. Go north, right, on Rt. 206 for 2.5 miles and turn right on Ward Road, to Crosswicks, just after the highway descends to a stream. In 2.4 miles the road crosses a deep stream-valley; to the left is the entrance to a gravel pit, the next stop.

Route description: Route 38 with its shopping-center sprawl is just south of Mount Holly and the North Branch of the Rancocas. The river itself is bordered by dune-sands here; after crossing 206 the road passes through dune hills. The route descends at Birmingham to the incised and meandering modern valley of the Rancocas. After turning on Arney's Mount Road and crossing a little bridge the route emerges into the open and the 240' hill of Arney's Mount appears. Surrounding Arney's Mount is the flat surface of the Pleistocene Lake floor. As the road approaches the mount it crosses a stretch of Colemantown soil, a black, fine sediment, probably a lake bottom deposit. Beyond rises the shoreline of the lake. The road passes through a cleft in the mount where the iron-stone deposits of a former bog are exposed. The limonite indurated the sands so that the mount remains, resistant to erosion.

The 140' declivity which surrounds a higher level of the presumed lake cuts into Arney's Mount; it may be seen rising behind the red, iron-stone Quaker Meeting House at the intersection. Below this high corner the land slopes off to the flat lake floor 70 feet below. The road to Juliustown runs along a second mount which also slopes off to this lake-bottom surface. About 2 miles north of Juliustown the road traverses another stretch of lake floor. The wooded parcel on the left contains outcrops of this mud; the land is part of the former estate of Pierre Lorilard and is accessible from the north. The water holes on the topographic sheet are not natural; they are Lorilard's ornamental ponds.

After the turn on to Springfield Meetinghouse Road, the road heads for the Fort Dix plateau and after crossing the Access Highway climbs right up the profile of the 140' escarpment, to the plateau. Dunes on the bluff of the slope raise the surface to 180'. The flatness of the uplands and the report of laminae in the sediments near Fort Dix suggest that this surface too may have undergone a similar, though earlier, sand erosion and redeposition process as the surfaces below. The steep slope here seems to be supported by the coherent Hornerstown Marl which crops out at this level; the sands below it were sapped out by the lake.

After following the bluff of the plateau the route descends the 140' declivity and after the turn to the north descends to 90', to the mid-level lake floor. A ridge bounds this surface; it appears to be the trace of another stream for it winds along for a couple of miles. A cross-roads follows this ridge. At the intersection watch for the brick house with the 1740 date in the gable.

The Fort Dix Access Road and Route 206 speed the way north to the furthest extent of the tour at Crosswicks. Near where 206 passes under the New Jersey Turnpike the land is at elevations of over 100' to 124' in a double line of hills. These uplands appear to be mantled with remnants of river gravels, indicated as Sassafras and Downer soils; this material covers much of the surface to the north around Hightstown; it is the Bridgeton formation and seems to mark the course of the ancestral Hudson. This line of uplands is held in place by the coherent sediments of the Woodbury and Merchantville Clays; the Turnpike was built on the crests of these uplands. To the south this ridge separates the lake's basin from the Delaware's valley.

Stop 4: Glauconitic sand deposits at Crosswicks, (Trenton East Quadrangle, gravel pit 0.3 miles west of Crosswicks,) This pits displays laminated sediments of the iron-rich glauconite alternated with sand from fluvial and low-energy slump and flow activities. While this location is near the river there are few signs of river gravels; the pile of cobbles in one corner is anthropogenic. At the north end of the pit is an outcrop of the dark, glauconitic Merchantville Clay from which the fine sediments were derived.

Drive: Leaving the sand pit continue 0.3 miles on Ward Road to Crosswicks. The Bordentown-Crosswicks Road is at the right as your enter the village, but before taking it, make a side trip to cross the Crosswicks Creek bridge in a half block. Return and take the Bordentown Road south for 2 miles. At the dead-end go right on the Bordentown-Chesterfield Road, over the Turnpike, and join 206 in 1.2 miles. Travel south (left) on 206 for 8.5 miles. Beyond the Columbus Farmers Market turn right, west, on Rt. 528, the Jacksonville Road. In 1 mile turn left, south, at an inconspicuous intersection beside a small home, on Warner Road. The final stop, Stop 5, is about 1.5 miles south along Warner Road. After this stop, proceed south to Route 537 in a half mile. Go left to Route 206.

To return to Stockton State College, turn right, south, on Rt. 206. Return to U.S. 30 at Hammonton; turn left, east, to Pomona. At Pomona go left at the light, then right on Jim Leeds Road, to the college.

Route discription: Streams such as Crosswicks Creek and Blacks Creek are steeply incised into the surface in the northern part of the lowland as they are presumeably still re-excavating their beds following the Wisconsinan glaciation. These streams rise out of flat lowlands and flow at he surface for several miles before entering incised valleys near the river. There is a bridge over Crosswicks Creek in the village of Crosswicks; at that point the stream is 60' below the village. Blacks Creek can be seen just after the route joins 206; at the highway bridge the gorge is 70' deep.

The route crosses several of the 100' escarpment outcrops which form a ridge along the Delaware. At Mansfield, a mile south of the turnoff to Fort Dix, the route climbs from a hilly stretch 60 to 70' in elevation up to a flat plateau which is quite uniformly at 105'. The route descends in a quarter mile but there are several flat hilltops nearby also just over 100' high. This surface appears to be the relict of the bed of the river which carried the waters of the ancestral Hudson and deposited the Bridgeton gravels; this surface, at about 110' becomes quite continuous a few miles to the north, near Hightstown.

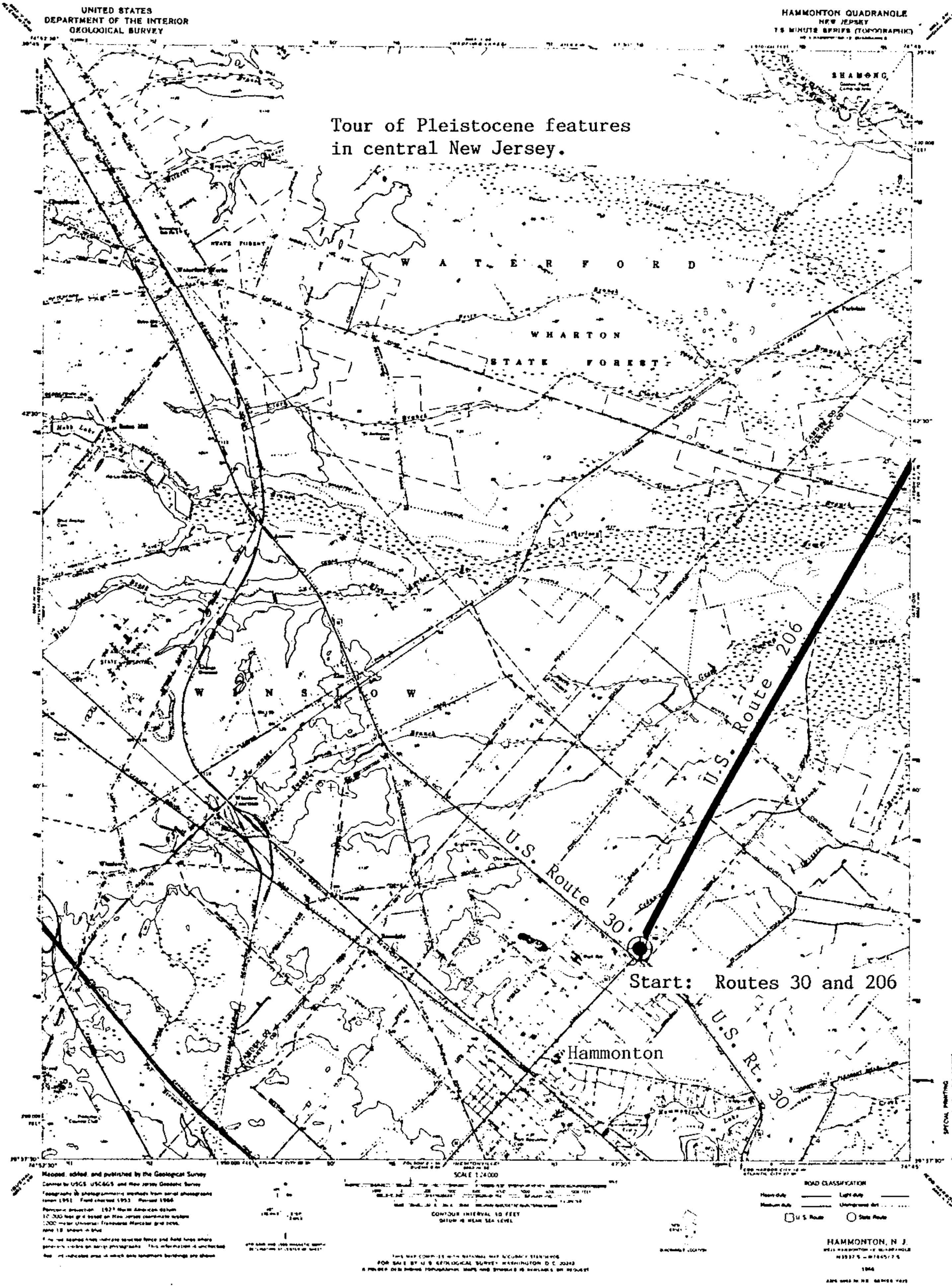
South of Mansfield Route 206 crosses another incised stream, bypasses Columbus, and descends again to the lowest surface of the sequence, a headwaters plain of the Assiscunk Creek at 40 to 50'.

The turnoff road from 206 to Jacksonville is on a distinct ridge which may be the inverse topography of a former river channel.

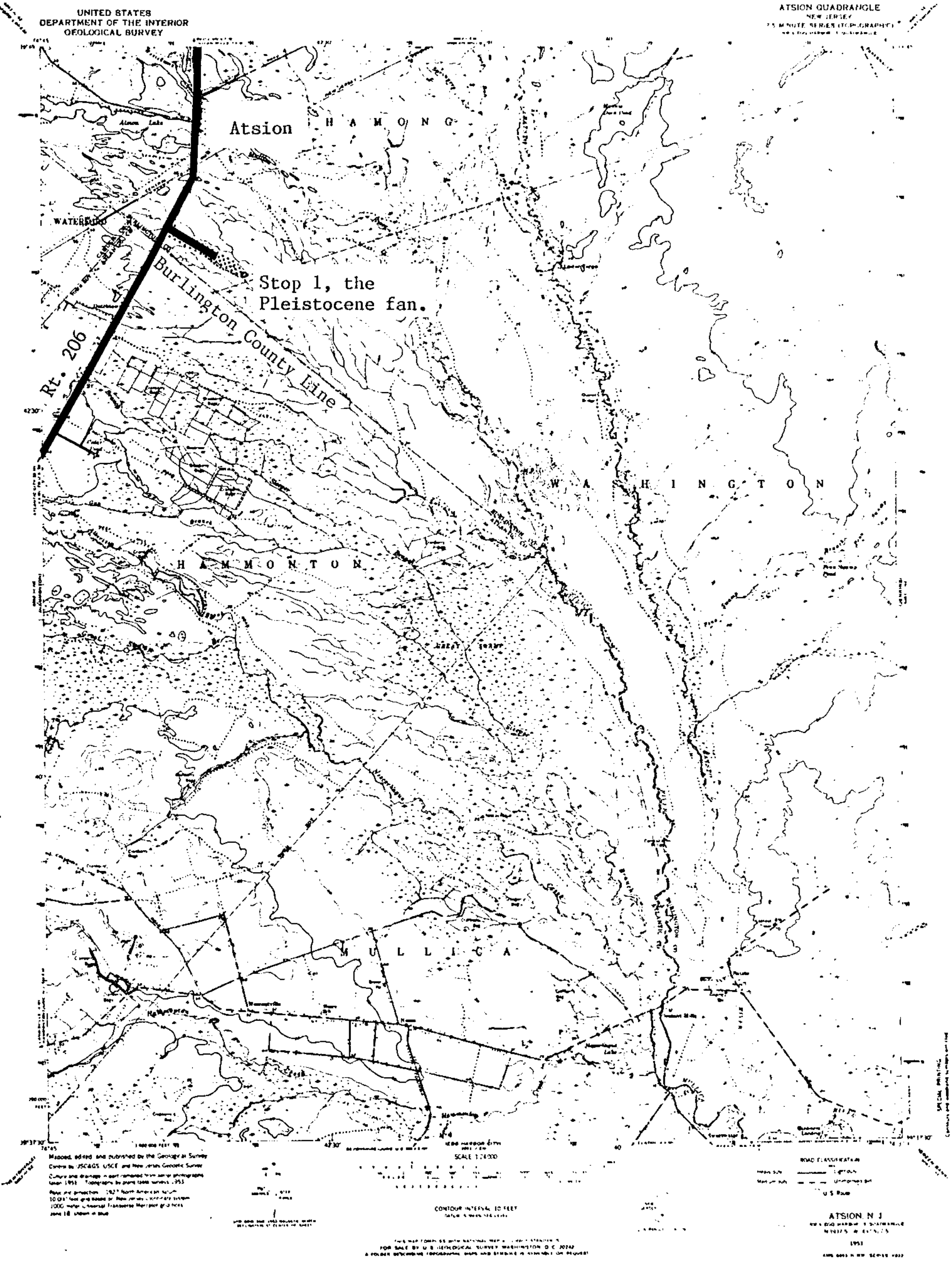
In a half mile the route turns left, off the ridge, and descends on a small road into a wide, flat plain which is at about 45' elevation, This plain is almost 3 miles across and stretches west toward the river for 4 miles, to the 100' escarpment which parallels the Delaware. This flat surface appears to be a remnant of the lowest and most recent lake-bottom, left as the Wisconsinan ice melted to the north. It is floored in much of its extent by the fine, black Colemantown soil which appears to be lake-bottom sediments. At the final stop a core will be displayed from those deposits.

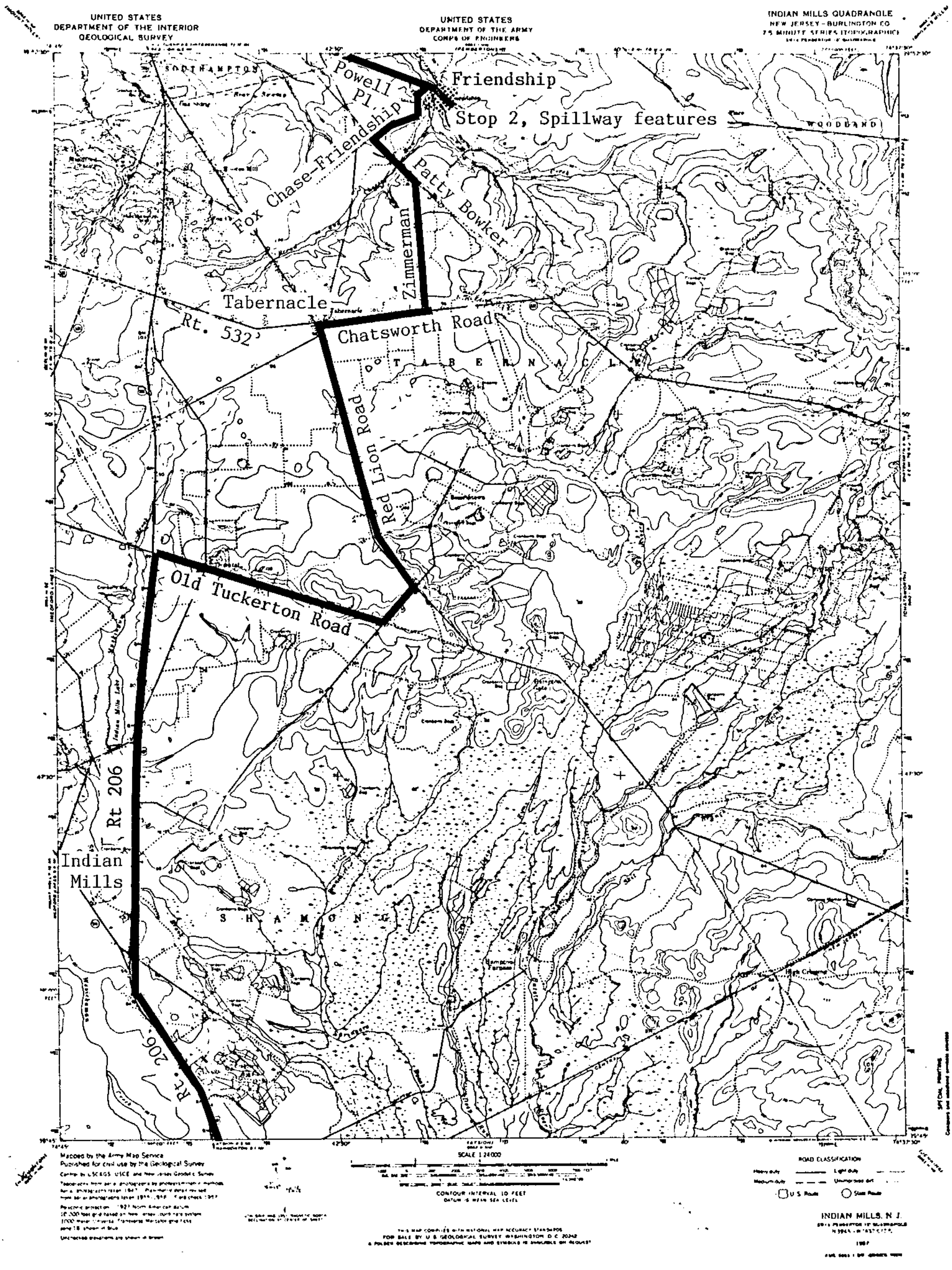
On the far side of the lowland the land rises abruptly to the 70' level. At this point, near Chambers Corners on Rt. 206, Arney's Mount may be seen again, two miles to the southeast. From near Chambers Corners to Arney's Mount lies the entire sequence of the two lake levels with the 140' cliff. The 140' declivity is present on all sides of Arney's Mount. Below the declivity the mount is surrounded by a beach-like slope at 100' and flattens out at 80' sloping to 70' toward Chambers Corners. There are deposits of the Colemantown soil in those flatlands near Chamber's Corners. That village sits at 70'; below it is the slight, coast-like declivity down to the lowest, 45', lake floor.

The route south along Route 206 recrosses the several levels of the lowland and then follows the course of the intermittent overflow south to the Mullica River. The spillway route begins after the highway enters the Pine Barrens, south of the turn-offs to Tabernacle.



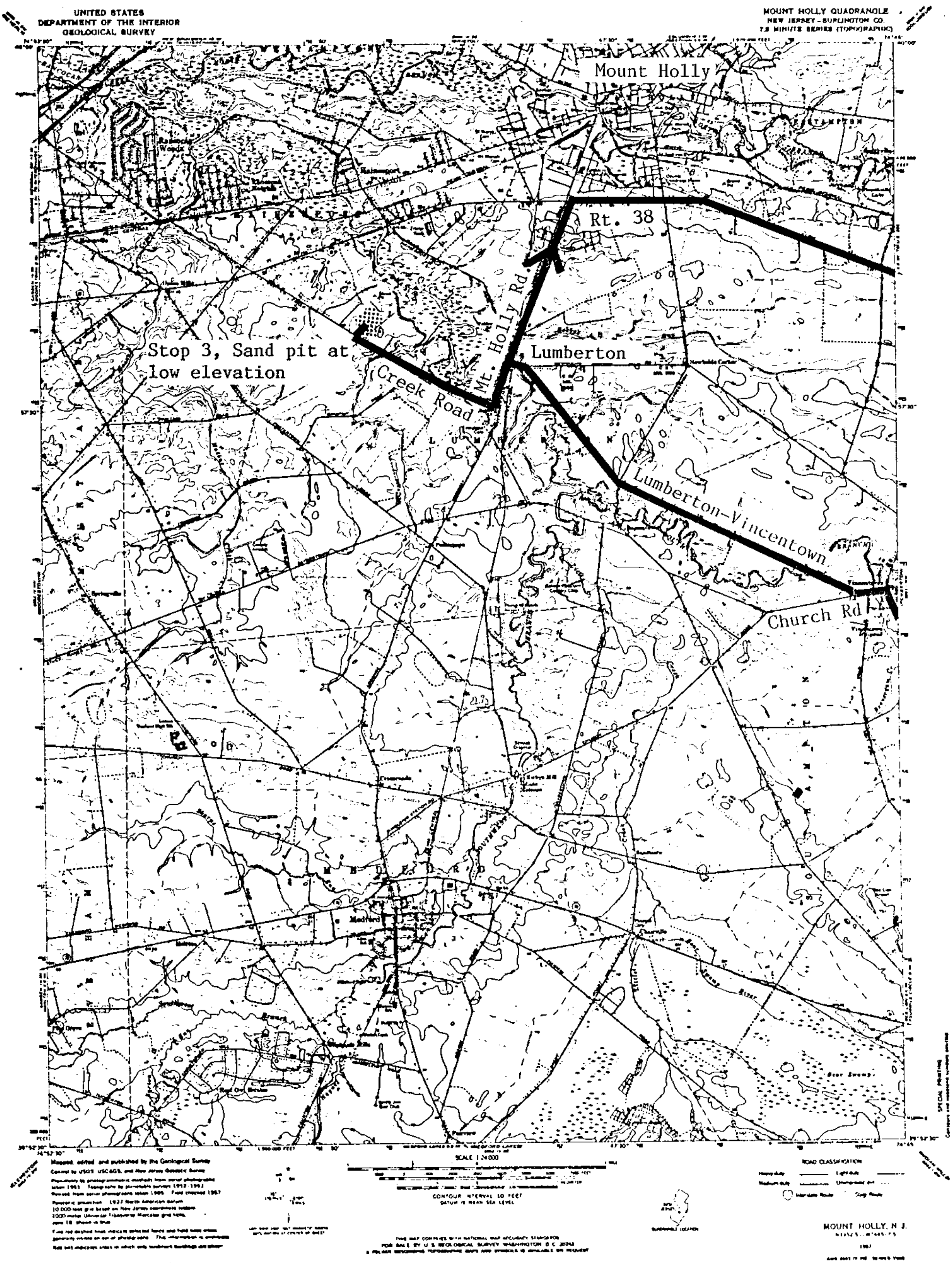
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
HAMMONTON QUADRANGLE
NEW JERSEY
7.5 MINUTE SERIES (TOPOGRAPHIC)
SHAMONG
Tour of Pleistocene features
in central New Jersey.
W A T E R F O R D
W H A R T O N
S T A T E F O R E S T
W I N S L O W
U.S. Route 206
U.S. Route 30
Start: Routes 30 and 206
Hammonton
U.S. Rt. 30
Mapped, edited, and published by the Geological Survey
SCALE 1:24000
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
ROAD CLASSIFICATION
HAMMONTON, N. J.


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
ATSION QUADRANGLE
NEW JERSEY
Atsion
H A M O N G
WATERFORD
Stop 1, the
Pleistocene fan.
Burlington County Line
Rt. 206
W A S H I N G T O N
H A M M O N T O N
M U L L I C A
CONTOUR INTERVAL 10 FEET
ATSION, N. J.
1953

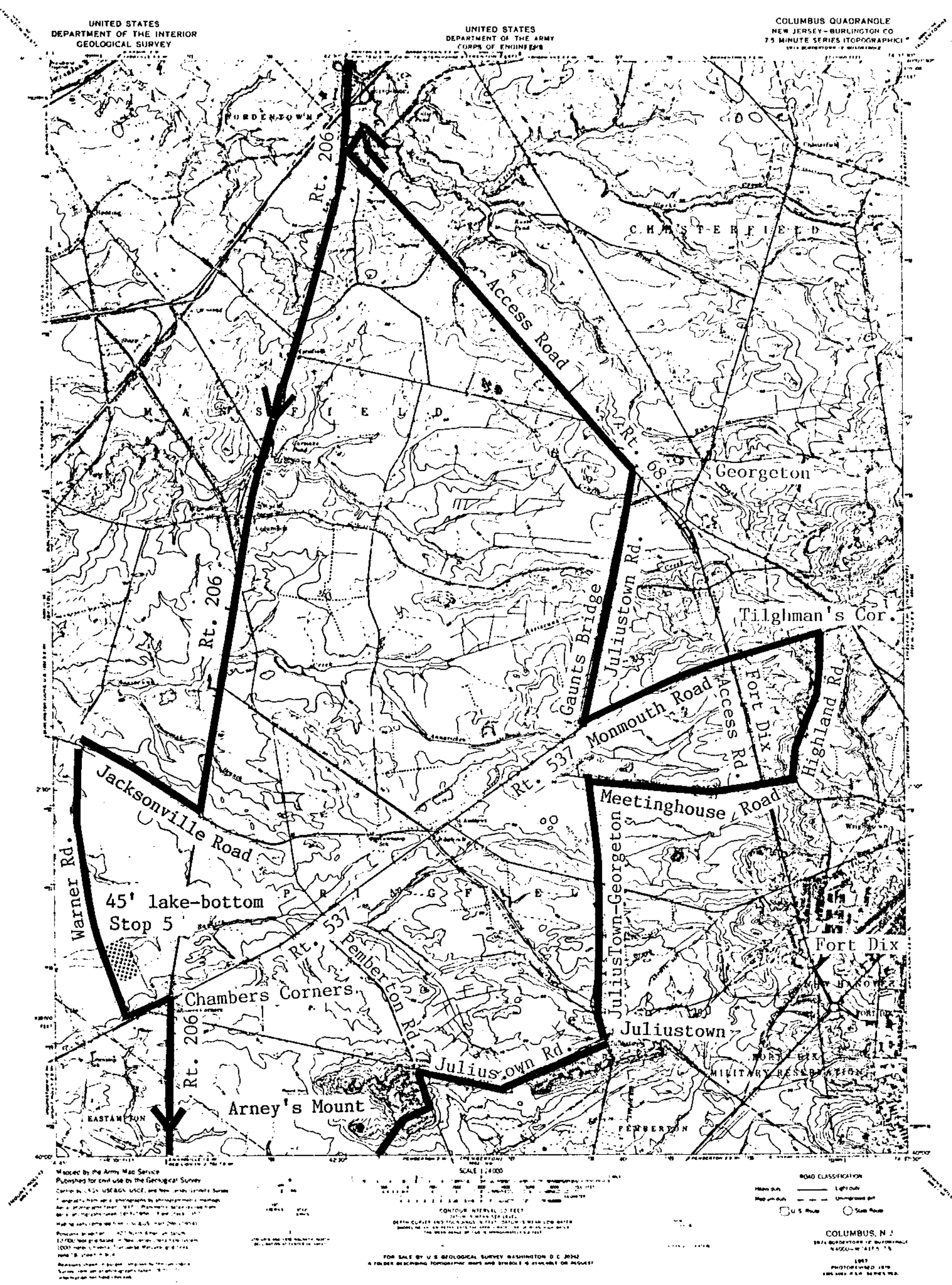

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
UNITED STATES
DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
INDIAN MILLS QUADRANGLE
NEW JERSEY - BURLINGTON CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
Powell
Pl.
Friendship
Stop 2, Spillway features
Fox Chase-Friendship
Patty Bowker
Zimmerman
Tabernacle
Rt. 532
Chatsworth Road
T A B E R N A C L E
Red Lion Road
Old Tuckerton Road
Rt 206
Indian
Mills
S H A M O N G
Rt. 206
SCALE 1:24000
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
ROAD CLASSIFICATION
INDIAN MILLS, N.J.

4

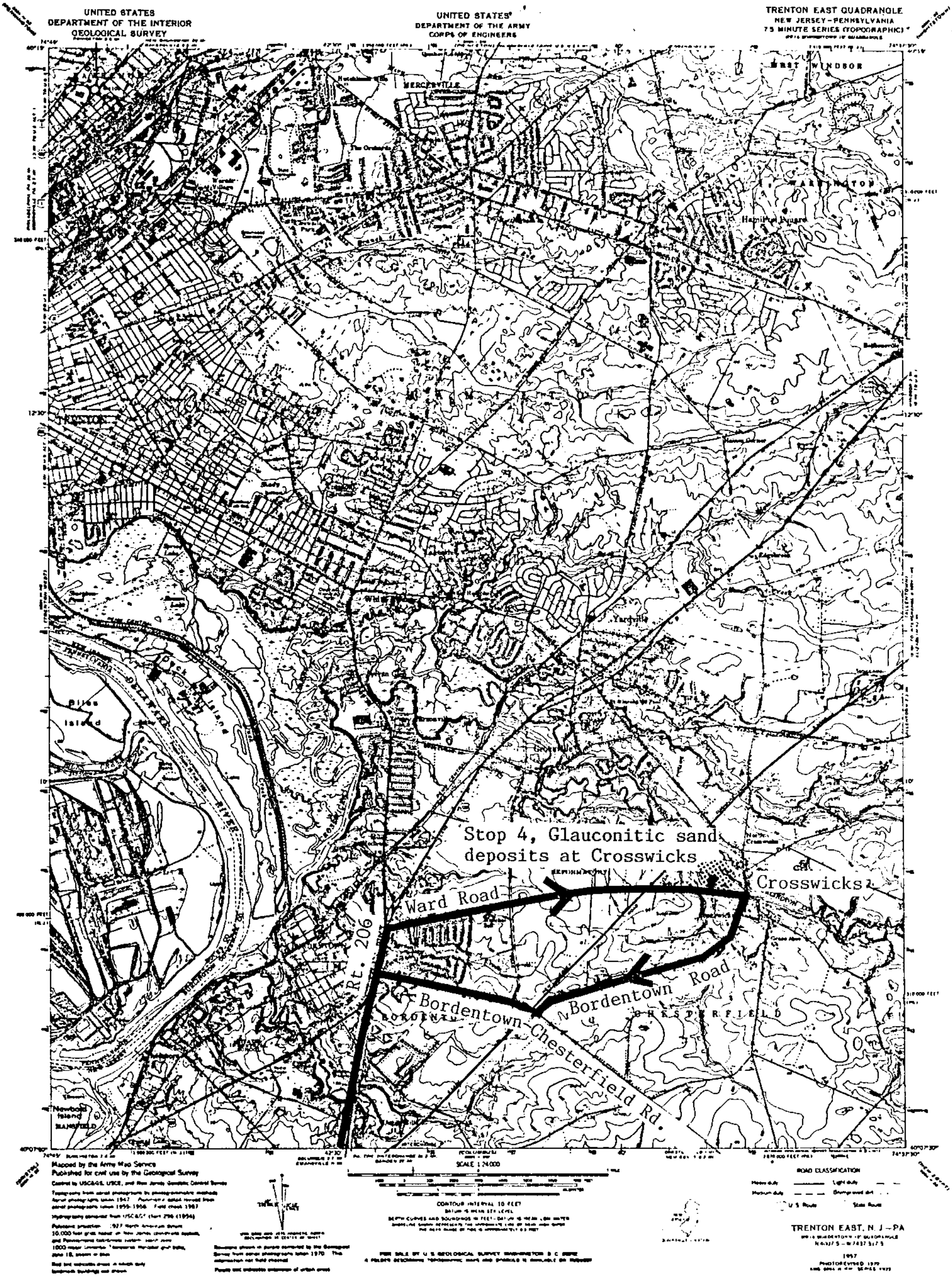
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
UNITED STATES
DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
PEMBERTON QUADRANGLE
NEW JERSEY - BURLINGTON CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
EASTAMPTON
Rt. 206
Arney's MOunt Rd.
Birmingham
Road
Route 38
Rt. 206
Birmingham
FORT
MILITARY RESERVATION
P E M B E R T O N
RANCOCAS CREEK
Vincentown Road
Retreat Road
S O U T H A M P T O N
Rt. 206
(Vincentown)
New Road (Vincentown)
New Road
Route 70
New Road
Powell Pl
WOODLAND
TABERNACLE
Mapped by the Army Map Service
Published for civil use by the Geological Survey
SCALE 1:24000
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
ROAD CLASSIFICATION
Heavy-duty
Light-duty
Medium-duty
Unimproved dirt
U.S. Route
State Route
PEMBERTON, N. J.
1957
PHOTOREVISED 1971


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
MOUNT HOLLY QUADRANGLE
NEW JERSEY - BURLINGTON CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
Mount Holly
Rt. 38
Mt. Holly Rd
Stop 3, Sand pit at
low elevation
Lumberton
Creek Road
Lumberton-Vincentown
Church Rd
SCALE 1:24000
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
MOUNT HOLLY, N.J.

6



UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
UNITED STATES
DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
COLUMBUS QUADRANGLE
NEW JERSEY-BURLINGTON CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
Rt. 206
Access Road
Rt. 68
Georgeton
Juliustown Rd.
Gaunts Bridge
Tilghman's Cor.
Monmouth Road
Rt. 537
Access Rd.
Fort Dix
Highland Rd.
Meetinghouse Road
Jacksonville Road
Rt. 206
Warner Rd.
45' lake-bottom
Stop 5
Rt. 537
Pemberton Rd.
JuliusTown-Georgeton
Fort Dix
Chambers Corners
Juliustown
Rt. 206
Juliustown Rd.
Arney's Mount
COLUMBUS, N.J.


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
UNITED STATES
DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
TRENTON EAST QUADRANGLE
NEW JERSEY-PENNSYLVANIA
7.5 MINUTE SERIES (TOPOGRAPHIC)
MERCERVILLE
WEST WINDSOR
Hamilton Square
Yardville
Biles Island
DELAWARE RIVER
Newbold Island
Stop 4, Glauconitic sand deposits at Crosswicks
Crosswicks
Ward Road
Rt. 206
Bordentown Road
Bordentown-Chesterfield Rd.
Mapped by the Army Map Service
Published for civil use by the Geological Survey
SCALE 1:24000
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
ROAD CLASSIFICATION
U.S. Route
State Route
TRENTON EAST, N.J.-PA.
1957
PHOTOREVISED 1970

FIELD TRIP B

FIELD TRIP NOTES-TRIP B

EXPLORATION OF SHORE PROTECTION PROJECTS AND COASTAL PROCESSES

by Susan D. Halsey, Leita Hulmes-Hood
and David Charette
from NJDEP-Division of Coastal
Resources, Trenton, NJ

Stops for this field trip will be designed around the number of cars in the caravan. There are some places along our coast that are not particularly suited to receiving a large flock of vehicles, even in October, namely Atlantic City. We are also very open to suggestions by the participants. Please let us know if there are any particular locations you would like to inspect. And then there are questions of timing-driving speeds, parking, in-out time from vehicles and stragglers all influence the number of stops we can inspect. Therefore, there are probably more stops included in these notes than we can see in a day. Perhaps you can use them some other day--at your leisure.

Stop 1. Brigantine-North end near Brigantine Castle and Pier. Park in lot across street.

GEOMORPHIC FEATURES: Brigantine Natural Area to north gives one a view of the "natural" half of this island-beach and wide dune field; to south the "developed" half of the island. Note bulkheads, width of beach, health of dunes, nature of access points to beach.

MANAGEMENT FEATURES: Development continues in hazardous areas of the City. DEP has recommended pull-back from these areas so that the beach and dune has room to regenerate, the City wants more shore "protection" devices, obviously a conflict exists.

NOTES: This area is in the nodal zone of this island. Erosion characterizes all nodal zones produced by inlet processes. This concept will be discussed in the field. This concept is not well known by engineers and the construction of shore "protection" devices many times are in conflict with coastal processes. This area is undergoing approximately 3 feet of erosion per year. Storms may have a greater effect on areas such as this that are in a weakened condition-we will note effects of Hurricane Gloria, if we can find them.

Stop 2. Brigantine-South end, near inlet. We will travel down the length of the island trying to stay as close the the ocean as possible-note as we go south, the dune widens and it becomes less possible to see the ocean. Note also the number of large scale housing developments as we go south.

GEOMORPHIC FEATURES: To the east, note the very wide dune, grown progressively eastward by the creation then lengthening of this jetty. As Brigantine's dune field grows, Atlantic City's beaches starve. To south, note Inlet Section of Atlantic City-is boardwalk still visible? Along inside of north jetty, is shoal-island still visible?

MANAGEMENT FEATURES: The management considerations as they relate to the above will be discussed. The spring of 1986 will bring a large beachfill for Atlantic City, the sand for which will be taken from this inlet area, but not from the shoal-island.

Stop 3. Margate-Longport. This may be a "drive along" stop due to the lack of an ocean parallel road and the presence of many no parking areas. We will try to find a place to stop for a field inspection.

GEOMORPHIC FEATURES: Before you get to the beach, are you aware of the fact that you are on a barrier island? As we drive south look east to your left-can you see the ocean? What do you see instead? At the stop, note presence of bulkheads or seawall, presence of dunes, width of dunes or beaches. If we stop at 11th street in Longport, we will discuss what happened to the other 10 blocks that used to be south of this street.

MANAGEMENT FEATURES: Compare geomorphic features such as dunes, beaches with presence and proximity of shore protection devices and development. Consider hazard level for this area.

Stop 4. Ocean City. From Longport take Rte. 152 if it is open, go over toll bridge into Ocean City.

GEOMORPHIC FEATURES: Look at width of beaches, where do dunes start? Note relationship of groins, boardwalk, and beach in relation to development.

MANAGEMENT FEATURES: In 1982, DEP spent $4 million of Shore Protection Funds to beachfill the northern end of Ocean City. It literally lasted a couple of months, erosion now is worse than before the beachfill. The reasons for this erosion will be discussed.

Stop 5. The Whale Beach Section of Strathmere (Upper Twsp.) and Sea Isle City

GEOMORPHIC FEATURES: Rapidly transgressing barrier island due to nodal zone, outcrops of lagoonal peat in surf zone-beachface after storms, "cultured" dunes, low profile groins, overwash area

MANAGEMENT FEAURES: Many dollars spent to protect this road, the infrastructure and some houses from relentless erosion. DEP now considering buying up this area for a State Park,allowing the beach-dune system to consume the present road, removing almost all of the houses, relocating the road westward and letting Nature take her own course. What are your ideas of the type of activities you would like to see if this area were a State Park, considering the above? (Don't even suggest a nude beach-that's not in the management plan!)

NOTES: The 1962 storm removed two to three blocks of homes that were located seaward of Ocean Drive. Federal/State monies paid $1 million in 1962 dollars to create 6.5 miles of the grandparents of the articial dunes you may or may not see today. The tides after Gloria deposited most of the latest attempt at dune creation back into the street. The County is getting weary of plowing out this road after almost every spring tide.

Historical erosion rates average 1.5 meters per year. since 1842 using USGS maps/charts. When the railroad was constructed in 1884,the beach was more that 1000 feet seaward of its present location. Right after the 1984 storm, Stew Farrell found remnants of the railroad out on the beach. After storms peat outcrops are visible on the beach. Norb Psuty has dated these outcrops at circa 200 years B.P. This is correlative to Kraft's dates on peat in the Dewey Beach area of Delaware.

Stop 6. North end of Avalon-Townsend's Inlet

GEOMORPHIC FEATURES: Beaches and shoals in inlet. Main channels of inlets and their relationship to beach location. Downdrift offset inlets.

MANAGEMENT FEATURES: Location of development and shore protection structures in relation to geomorphic features. Plans for additional shore protection projects will be discussed-raising and lengthening of the terminal jetty and plans for a major beachfill.

Stop 7. Avalon High Dune Area, 52-54th Street

GEOMORPHIC FEATURES: Multiple dune ridges: some natural-some cultured.

MANAGEMENT FEATURES: Techniques fot dune construction, walkway construction.

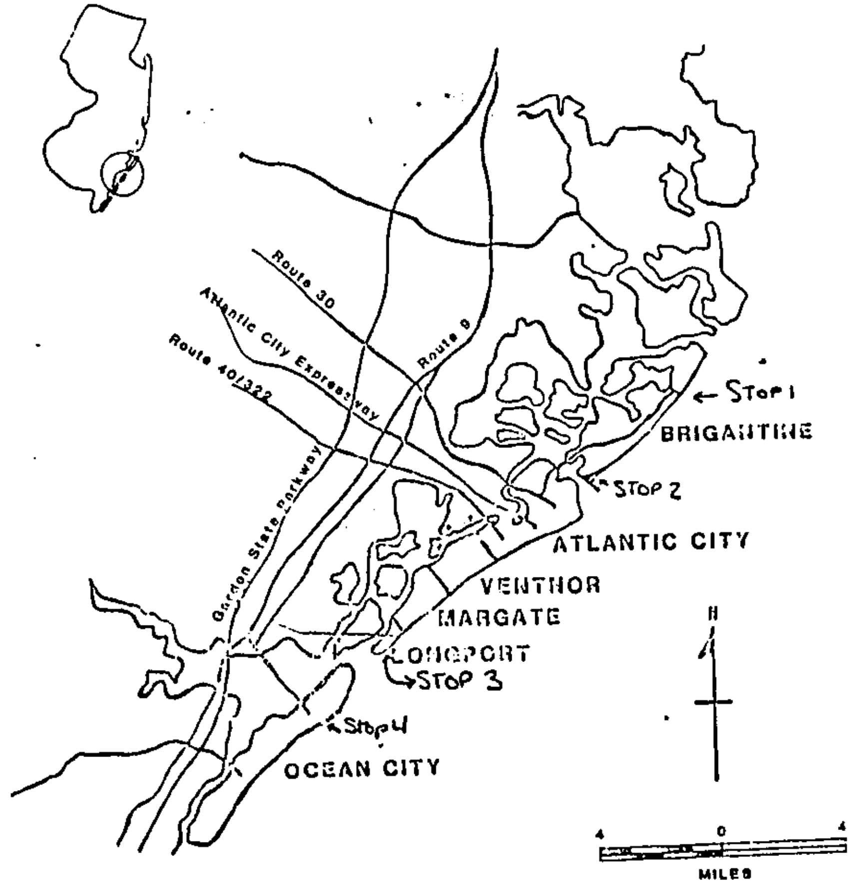
NOTES: The original dunes prevented overwash and flooding damage during the 1962 storm. The oceanfront was not as heavily populated in this community as other municipalities were; therefore, the majority of the dune field was kept undeveloped after the storm. Since the 1962 storm, diligent dune building activities have augmented the dune field. A point recently made by Paul Gares now at Colgate indicates that man-made or "cultured" dunes are often built seaward onto the beach, at the expense of the backbeach area. Therefore, during storms, these dunes are sacrificed and the community rebuilds them. In the face of rising sealevel, dunes should be migrating westward to keep their place in the beach-dune profile. How do we get dunes to migrate landward when there are roads and houses in the way?

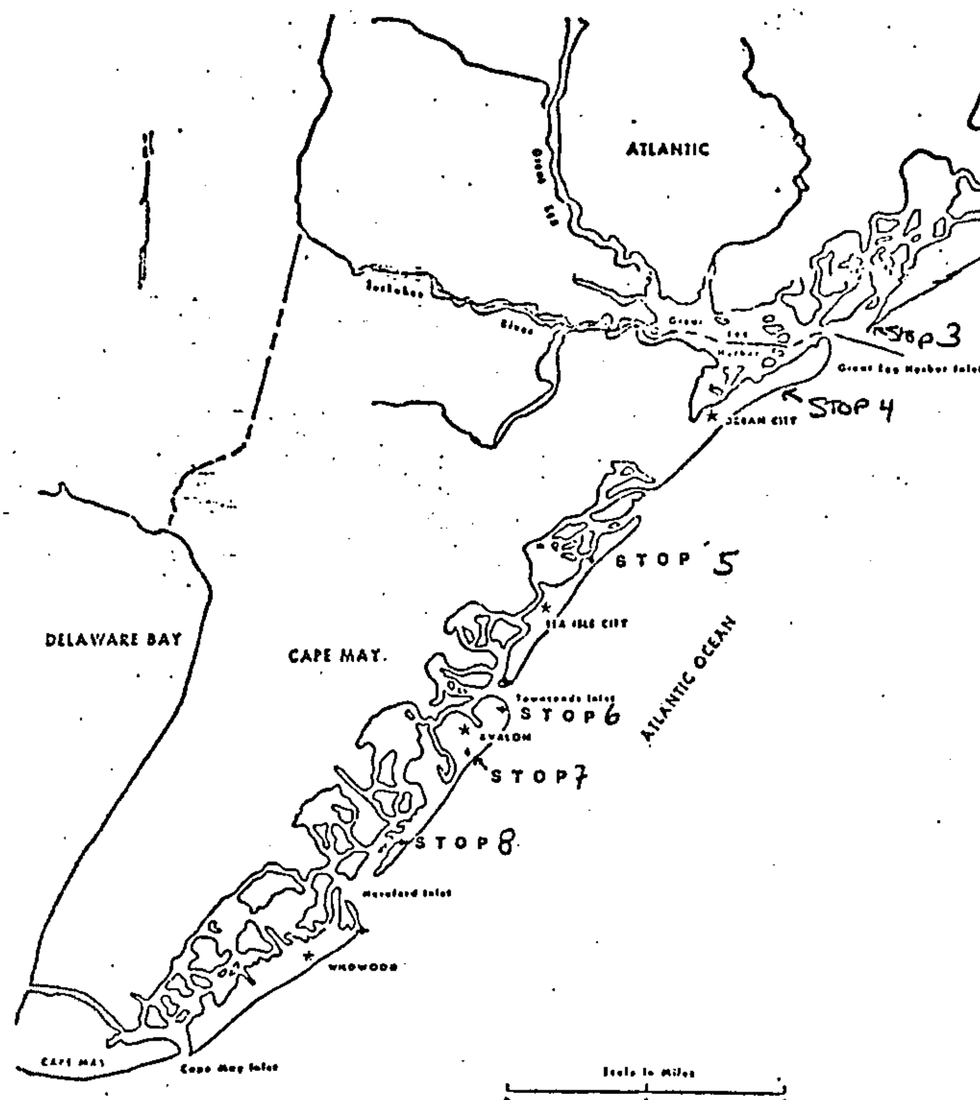
Stop 8. Stone Harbor Point. Parking lot at 127th Street

GEOMORPHIC FEATURES: Comparison of undeveloped vs developed sections of island: beaches, dunes, overwash areas, erosion effects of terminal groin

MANAGEMENT FEATURES: Shore protection structure: bulkhead, groins, mitigation attempts, Seascape installation

NOTES: The bulkhead that you see was built in 1969 more than 200 feet landward of MHW and the Stone Harbor spit continued south with no evidence of erosion at all. The beginning of the severe erosion began in 1972 but the bulkhead return was not damages until the 1977-1978 trio of storms which significantly damaged the structure. Since then, the community has been negotiating with the State to "fix" this erosion although no development exists to protect. As an experiment, this areas was also the location for the installation of the artifical seaweed called Seascape. The inventor claimed that after the installation, a bar would be formed that would protect this area from erosion. Obviously, it didn't work. The only evidence of the Seascape now is occasional frond or the pieces of the fabric which litter the beach.


Route 30
Atlantic City Expressway
Route 40/322
Route 9
Garden State Parkway
STOP 1
BRIGANTINE
STOP 2
ATLANTIC CITY
VENTNOR
MARGATE
LONGPORT
STOP 3
Stop 4
OCEAN CITY
N
4 0 4
MILES


ATLANTIC
Stop 3
STOP 4
OCEAN CITY
STOP 5
SEA ISLE CITY
DELAWARE BAY
CAPE MAY
ATLANTIC OCEAN
Townsends Inlet
STOP 6
AVALON
STOP 7
STOP 8
CAPE MAY
Cape May Inlet
Scale in Miles

FIELD TRIP C

Biostratigraphic Succession Across the Cretaceous-Tertiary Boundary at the Inversand Company Pit, Sewell, N.J.

by William B. Gallagher and David C. Parris

New Jersey State Museum

During the nineteenth century the mining of glauconite, or "greensand marl" as it was popularly known, was a flourishing industry along the strip of New Jersey's Inner Coastal Plain that contains Upper Cretaceous and Lower Tertiary deposits. Glauconite was extensively dug for use as fertilizer, and it was from these many greensand pits that early vertebrate paleontologists such as Joseph Leidy, Edward Drinker Cope, and Othniel Charles Marsh obtained numerous specimens. Today, only one such operation persists: the Inversand Company pit at Sewell, N.J., where glauconite is dug for water softener and other industrial purposes.

Unfortunately, the early collectors were less careful in their record-keeping than many modern workers would like. Frequently they paid marl diggers to save bones for them, and so were not on the spot when the specimens were excavated. Hence many of the fine specimens collected during the heyday of glauconite mining have very few useful stratigraphic or locality data; museum labels attached to these specimens will often merely note something like "Greensand marl, Burlington County, N.J."

This situation has been exacerbated by the modern lack of exposure of the critical and controversal stratigraphic interval spanning the Cretaceous - Tertiary Boundary in New Jersey. During a time of renewed interest in the C/T extinctions and extinction theory in general, an exposure containing the Cretaceous - Tertiary interface assumes a new significance. The Inversand Pit may contain such an exposure.

Early workers (Morton, 1832; Rodgers, 1836; Lyell, 1845; Leidy 1858, 1870; Cope, 1868, 1875; and Weller, 1907) considered all of the so-called "greensand marls" to be Upper Cretaceous in age. It wasn't until well into this century that the base of the Tertiary system in New Jersey was extended down to the bottom of the Hornerstown Formation (Cooke and Stephenson, 1928). Since then, this has become the standard age assignment, as emphasized by a number of U.S.G.S. studies (Minard et al., 1969; Owens and Sohl, 1969; Owens et al., 1970; and Owens and Sohl, 1973).

Numerous workers have questioned the propriety of a Paleocene age for the basal Hornerstown, largely because of the predominantly Cretaceous affinities of the fossils contained in the lower part of this formation (Miller, 1967; Olsson, 1963; Baird, 1964; Richards and Gallagher, 1974; Parris, 1974; Koch and Olsson, 1974, 1977; and Gallagher, 1984). Much of the fossil material supporting a Cretaceous assignment has come from the Main Fossiliferous Layer (MFL) at the Sewell Inversand Pit.

The New Jersey State Museum Science Bureau has maintained a careful monitoring of fossils from the pit for a number of years. Recently, because of a change in excavation techniques and a lowering of the water table due to drought, we have had the opportunity to investigate the Navesink fossil assemblage, normally not as well-exposed in this pit. The recognition of a third assemblage in the upper part of the Hornerstown Formation at this site has provided us with a chance to construct a more accurate biostratigraphic succession across the Cretaceous - Tertiary boundary in this area. Faunal lists for each assemblage follow; NJSM refers to specimens in the collection of the New Jersey State Museum, ANSP to those at the Academy of Natural sciences, and PU Princeton University.

Navesink Formation

INVERTEBRATA

Porifera

Cliona cretacica Fenton & Fenton	NJSM 12932

Brachiopoda

Choristothyris plicata (Say)	NJSM 12925

Pelecypoda

Pycnodonte mutabilis Morton	NJSM 12886
Pycnodonte convexa (Say)	NJSM 12862
Gryphaeostrea vomer Morton	NJSM 12882
Exogyra costata Say	No Number
Cucullaea neglecta Gabb	NJSM 12863
Cucullaea antrosa Morton	NJSM 12898
Cucullaea vulgaris Morton	NJSM 12978
Cucullaea tippana Conrad	NJSM 12301
Trigonia mortoni Whitfield	NJSM 12867
Crassatellites vadosus (Morton)	NJSM 12874
Liopistha cf. protexta (Conrad)	NJSM 12875
Spondylus sp.	NJSM 12873
Dianchora echinata (Morton)	NJSM 12880
Cardium (Pachycardium) spillmani Conrad	NJSM 12881
Agerostrea nasuta (Morton)	NJSM 12927
Solyma cf. lineolatus Conrad	NJSM 12946
Lithophaga ripleyana Gabb	NJSM 12949

Gastropoda

Pyrifusus macfarlandi Whitfield	NJSM 12865
Turbinopsis curta Whitfield	NJSM 12866
Volutomorpha ponderosa Whitfield	NJSM 12870

Gyrodes abyssinus (Morton)	NJSM 12872
Lunatia halli Gabb	NJSM 12950
Anchura cf. *abrupta* Conrad	NJSM 12307
Anchura pennata (Morton)	NJSM 12900
Turritella sp.	NJSM 12887
Nautiloidea	
Eutrephoceras dekayi Morton	NJSM 12876
Ammonoidea	
Baculites cf. *ovatus* Say	NJSM 12931
Indeterminate coiled ammonite	
VERTEBRATA	
Chondrichthes	
Squalicorax pristodontus Morton	NJSM 12939
Scapanorhynchus texanus (Roemer)	NJSM 12944
Osteichthyes	
Enchodus ferox Leidy	NJSM 12186, 12187
Chelonia	
Cheloniidae	NJSM 11884
Peretresius ornatus Leidy	NJSM 11051
Lacertilia	
Mosasaurus maximus Cope	NJSM 11053
Mosasaurus sp.	NJSM 11052, 12146
cf. *Platycarpus*	NJSM 12259
Prognathodon rapax (Hay)	NJSM 9827

Ornithischia

Edmontosaurus minor (Marsh)	ANSP 15202, NJSM 11880
cf. *Tsintaosaurus* sp. (?n. gen.?)	NJSM 11961

Main Fossiliferous Layer, Basal Hornerstown Formation

INVERTEBRATA

Brachiopoda

Terebratulina atlantica Morton	NJSM 12152

Gastropoda

Gyrodes abyssinus Morton	NJSM 11301
Acteon cretacea Gabb	NJSM 11311
Anchura abrupta Conrad	NJSM 11337
Turbinella parva Gabb	NJSM 11327
Lunatia halli Gabb	NJSM 11326
Pyropsis trochiformis Tuomey	NJSM 11283
Volutoderma ovata Whitfield	NJSM 11318
Turbinella subconica Gabb	NJSM 11331
Turritella vertebroides Morton	NJSM 11282

Pelecypoda

Cardium tenuistriatum Whitfield	NJSM 11317
Glycymeris mortoni Conrad	NJSM 11312
Gryphaea convexa Say	NJSM 11320
Gervilliopsis ensiformis Conrad	NJSM 11313
Gryphaeostrea vomer Morton	NJSM 11316
Panopea decisa Conrad	NJSM 11310
Veniella conradi Morton	NJSM 11319
Crassatella vadosus Morton	NJSM 11324
Cucullaea vulgaris Morton	NJSM 11322
Lithophaga ripleyana Gabb	NJSM 11325
Xylophagella irregularis Gabb	NJSM 12151

Nuculana stephensoni Richards	NJSM 11336
Etea delawarensis Gabb	NJSM 11314
Nautiloidea	
Eutrephoceras dekayi Morton	NJSM 11852
Ammonoidea	
Baculites ovatus Say	NJSM 11321
Sphenodiscus lobatus Tuomey	NJSM 11328
Pachydiscus (Neodesmoceras) sp.	NJSM 11284
Crustacea	
cf. *Hoploparia* sp.	NJSM 11360
VERTEBRATA	
Chondrichthyes	
Lamna appendiculata Agassiz	NJSM 11291
Odontaspis cuspidata Agassiz	NJSM 11276
Squalicorax pristodontus Morton	NJSM 11273
Hexanchus sp.	NJSM 11899
Edaphodon stenobyrus Cope	NJSM 11301-L
Edaphodon mirificus Leidy	NJSM 11301-X
Ischyodus cf. *thurmanni* Pictet & Campiche	NJSM 11301-M
Squatina sp.	NJSM 12150
Myliobatis cf. *leidyi* Hay	NJSM 11339 and NJSM 11898
Ischyrhiza mira Leidy	NJSM 12148
Rhinoptera sp.	NJSM 12149
cf. *Rhombodus levis* Capetta and Chase	NJSM 12112
Osteichthyes	
Enchodus cf. *ferox* Leidy	NJSM 11304
Enchodus cf. *serrulatus* Fowler	NJSM 11308
Paralbula casei Estes	NJSM 11855

Chelonia

Adocus beatus Leidy	ANSP 15356
Osteopygis emarginatus Cope	ANSP 15335 and NJSM 11872
Taphrospys molops Cope	NJSM 11306
Taphrospys sulcatus Leidy	ANSP 15358 and PU 18706, PU 18707 and NJSM 11340
cf. *Dollochelys* sp.	NJSM 11307

Crocodilia

cf. *Procaimanoidea* sp.	NJSM 11305 and NJSM 11886
Hyposaurus sp.	NJSM 11882
Thoracosaurus sp.	NJSM 11885
Bottosaurus harlani Meyer	NJSM 11265
Diplocynodon sp.	NJSM 11902 and NJSM 11903

Lacertilia

Mosasaurus sp.	NJSM 11299 and NJSM 11332 and NJSM 11895
cf. *Plioplatecarpus depressus*	NJSM 11070

Also present are numerous coprolites of sharks and crocodilians, some amber, phosphatized wood, and a few seeds. Approximately ten bird fossils of at least five taxa have been found and are soon to be described (Olson and Parris, in preparation).

Upper Hornerstown Fossiliferous Layer

INVERTEBRATA

Porifera

Peronidella dichotoma Gabb	NJSM 12188

Coelenterata

Flabellum mortoni Vaughan	NJSM 11323

Brachiopoda

Terebratulina manasquani Stenzel	NJSM 12189

Pelecypoda

Cucullaea macrodonta Whitfield	NJSM 10863
Ostrea glandiformis Whitfield	NJSM 10860
Crassatellites cf. *littoralis* Conrad	NJSM 10857
Caryatis veta Whitfield	NJSM 11315

Castropoda

cf. *Volutocorbis* sp.	NJSM 10566

Nautiloidea

cf. *Aturia* sp.	NJSM 10859

VERTEBRATA

Chondrichthyes

Odontaspis sp.	NJSM 12212
Lamna cf. *obliqua* (Agassiz)	NJSN 10858
Edaphodon agassizi (Buckland)	NJSM 11335

Chelonia

Dollochelys sp.	NJSM 11254

Crocodilia

Hyposaurus rogersii Owen	NJSM 11069

Within these three faunal associations we can see certain persistent elements, while each assemblage contains unique species. The general trend is toward a reduction of diversity upward in the section, as one would expect in a C/T stratigraphic interval. However, the major reduction in diversity does not occur between the Navesink and the Hornerstown Formations, but within the Hornerstown between the basal MFL layer and the upper assemblage.

The Navesink is unquestionably Maastrichtian (Latest Cretaceous) in age. Besides the dinosaurs and the ammonites, the characteristic Navesink zone fossils

Choristothyris plicata, Exogyra costata, and Dianchora echinata mark this lower "chocolate marl" as Cretaceous. The fauna is a typical mid-shelf marine community, with terrestrial components such as the ornithischians floating in as carcasses.

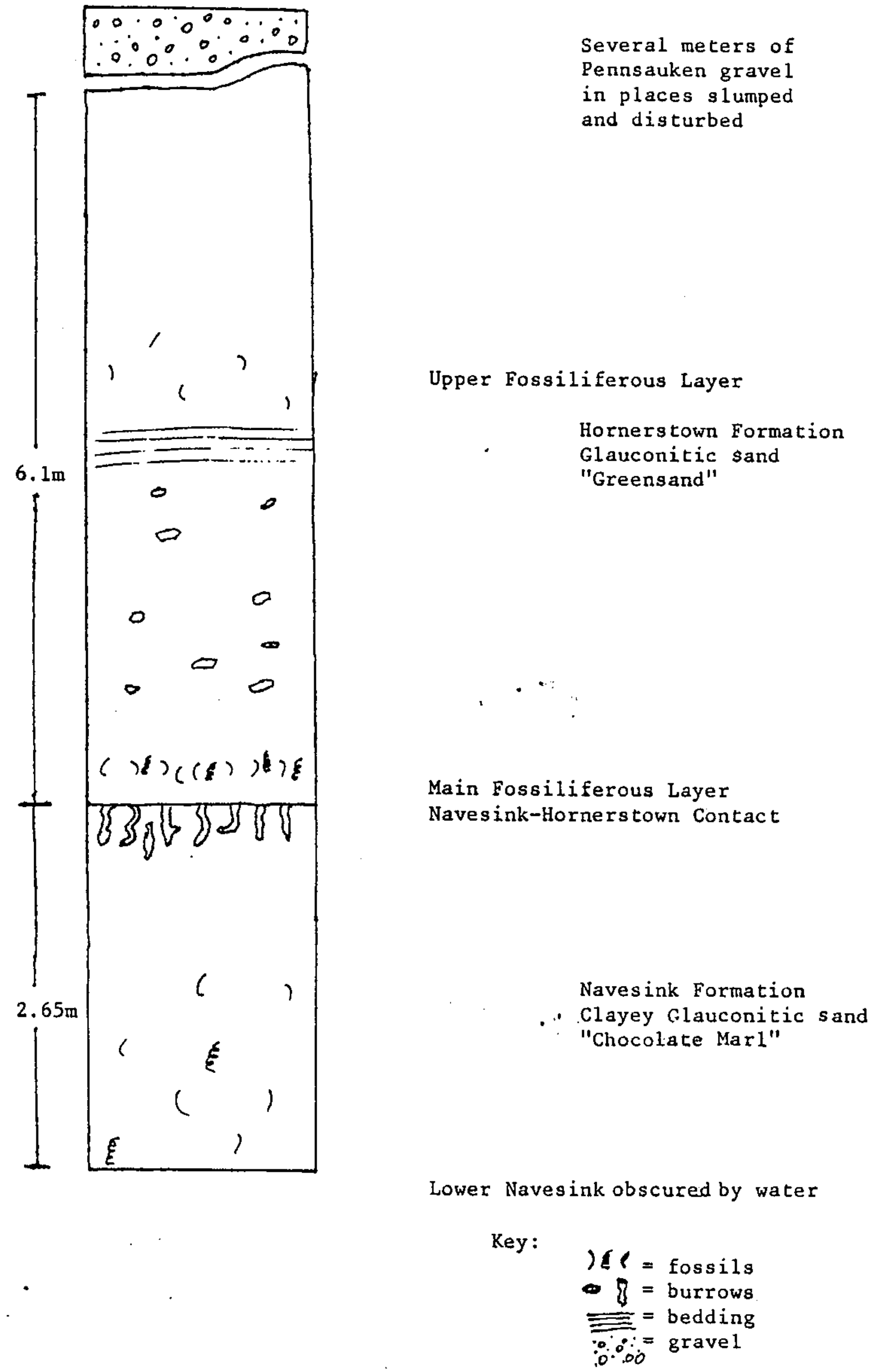
The contact between the Navesink and Hornerstown is extensively burrowed, smearing out any sharp stratigraphic boundary between the two formations. Above this level, a purer glauconitic sedimentation predominates. At about 32 cm above the contact, the MFL of the basal Hornerstown occurs. This is a thin layer, perhaps a foot in thickness. Thus there was some protracted period of low sedimentation rate usually associated with glauconitic deposition before and during accumulation of the MFL fossil assemblage. This interval argues against the reworking of fossils from underlying Cretaceous units into the basal Hornerstown, since the MFL fossils are not strictly at the bottom of the formation but are separated from it. Moreover, the MFL assemblage, while distinctly Cretaceous in aspect, is also distinguishable from the subjacent Navesink on the basis of its unique components. The mosasaurs, the ammonites and certain other molluscan species (for example, Gyrodes abyssinus, Pyropsis trochiformis, Cardium tenuistriatum, Gervilliopsis ensiformis) all suggest a Cretaceous age. Among the ammonites, both Sphenodiscus lobatus and Pachydiscus (Neodesmoceras) sp. argue for a latest Maastrichtian (Latest Cretaceous) age. Again, the fauna of the MFL is shelf marine, perhaps a deeper-water assemblage than the Navesink.

Three meters above this, the upper Hornerstown contains a diffuse fauna that also indicates mid to outer shelf conditions. Here, however, we see a reduction in diversity, with typically Tertiary forms dominating (such as Peridonella dichotoma, Flabellum mortoni, and Terebratulina manasquani). These species are Danian or Midway in age, that is, earliest Tertiary (Paleocene).

It is our contention that the diversity reduction and faunal replacement of Maastrichtian by Danian forms within the Hornerstown reflects a real event, e.g. the Cretaceous-Tertiary extinction, and not merely the vagaries of reworking. The depauperate Danian fauna at the top of the Hornerstown can be characterized as dominated by generalist, "primitive" types such as one would expect in a disturbed environment; indeed, the sponge-coral-brachiopod association is almost Paleozoic in its simplicity. By contrast, the MFL contains specialized Cretaceous forms (mosasaurs, ammonites, various other molluscs) suggesting the last remnants of a longstable Mesozoic environmental regime. All of this took place in a low-energy, low-sedimentation rate depositional environment, another argument against reworking. The relative thinness of the section involved presents no difficulty; long periods of time would be required to produce a section of glauconite this thick, in comparison to thicker Western Interior sequences of the same time produced as a result of active tectonics and concomitent clastic shedding and deposition.

Research is continuing on the C/T interval at the Inversand Pit. In addition to the biostratigraphic investigations, paleoecological, taphonomic and geochemical studies are planned or in process. We may not have the wealth of exposures available to the early workers, but we can pay careful attention to what we do have by applying our larger array of available methodologies.

Figure 1. Stratigraphic Section of Inversand Pit, Sewell, N.J.



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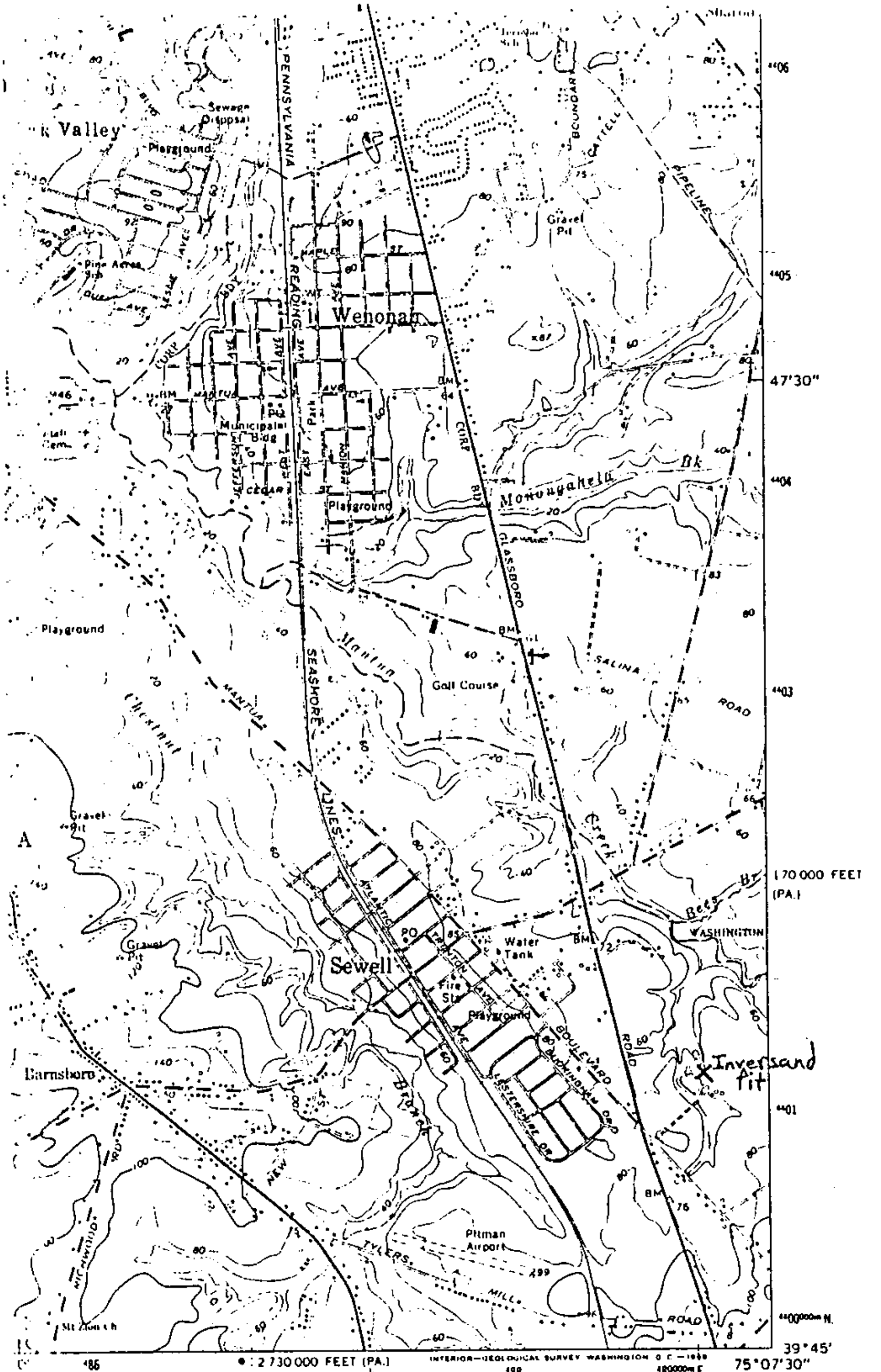
DIRECTIONS TO THE INVERSAND PIT FROM STOCKTON STATE COLLEGE

Take Route 557 south from Stockton State College to Route 322 heading west. Follow 322 to Williamstown, where it forks off to the left. Go through Williamstown to Glassboro; make a right (north) onto Route 47 (Delsea Drive) at the T-intersection. Look for a fork off to the left shortly after leaving Glassboro; this will be Route 553, and the exit sign will read 'Pitman.' Take this fork to the left, and continue on 553 through downtown Pitman. 553 is also called 'Glassboro Road.' Keep going north toward Sewell; shortly you will come to major road excavations, and less than 1/4 mile beyond this will be the intersection with Mantua Boulevard, Route 676; make a right on 676 even though it may look like the road is closed due to the highway construction. Make an immediate left at the 'Inversand Company' sign and follow the unimproved road through thr plant's gate. Parking is on the right. BE PREPARED TO GET MUDDY AND WET!

MEET AT THE INVERSAND PIT AT 10:00 AM



ROAD CLASSIFICATION

Heavy-duty — Light-duty

Medium-duty — Unimproved dirt

Interstate Route — U. S. Route — State Route

NEW JERSEY

QUADRANGLE LOCATION

WOODBURY, N. J. – PA.

SW/4 PHILADELPHIA 15' QUADRANGLE

N3945—W7507.5/7.5

1967

AMS 5963 I SW—SERIES V822

ABSTRACTS

EARTH SCIENCE TEACHERS SYMPOSIUM

ABSTRACT

Joyce Richard
Haddonfield Middle School
Haddonfield,New Jersey 08033

EARTH SCIENCE IDEAS THAT WORK

This workshop will include project and laboratory activities that can be utilized in an Earth Science course. Several ideas for the implementation of the computer into an earth science curriculum will be discussed and different software will be demonstrated. The Commodore 64 computer will be used, but project ideas are appropriate for almost any type of cumputer system.

Dr. John F. Herrmann

Halley's Comet - A Practical Approach

Dr. Hermann will present a series of fascinating slides and hands-on activities that will enable conference participants to locate Halley's Comet. Tips on easy-to-accomplish astrophotography will also be presented. If weather permits, the celestia-14 will be used to view Jupiter and other celestial object, to.

DINOSAURS: PAST AND PRESENT

Roger C. Wood
Faculty of Science and Mathematics
Stockton State College
Pomona, N.J. 08240

Dinosaurs have always been a subject of particular fascination to the general public ever since their first discovery in the 1830's. This popular interest has not always been matched by comparable scientific attention. But within recent years there has been a resurgence of discovery and research pertaining to dinosaurs that has been unmatched at any time in the past.

Recent scientific interest in dinosaurs has focused on two questions:

1) were dinosaurs essentially overgrown lizards, or were they in fact more comparable in terms of their metabolism and social behavior to modern birds (now known to be direct descendants of dinosaurs) and mammals? and

2) what caused the large-scale extinction of dinosaurs (and many other types of organisms) some 60 million years ago at the end of the Cretaceous?

Dinosaurs are an excellent topic through which to introduce students at virtually any level of education to science. First, there is a natural predisposition on the part of students to be interested in dinosaurs even though they might feel a strong antipathy to science in general. Second, in order to understand adequately the life and times of dinosaurs, elements of a wide variety of scientific disciplines must be understood - evolution, ecology, stratigraphy, geologic time, plate tectonics, even a smattering of physics and astronomy. And third, changing scientific views about dinosaurs over time provide an easily-comprehended case study of scientific method, a fundamental aspect of science rarely understood by most people.

This presentation, therefore, has several objectives:

1) to provide a brief overview of the lives and times of dinosaurs, and changing interpretations thereof;

2) to suggest ways in which dinosaurs can be used in the classroom or laboratory to acquaint otherwise-reluctant students with some fundamental aspects of science; and

3) to furnish information about useful literature, audio-visual materials, fossil reproductions, and field trips that may be helpful to teachers in tailoring dinosaur topics to their individual instructional needs.

A B S T R A C T

WORKSHOP ON MICROPALEONTOLOGY

Don Zalusky

Glassboro State College

A hands-on workshop in Micropaleontology for those desiring familiarity with common micro forms. Participants receive a brief introduction to the methods of collecting and study and a simple identification procedure for the Foraminifera.

A manual prepared for this workshop, which may be retained, illustrates morphological features of the forams as an aide to identification.

Material recovered from deep sea cores constitutes the study material and each participant may retain ten specimens for future use. Radiolaria, conodonts and other micro forms may be viewed.

ABSTRACT

Paleontology and Stratigraphy of the Upper Cretaceous and Lower Tertiary Deposits of the New Jersey Coastal Plain.

by William B. Gallagner
New Jersey State Museum
and
Geology Department, University of Pennsylvania

The Upper Cretaceous-Lower Tertiary (C/T) section exposed along the Inner Coastal Plain of New Jersey is a classic sequence first studied by the founding fathers of paleontology in North America. Despite this history, our understanding of this section is imperfect because of extensive plant cover and concomitent paucity of exposure; in addition, urbanization of the Inner Coastal Plain has destroyed or restricted historically important outcrops. But additional complications have arisen from the traditional "layer-cake" interpretations of C/T deposits in this area. These approaches have failed to completely account for the subtleties of facies and faunal changes along strike within individual units and also between units within the section. Along any segment of southern New Jersey shoreline today, a system of coastal environments exists in close proximity while each environment has its own characteristic sedimentation regime and biota. This sublittoral-barrier island-estuarine-fluvial complex is offered as an actualistic model for some aspects of C/T facies changes and paleontology. Other features of C/T sedimentology and paleoecology must be explained by unique oceanographic conditions associated with a smaller North Atlantic Ocean and the influence of an equatorial Tethyan circulation. The entire sequence can be viewed as the product of sea-level change along a passive continental margin coupled with gradual subsidence of rifted margin lithosphere and shifting axes of maximum deposition. Within this context, the faunal changes within and between units is explainable as variations in diversity due to eustatic change. The major exception is the C/T extinction, which is placed within the Hornerstown on the basis of invertebrate, vertebrate and micropaleontological studies. This makes the C/T interface in New Jersey a target for geochemical analysis, and such a study is already in progress.

ABSTRACT

Mineral and Rock Identification Workshop
for Earth Science Teachers

Minerals and rocks will be identified on the basis of their physical and chemical properties.

Physical properties noted will include color, texture, streak, luster, hardness, density and cleavage.

Chemical properties noted will include reactions with dilute hydrochloric acid.

Identification tables and worksheet will be provided.

AQUIFER SYMPOSIUM

The Role of the Geologist in Today's Ground Water Problems

Haig F. Kasabach,
State Geologist

When I first began to work with the State of New Jersey in 1960, there were only 6 people who held geologist titles working for the State. The shift in the economic situation and environmental regulations have made the state the largest employer of geologists in New Jersey(over 90 people). Specialists are now required in hydrogeology, geophysics, and soil science to handle the complex environmental problems and especially those related to ground water. New Jersey's colleges and universities must prepare their students for these new challenges. Virtually every major project in New Jersey, which may have an impact on ground water, requires input from a geologist either during its inception or in the regulation process.

Discovery of the Aquifers of the New Jersey Coastal Plain in the Nineteenth Century

Dr. Claude M. Epstein
Stockton State College
Pomona, New Jersey 08240

The aquifers of the New Jersey coastal plain were discovered as part of a search for new water resources. The region's population tripled, industries expanded and the threat of water-bourne disease made this search necessary. The discovery of these water resources was the result of a combined effort on the part of the New Jersey State Geological Survey, the state's well drillers and some of the region's most prominent citizens.

The search for new water sources, commenced by the Survey's director George Cook in the 1860's, led to the recommended use of cisterns and transported surface water. Coastal wells had proven to be subject to salt water intrusion and surface pollutant contamination while those on the mainland often proved to be too mineral enriched to be used for industry and were also subject to surface pollutant contamination. Cook revised this initial policy in the early 1880's when it became clear that ground water was plentiful throughout the coastal plain and could be easily obtained by means of artesian wells. Moreover the newer wells, tapping deeper horizons, were free of surface contaminants and salt water and were useful for domestic consumption and industrial use. Cook also established a system were well drillers freely gave the survey their well logs. Over 1200 well logs had been collected by 1901.

Lewis Woolman actually discovered and correlated most of the aquifers known today during the period from 1889 to 1902. He first recognized the aquifers beneath Atlantic City and correlated those on the outer coastal plain with those in Atlantic City by means of fossils and confining beds. He later recognized those beneath in the inner coastal plain and refined his work on the outer coastal plain. G.N. Knapp first applied the names Kirkwood and Cohansey to Cook's outer coastal plain horizons in 1903 while H.B. Kummel and H. Poland applied the modern names to those Cook recognized beneath the inner coastal plain in 1909.

The hazards facing aquifer use were identified by the first two survey directors. George Cook recognized the cause of well contamination by surface pollutants and salt water intrusion in the 1860's. John Smock recognized the hazard of well drawdown interference and ground water diversion rights in the 1890's. Thus a general understanding of the aquifers beneath the New Jersey coastal plain and the hazards to which they were subject were known before the turn of the century.

ABSTRACT

MARINE WELL-DRILLING PROGRAM FOR ESTIMATING THE SEAWARD EXTENT OF FRESH GROUND WATER AND EVALUATING THE LIKELIHOOD OF SALTWATER INTRUSION NEAR ATLANTIC CITY, NEW JERSEY

GARY N. PAULACHOK, RICHARD L. WALKER, GARY J. BARTON, JEFFREY S. CLARK, PHILIP B. DURAN, and JOSEPH J. HOCHREITER (U.S. Geological Survey, Trenton, NJ 08608); JOHN FARNSWORTH and JAMES T. BOYLE (New Jersey Dept. of Environmental Protection, Geological Survey, Trenton, NJ 08625)

From July until September 1985, the U.S. Geological Survey, in cooperation with the New Jersey Department of Environmental Protection, drilled two deep marine-observation wells at sites 1.9 miles and 5.3 miles southeast of Atlantic City, New Jersey to estimate the seaward extent of fresh ground-water supplies and to evaluate the likelihood of saline ground water intruding into those supplies. The Atlantic City area was selected for study because ground-water levels there are as much as 80 feet below sea level, thereby increasing the potential for intrusion of saline water into landward parts of the 800-foot sand of the Kirkwood Formation, locally a major source of potable water.

At both the first site (herein called inshore) and second site (herein called offshore), an 11-inch diameter borehole was drilled by the hydraulic rotary method to depths below seafloor of 933 feet and 1025 feet, respectively. Drilling operations were conducted aboard a jack-up platform 113 feet long and 57 feet wide. Lithologic samples

from the boreholes will be analyzed for mineralogy, paleontology, palynology, pore-water quality, and hydraulic properties. Borehole testing included vertical seismic profiling and collection of complete suites of geophysical logs. Each borehole was completed as a well with four-inch diameter screen and casing. The inshore well was pumped continuously at 40 gallons per minute for six days; the specific conductance stabilized on the sixth day at 220 microsiemens per centimeter. Water samples for complete chemical analyses were collected during the later stages of pumping. Following pumping of the inshore well, four nearby wells onshore were pumped continuously at a total rate of 2,500 gallons per minute for six days while drawdown was measured at the inshore well and two wells onshore. By the conclusion of onshore pumping, water levels had declined about 6 feet in the inshore well. Subsequently, the offshore well was pumped continuously at 50 gallons per minute for six days; the specific conductance stabilized on the sixth day at 502 microsiemens per centimeter. Water samples for complete analyses were collected at the final stages of pumping.

Following pumping and sampling, three differential pressure transducers and three conductivity electrodes were permanently installed in each marine well. Measurements of head and specific conductance will be made periodically by retrieving peripheral connections stored on the seafloor, attaching them to appropriate instruments aboard ship, and interrogating the downhole sensors. Preliminary results from both wells suggest that a large body of fresh water in the 800-foot sand extends seaward from Atlantic City. The downhole sensors are intended to detect any encroachment of saline water toward onshore fresh-water supplies.

ABSTRACT

Progress report on the Hydrogeology and Saltwater Intrusion of the Raritan-Magothy aquifer system in central New Jersey.

By Amleto A. Pucci, Jr

Detailed hydrogeologic data are needed to numerically simulate the migration of the freshwater-saltwater transition zone in two areas of saltwater intrusion. Data requirements are: (1) lithologic information, to delineate the hydrogeologic framework, and (2) the hydraulic properties of the sediments.

The first area is in the Townships of Sayreville, South River, and South Amboy, all in Middlesex County, where saltwater intrusion into the Farrington Sand Member of the Raritan Formation dates back to the 1920's. The Washington Canal, and the Raritan and South Rivers are known sources of saltwater intrusion. The second area is in the Boroughs of Keyport and Union Beach, both in Monmouth County, where saltwater from Raritan Bay was detected in the Old Bridge Sand Member of the Magothy Formation in the mid-1970's.

More than 400 lithologic logs are available from these sites. Geophysical data include records of seismic and aeromagnetic surveys. Specific data requirements include: (1) the extent to which the Palisades still, a Triassic diabase sill, restricts flow in the Farrington aquifer in some places; (2) the hydraulic properties and the areal extent of sediments in the saltwater infiltration areas; and (3) the areal extent and hydraulic properties of the confining units overlying the Old Bridge aquifer beneath Raritan Bay.

Marine seismic reflection data were collected by the U.S. Geological Survey at the Washington Canal, the Raritan and South Rivers, and Raritan Bay and the data are currently being analyzed.

These data, combined with borehole information, were used to define silty bottom sediments beneath the waterways. Seismic reflectors 400 feet below sea level have been identified.

Surface geophysical surveys by the New Jersey Geologic Survey (NJGS) are being conducted for this investigation to delineate the-extent of the Palisades sill. Gravimetric, magnetic, and seismic methods are being employed. Using surface geophysics techniques, the saltwater plume and the hydrogeologic framework in the Keyport and Union Beach area will be defined. Borehole geophysics and lithologic logs of wells to be drilled will also be used th define the framework.

An observation well is being drilled by the NJGS for the study for stratigraphic control and chloride monitoring at Conaskonk Point in Union Beach Borough. In addition an aquifer test will be conducted in this vicinity to: (1) ascertain the local hydrogeology; and (2) determine the location and width of the freshwater-saltwater transition zone.

Ground-Water Pollution in an Outcrop Area of a Coastal Plain Aquifer System: Logan Township, New Jersey

Joseph J. Hochreiter, Jr., Jane Kozinski, Pierre J. Lacombe, and Jean C. Lewis (Hydrologists, U.S. Geological Survey, Water Resources Division, Trenton, N.J.)

The Potomac Group and the Raritan and Magothy Formations comprise the basal units of the New Jersey Coastal Plain and together form the Potomac-Raritan-Magothy aquifer system. These Cretaceous formations, along with the Merchantville Formation, crop out in Logan Township. Geophysical logs and core samples show that the clay confining units separating aquifer units farther downdip are discontinous in the vicinity of four hazardous-waste-disposal sites. Regionally, recharge to the aquifer occurs in the outcrop area. Pollutants entering the aquifer system in this critical area were monitored to determine the extent of contaminant transport in the subsurface.

The areal limits of gross contamination were defined at three sites using surface electromagnetic-conductivity surveys. This technique proved to be quick and effective for delineating conductive contaminant plumes in the upper 50 feet of unconsolidated sediments. Contamination beneath each of the disposal sites was confirmed with ground-water-quality data collected from more than 50 wells. Geochemical data obtained from shallow monitoring wells are consistent with the results of the geophysical surveys. Access to each site was granted by each company for the purpose of defining the magnitude and extent of ground-water contamination.

Contamination plumes beneath Chemical Leaman Tank Lines and the abandoned Bridgeport Rental and Oil Services (BROS) extend to nearby wells beyond the boundaries of each site, to depths of at least 100 ft. Ground water beneath Rollins Environmental Services is contaminated to a depth of about 70 ft; however contamination has not travelled beyond Rollins' property due to the operation of an abatement pumping system. Contamination beneath Monsanto Chemical Co., is effectively contained by cones of depression surrounding high-capacity productions wells on site.

The most frequently detected organic priority pollutants, present in at least 30 percent of the wells sampled, included trichloroethylene, naphthalene, benzene, 1,2-<u>trans</u>-dichloroethyene phenol, 1,2 dichloroethane, toluene, ethylbenzene, and methylene chloride. Most of these compounds have relatively low molecular weights and high vapor pressures. Very high concentrations of at least 10 mg/L were observed for samples containing methylene chloride (18 mg/L), toluene (12 mg/L), 2,3-dimethylphenol (11 mg/L), and 1,2-<u>trans</u>-dichloroethylene (10 mg/L). Where man-made organic contamination was detected, volatile organic compounds were almost always present. In addition, up to 90 percent of the organic compounds tentatively identified in water samples from highly-contaminated wells were not included on the EPA priority pollutant list. Over 100 organic non-priority pollutants were tentatively identified. The most frequently detected non-priority pollutants were tabulated by site in an attempt to fully characterize the nature of ground-water contamination.

Although the sources of waste at the four sites were very different, a group of acid-extractable, base/neutral-extractable, and volatile organic priority pollutants was repeatedly observed. Despite this, characteristic features were observed that enabled identification of the unique nature of contamination at the four sites. Ground water sampled at the BROS site had high concentrations of one- and two-ring aromatic hydrocarbons, phenol, total organic carbon, sulfate, and lead. Ground water sampled at the adjacent Chemical Leaman site contained higher concentrations of chlorinated aliphatic compounds, such as trichloroethylene. Ground water sampled at the Rollins site contained the most diverse group of organic pollutants, with high concentrations of alkalinity (up to 1400 mg/L) and several phenolic compounds (up to 8.4 mg/L for 2,4 Dimethyl phenol). The highest concentrations of arsenic, mercury, and ammonia were detected in wells at the Rollins site. Pollutants beneath the Monsanto site were observed at much lower concentrations than for the other sites. The occurence of phthalate esters proved to be characteristic of contamination at the Monsanto site.

Geological Investigations of the Coastal Plain of Southern New Jersey

Part 2:

A. Hydrogeology and the Coastal Plain

edited by Claude M. Epstein

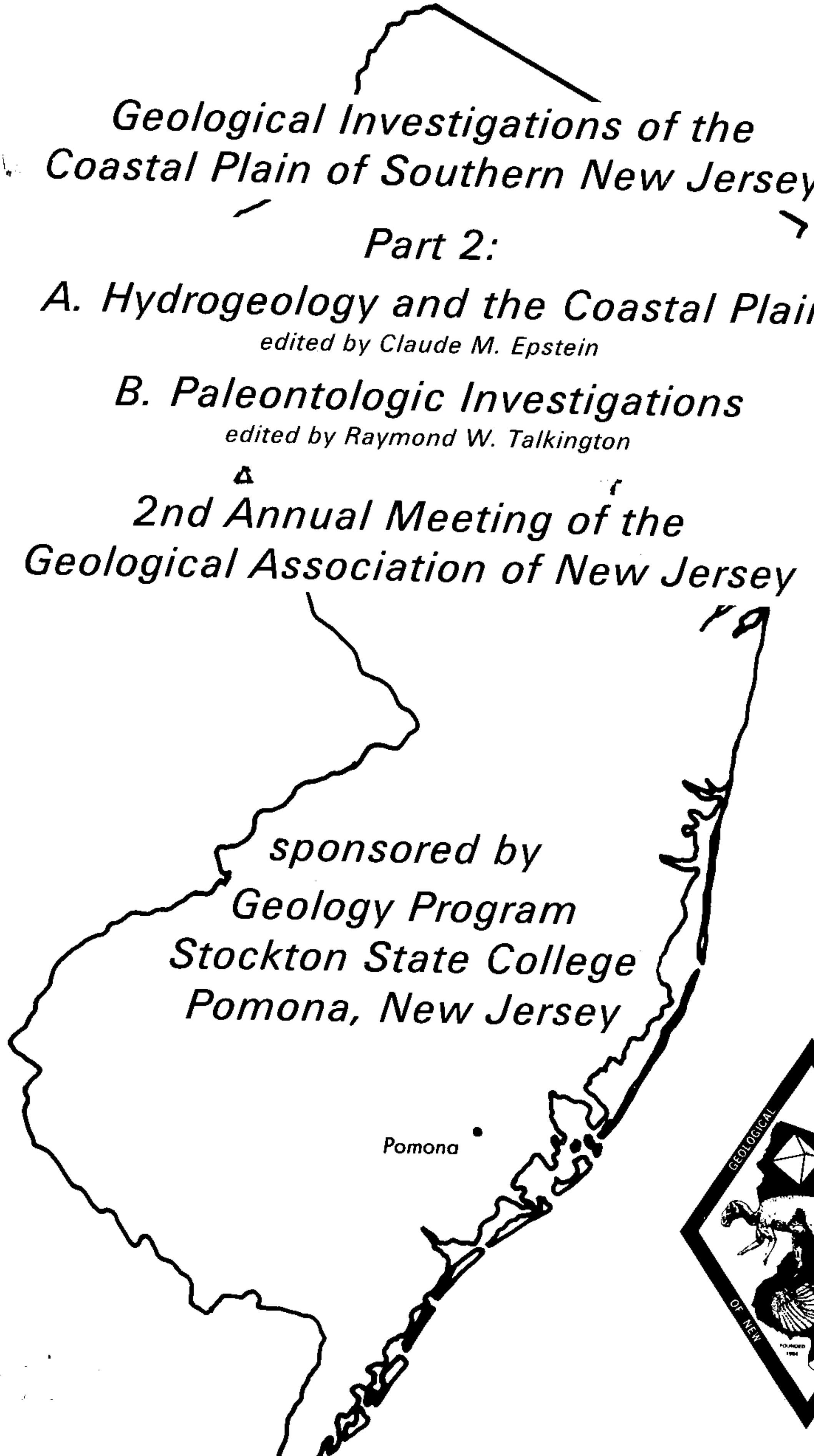
B. Paleontologic Investigations

edited by Raymond W. Talkington

2nd Annual Meeting of the Geological Association of New Jersey

sponsored by

Geology Program
Stockton State College
Pomona, New Jersey



Hydrogeology and the New Jersey Coastal Plain

The economic development and the population growth of the New Jersey coastal plain depended on the acquisition of adequate supplies of water. Hydrogeologists, or people who would be referred to as such, played, and continue to play, a significant role in the exploration, development, and protection of these supplies.

This symposium was convened to discuss how hydrogeologists have, are currently, and will continue to discover, develop, and protect the groundwater resources of the New Jersey coastal plain. Claude Epstein's paper deals with those activities undertaken by the New Jersey State Geological Survey in the nineteenth century. The papers of Amleto Pucci Jr., Gary Paulachok, and Anthony Navoy deal with the current activities of the U.S. Geological Survey on the coastal plain. The concluding paper by the current director of the New Jersey State Geological Survey Kaig Kasabach deals with the current and future need for hydrogeologists in New Jersey.

In addition, this symposium served as a means to inform the geologists working and living in New Jersey of the current state of knowledge on coastal plain hydrology. It is hoped that the reader will find these papers as interesting and exciting as did the participants attending the conference last October.

Dr. Claude M. Epstein, editor
Stockton State College

Discovery of the Aquifers of the New Jersey Coastal Plain in the Nineteenth Century

Dr. Claude M. Epstein
Stockton State College
Pomona, New Jersey 08240

The aquifers of the New Jersey coastal plain were discovered as part of a search for new water resources. The region's population tripled, industries expanded and the threat of water-bourne disease made this search necessary. The discovery of these water resources was the result of a combined effort on the part of the New Jersey State Geological Survey, the state's well drillers and some of the region's most prominent citizens.

The search for new water sources, commenced by the Survey's director George Cook in the 1860's, led to the recommended use of cisterns and transported surface water. Coastal wells had proven to be subject to salt water intrusion and surface pollutant contamination while those on the mainland often proved to be too mineral enriched to be used for industry and were also subject to surface pollutant contamination. Cook revised this initial policy in the early 1880's when it became clear that ground water was plentiful throughout the coastal plain and could be easily obtained by means of artesian wells. Moreover the newer wells, tapping deeper horizons, were free of surface contaminants and salt water and were useful for domestic consumption and industrial use. Cook also established a system were well drillers freely gave the survey their well logs. Over 1200 well logs had been collected by 1901.

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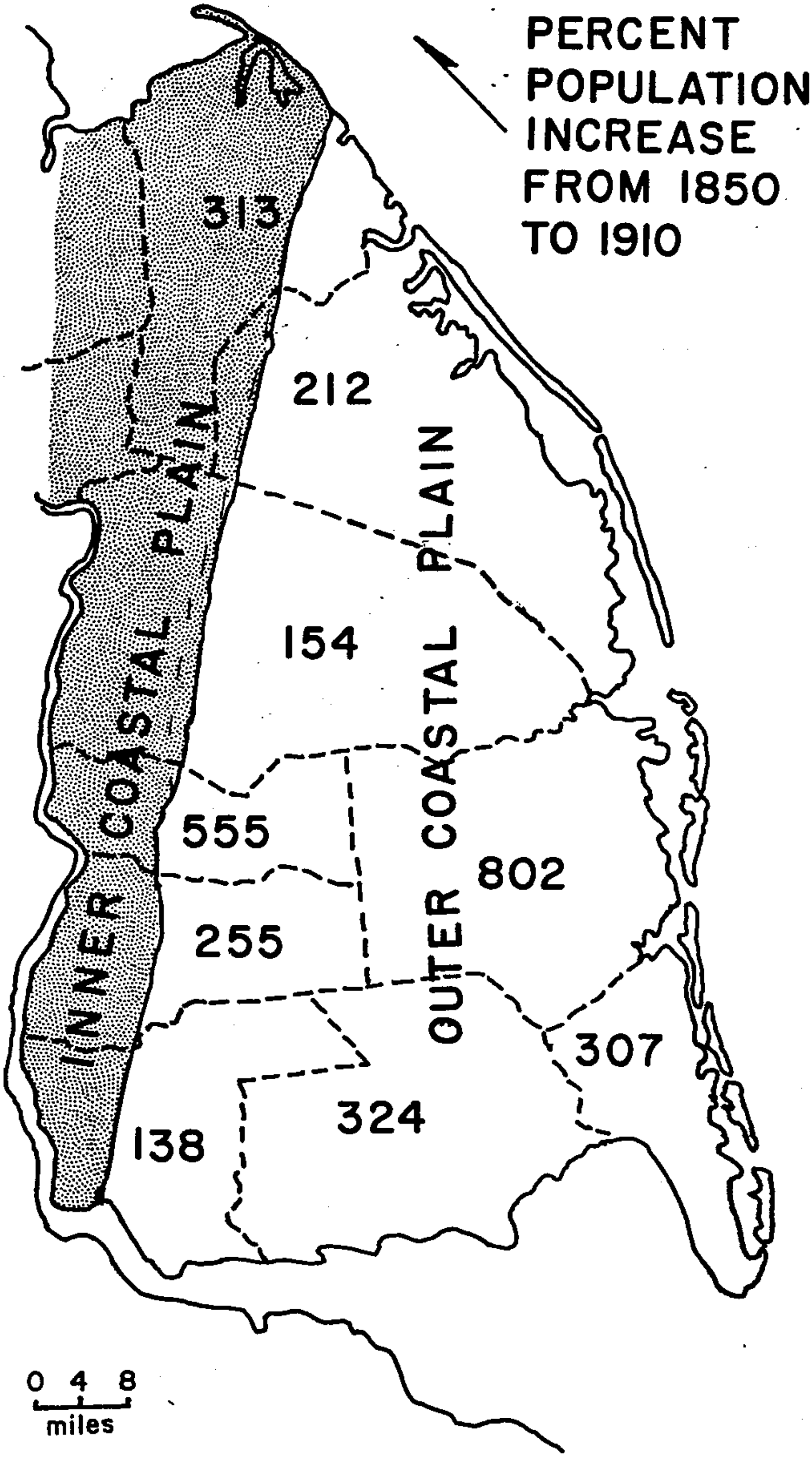
Introduction : Population Growth, Economic Development, Epidemics & the Search for Water

The aquifers of the New Jersey coastal plain were discovered as part of a search for new, abundant water supplies. The population of the coastal plain counties tripled from 1850 to 1910(see Figure 1). Towns grew, new industries were established, and farm acreage increased in the wake of this population growth. Vast quantities of water from new sources were required to support these developments. Moreover water-bourne epidemics, such as typhoid fever, were a constant threat to the health to the people of the coastal plain.

Ground water had proven to be an unreliable source. The wells along the shore tended to become salty after a short period of use. The well water on the mainland was often too mineralized, causing boilers for "rust out" quickly and staining paper and textiles thereby reducing their value. Moreover wells throughout the coastal plain often became contaminated by surface pollutants with time as the population around those wells grew. Yet ground water proved to be the most feasible water supply for the coastal plain. The discovery of those water resources in the second half of the nineteenth century is the subject of this study.


PERCENT
POPULATION
INCREASE
FROM 1850
TO 1910
313
212
154
555
255
802
307
324
138
INNER COASTAL PLAIN
OUTER COASTAL PLAIN
0 4 8
miles

The Initatives of George Hammell Cook(1863-1888)

The combined efforts of many people led to the discovery of the aquifers of the New Jersey coastal plain. But it was George Cook, director of the Third Geological State Geological Survey 1863-89) who began the search. He first studied the coastal plain as assistant geologist in charge of the southern division of New Jersey during the second state geological survey directed by William Kitchell(1854-1857)[Cook, 1863]. In addition, he had much experience working with the state legislature as director of the survey and as administrator of Rutgers College[Sidar, 1976]. Thus knowing the regional geology and the local political set up, Cook was in a good position to see what needed to be done to locate and develop coastal plain water resources.

Cook first looked into the issue of water quality. He knew that town wells became contaminated by surface pollutants, that wells along the shore frequently became contaminated with salt water, and that boilers which powered south Jersey industry on the mainland were prematurely corroded by the chemical components of artesian well water[Cook, 1857]. Cook, in his first article concerning water resources, published in 1868, reiterated his understanding of the origin of ground water and the causes of its contamination. But the major innovation of that year was the establishment of a water quality testing laboratory at the survey whose purpose was to assess the quality and healthfulness of the states water supplies. Cook recognized a distinction between the water quality of wells tapping Cretaceous strata, which tended to be sulfur-enriched, and those of the Tertiary strata, which tended to be relatively pure[Cook, 1868a].

Cook undertook the first water resource survey in 1875 for the growing resort town of Atlantic City. As the resort grew, conventional water supplies tended to become contaminated. Cook was, at this time, skeptical about the efficacy of ground water as a source of supply. He recommended cisterns for the wealthier citizens and stream water from Absecon Creek on the mainland transported via pipeline to Atlantic City for the municipal water supply[Cook, 1875].

But the outbreak of typhoid fever in 1878 spurred on the development of ground water resources. Several inmates of the Jamesburg Reform School died during that epidemic[Cook, 1878]. Cook also lost his daughter during this outbreak[Sidar, 1976]. From 1878 on, Cook sought to develop the ground water resources in the coastal plain as the source of water supply.

Cook established a method for assessing the ground water resources of the coastal plain. He enlisted the participation of many of New Jersey's well drillers. (Over 46 firms are named in the Annual Reports.) These drillers gave Cook their well logs. Cook analyzed these and published his results so that the drillers could use this now public information for their benefit. (The New Jersey Division of Water Resources continues this practise to this day though drillers are now required to submit their well logs.)

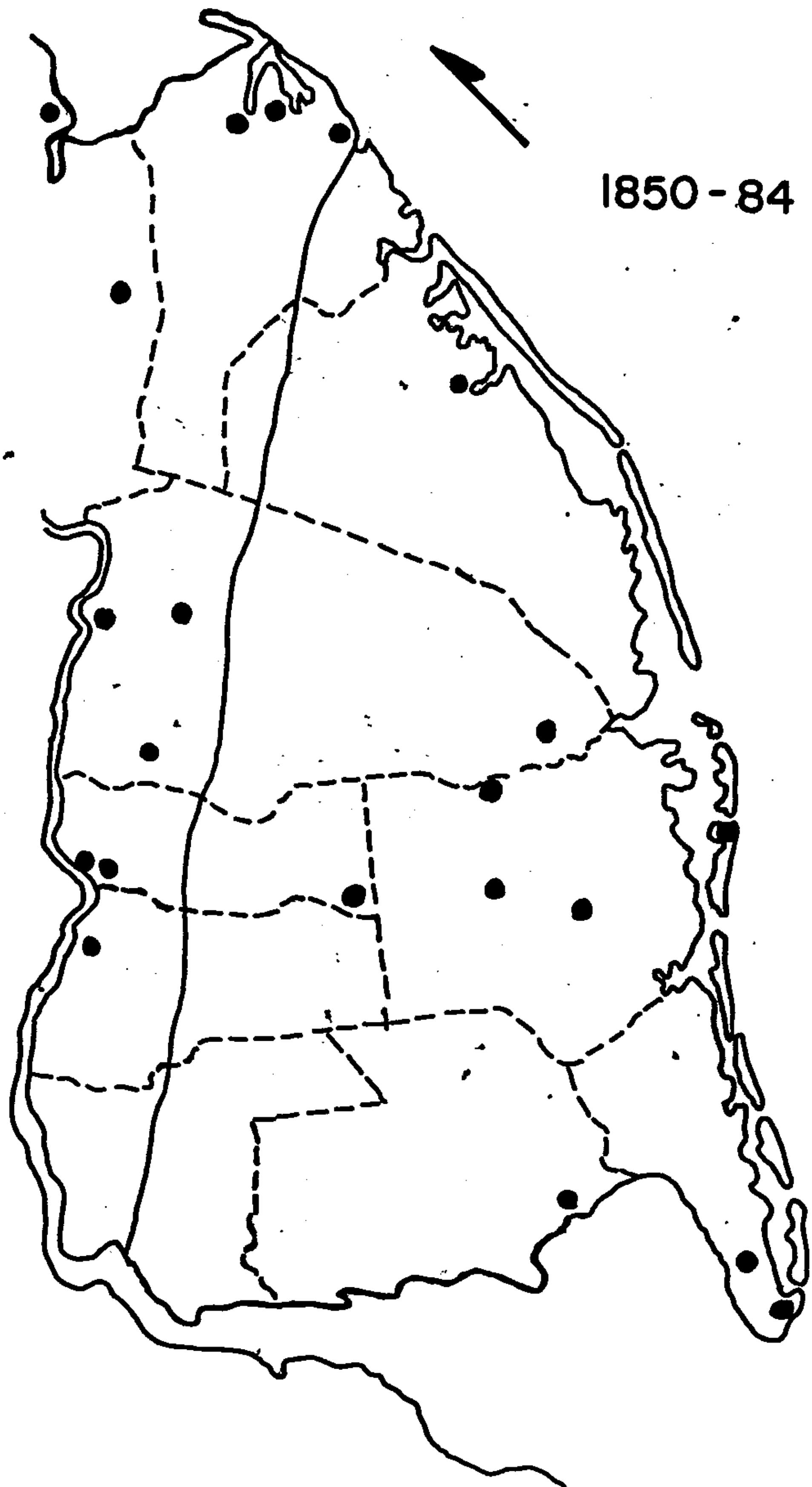
The successful completion of artesian wells throughout the late 1870's and early 1880's demonstrated to Cook the utility of this source of water supply. A major achievement was the successfuly completion of a 1970 foot well in Charleston, South Carolina. This showed Cook that artesian wells could even be used along the shore[Cook, 1880]. Cook now collected more well logs. These came from deeper wells from more parts of the coastal plain (see Figures 1, 2, 3). The number of wells reported in the outer coastal plain tripled while the maximum depth reached jumped from 475 feet for the period from 1880-1884 to 1400 feet for the next five year period. The major proliferation of wells in the inner coastal plain would have to wait until the 1890's(see Table1).

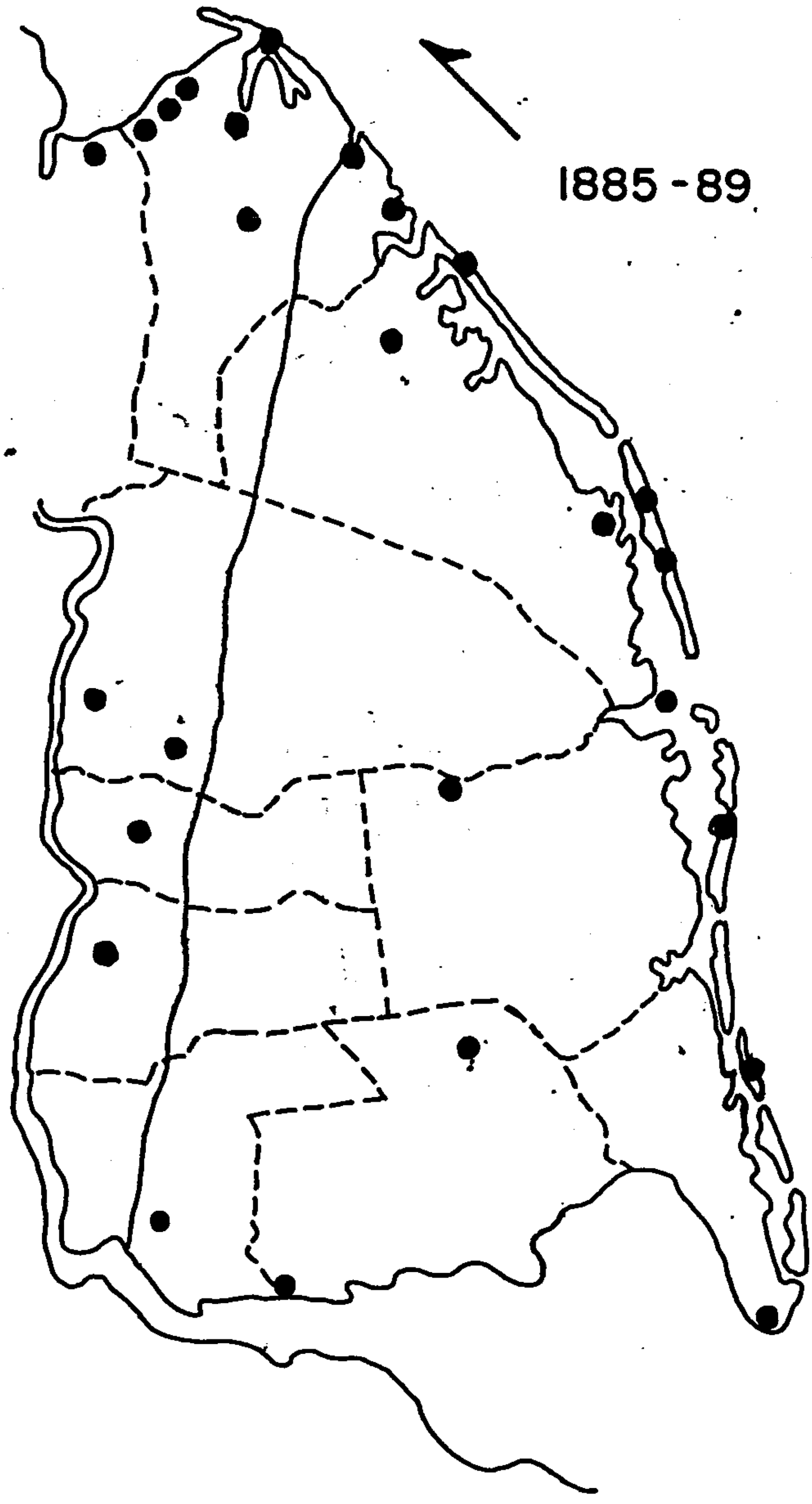
Armed with this well log data and his experience with coastal plain stratigraphy, Cook made several attempts to identify the aquifers of the coastal plain and to correlate these across the state. His first attempt was in 1879 when he correlated 21 well logs. He assumed that most of the strata were of constant thickness, dip and lithology and that unconformities existed only at the base of the Cretaceous sequence and between it and the overlying Tertiary strata[Cook, 1868b, 1879]. His projection for depth to bedrock beneath Atlantic City was 1500 feet, too meagre by a factor of four. This analysis resulted in Cook's hydrogeologic cross section of 1885(see Figure 4)[Cook, 1885].

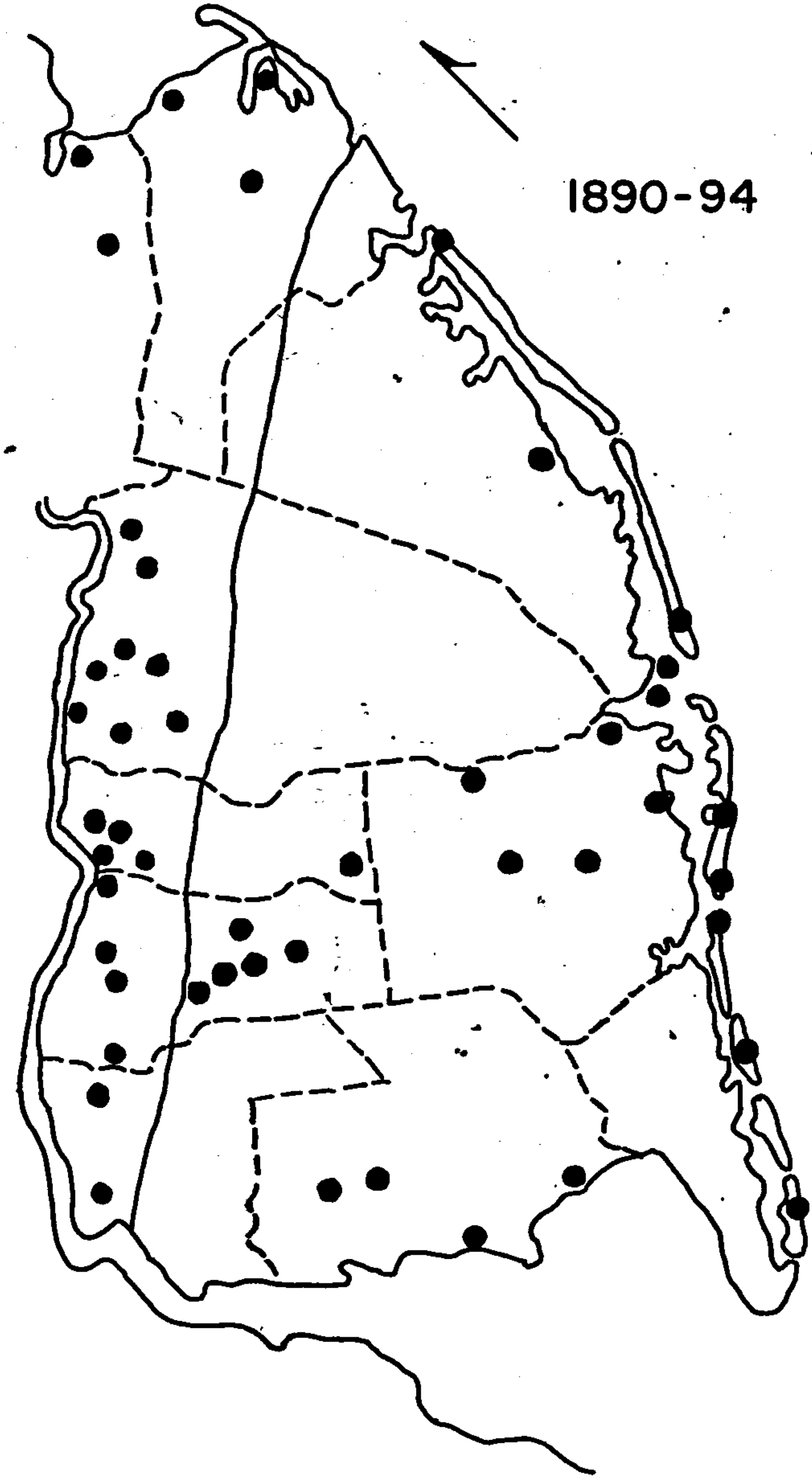
However, Cook felt he needed more data from the barrier islands. He had requested, as early as 1882, that wealthier entrepreneurs attempt a very deep well along the shore[Cook, 1882]. This finally happened in 1888 when a well was sunk in

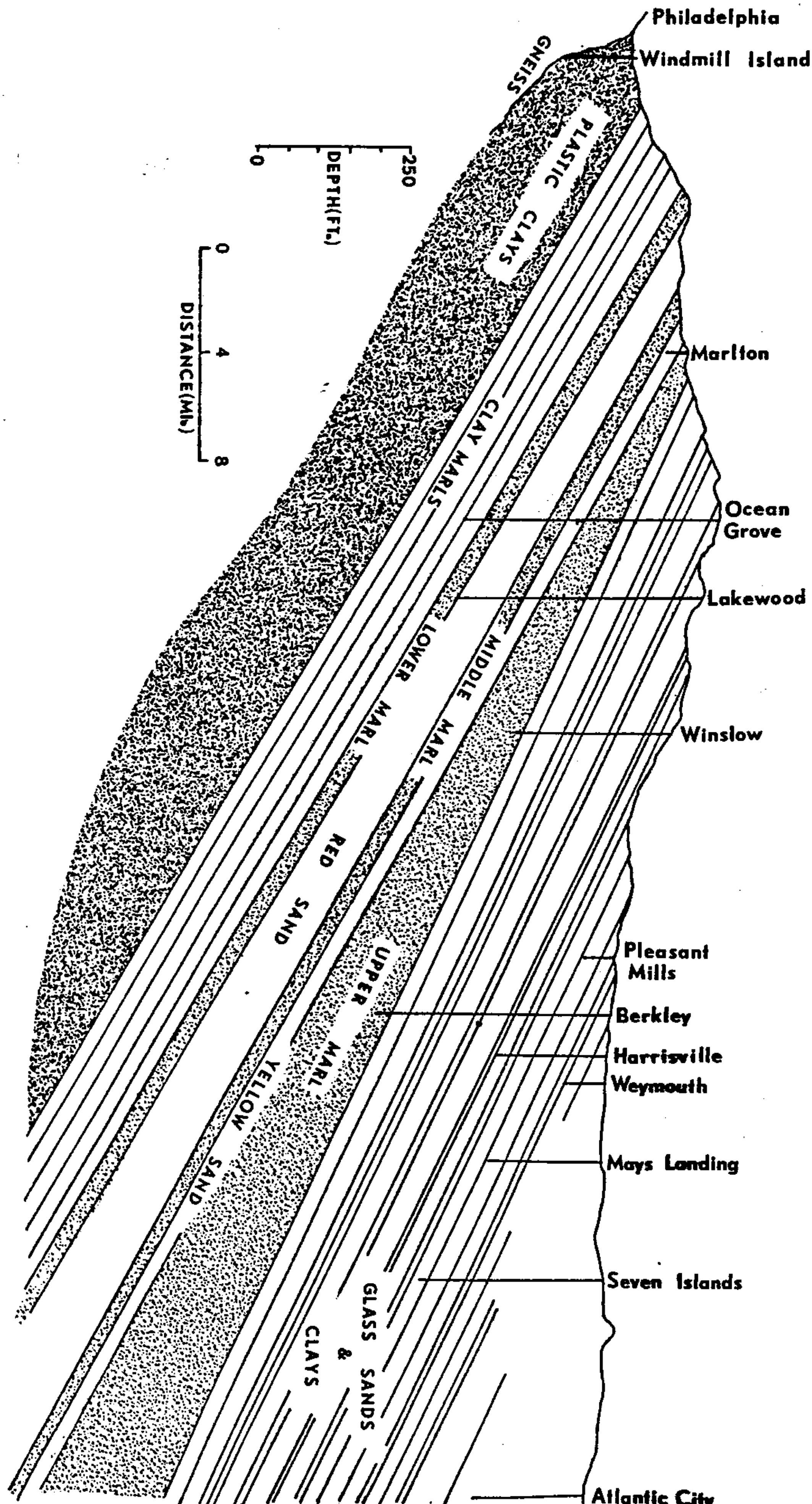
TABLE 1. Number of Well Logs Published & Maximum Depth Reached in Nineteenth Century Coastal Plain Wells

	Outer Coastal Plain		Inner Coastal Plain	
Time Interval	Number of Wells	Maximum Depth (Ft)	Number of Wells	Maximum Depth (Ft)
1900-04	71	2306	102	710
1895-99	51	940	188	730
1890-94	45	931	89	776
1885-89	21	1400	17	475
1880-84	6	475	7	481
1870-79	7	118	20	356
1850-69	8	335	-	-


1850-84


1885-89


1890-94


Philadelphia
Windmill Island
Marlton
Ocean Grove
Lakewood
Winslow
Pleasant Mills
Berkley
Harrisville
Weymouth
Mays Landing
Seven Islands
Atlantic City
GNEISS
PLASTIC CLAYS
CLAY MARLS
LOWER MARL
RED SAND
MIDDLE MARL
UPPER MARL
YELLOW SAND
GLASS SANDS & CLAYS
DEPTH (FT.)
0
250
DISTANCE (MI.)
0
4
8

Atlantic City to a depth of 1150 feet[Cook, 1888]. Unfortunately, Cook died the following year before he could refine his analysis.

Aquifer Identification by Lewis Woolman(1889-1902)

John C. Smock replaced Cook as survey director in 1889 and commenced a study on the artesian wells of the state. He hired Lewis Woolman to study the artesian wells of the coastal plain. Woolman published a series of fourteen articles in the Annual Reports that traced the steps of his analysis. His first step was to define his type section in Atlantic City[Woolman, 1889]. He recognized four water-bearing horizons and a nearly 300 foot thick confining bed. This he named the "Great Diatom Clay" after its fossil contents. He also determined the relative age of these units and correlated their fossil horizons with those known on the mainland.

His second step involved the correlation of the "Great Diatom Clay" of Atlantic City with its counterparts throught the coastal plain. This unit was to serve as the datum from which deeper and shallower horizons would be measured. He now associated the Atlantic City water-bearing horizons with their positions relative to the "Great Diatom Clay". Next, he traced the "Great Diatom Clay" across the state into Delaware[Woolman, 1890, 1891]. Now he was in a position to attempt to correlated these water-bearing horizons with those found at 11 mainland locations[Woolman, 1890].

The third step involved the identification of the aquifers throughout the entire outer coastal plain. As mentioned before, the number of well logs reported by the survey increased. Moreover, these wells were from parts of the coastal plain not previously examined and drilled to greater depths than ever before (see Table 2 and Figures 1, 2, 3). Woolman recognized 8 water-bearing strata in the outer coastal plain[Woolman, 1889, 1893, 1897]. The last one recognized was the Atlantic City 800 Foot Sand which shortly was to serve as the principal water source for Atlantic City's grand hotels and many shore municipalities. (It was recognized in the same year as the Raritan-Magothy aquifer, the largest aquifer in the state[Woolman, 1893].)

The fourth step involved the recognition of the water-bearing horizons of the inner coastal plain. Woolman recognized five major water-bearing units between 1893 and 1897(see Table 3)[Woolman, 1897]. Once again, this recognition was based on the large number of well logs coming into the survey during this period. Thus by 1897, the aquifers most commonly tapped today had been discovered.

The fifth step involved the recognition of the aquifers of Cape May county and their relationship with those of the rest of the outer coastal plain[Woolman, 1900].

Woolman attempted correlations of the coastal plain aquifers during his analysis. He published four hydrogeologic cross sections in 1894 utilizing a rather small number of well logs [Woolman, 1894]. But in 1898, Woolman published an hydrogeologic cross section of the 20 mile distance between Philadelphia and Atco, New Jersey that utilized over 150 well logs[Woolman, 1898].

His sections were more refined than those of Cook in that they were based on surveyed contact elevations. These were used to determine strata thickness and dip rather than the projection of pre-determined dips over large distances as done by Cook. Thus the subsurface conditions of the aquifers were better known.

Administrative Concerns of the 1890's

Survey director John Smock raised a prophetic issue in 1897 that had been previously unappreciated[Smock, 1897]. The city of Camden had recently switched its water source from Delaware River water to ground water tapped by a group of 98 closely spaced wells. Smock felt that under such circumstances each well might interfer with the ability of the other wells to draw water. In addition, so many wells pumping so much water might actually draw this water from far distant regions thereby depriving those regions of their own ground water. He suggested that in the future the issue of ground water diversion rights would prove to be as significant as surface water diversion rights.

By the turn of the century, between 1200 and 1300 well logs had accumulated at the Survey. These logs were in all manner of formats. Henry Kummel replaced Smock as survey director in 1901. He assigned the task of uniting these diverse well logs into a common format on file cards to a survey employee referred to as Miss Lee[Kummel, 1901]. Her accomplishment marks the establishment of the well permit files of the Division of Water

Resources of the New Jersey Department of Environmental Protection. This file, though changing format and now placed in a computer data base, is still used today much as it was at the turn of the century.

Installation of Modern Aquifer Terminology(1903-1909)

The aquifers identified by Lewis Woolman before 1900 were renamed in the first decade of the twentieth century. First, G. N. Knapp applied the term "Cohansey" to the four shallowest water-bearing horizons of the outer coastal plain and the term "Kirkwood" to the three deepest water-bearing horizons of the outer coastal plain[G.N.Knapp, 1903]. In 1909, the renaming was completed by director Kummel and H. Poland, who renamed the water-bearing horizons of the inner coastal plain with the names by which they are referred to today[H.B.Kummel & H.Poland, 1909].

The last Annual Report of the State Geologist was published in 1909. Water resource studies would be published as State Bulletins or as Professional Papers of the U.S. Geological Survey from then on.

Conclusions

The water resources of the aquifers of the New Jersey coastal plain were needed to support the growing population, industry, agriculture and resorts of southern New Jersey as well as to

TABLE 2. Development of Water-Bearing Horizon Nomenclature

Year Horizon Name First Published: 1889[a]	1893[a]	1897[a]	1903[b]	1909[c]	Current U.S. Geol.Surv. Name
328'					Cohansey
406'			Cohansey		
429'					Kirkwood/ Cohansey
554'					
–	650'				
–	700-20'	Atl.City 700'Sand			Rio Grande (Kirkwood)
–	760'		Kirkwood		
–	800'	Atl.City 800'Sand			Atl.City 800'Sand (Kirkwood)
950'		Atl.City 950'Sand			
–		Lindenwold	#9 Sand	Vincentown	Vincentown
–	"sand"		#7 Sand	Redbank	Redbank
–		Marlton	#5 Sand	Wenonah/ Mt.Laurel	Wenonah/ Mt.Laurel
–		Cropwell	#3 Sand	Englishtown	Englishtown
–		Sewell	Raritan		
–	Potomac Gravel	Raritan Group	Raritan		Potomac/ Raritan/ Magothy

[a] Terminology of L.Woolman

[b] Terminology of G.N. Knapp

[c] Terminology of H.B. Kummel & H. Poland

protect the public health of the region. George Cook recognized this and began the search for the region's water resources. The discovery of these aquifers was largely due to the efforts of Lewis Woolman and his corps of well drillers. The hazards faced by these aquifers- salt water intrusion, surface contamination, "hardness", and well drawdown interference- were all recognized by the New Jersey Geological Survey before the turn of the century.

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SUMMARY OF STUDIES ON THE HYDROGEOLOGY OF SALTWATER INTRUSION IN THE POTOMAC-RARITAN-MAGOTHY AQUIFER SYSTEM, CENTRAL NEW JERSEY--1926-85

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ABSTRACT

Saltwater intrusion of the Potomac-Raritan-Magothy-aquifer system is occurring in two areas of Middlesex and Monmouth Counties in central New Jersey. As part of a 5-year study, the U.S. Geological Survey, in cooperation with the New Jersey Geological Survey, is investigating the hydrogeology and saltwater intrusion in both areas.

A chronology of the occurrence of the saltwater intrusion problem indicates that saltwater was first noticed in the middle aquifer in 1926. Previous reports identified the Washington Canal and Raritan and South Rivers as sources of the saltwater. The Palisades sill is known to be an important factor affecting the migration of saltwater into the Farrington, or middle, aquifer, although the extent and location of the sill are not well defined. Little information is available on the hydrogeology of, and intrusion of saltwater from Raritan Bay into the Old Bridge, or upper, aquifer in Monmouth County.

Current data-collection programs include marine seismic geophysics, borehole and observation-well drilling, surface geophysics, and aquifer tests. Specifically, the programs will (1) delineate the extent of the Palisades sill in the area of intrusion in Middlesex County, (2) define the sediment units in the estuarine waterways and beneath Raritan Bay, and (3) ascertain the source locality of saltwater intrusion into the upper aquifer.

INTRODUCTION

Saltwater intrusion of the Potomac-Raritan-Magothy aquifer (PRMA) system is occurring in two areas of central New Jersey. In the area of Sayreville, and South River Boroughs and South Amboy City of Middlesex County, saltwater intrusion was first noticed in 1926 (Fairbanks, H.G., written commun. to Meredith Johnson, New Jersey State Geologist, 1936). In the area of Keyport and Union Beach Boroughs, saltwater intrusion was first noticed in 1970 (Schaefer and Walker, 1981). A chronology of the occurrence of these problems appears in table 1.

Excessive ground-water withdrawals from the middle and upper aquifer units of the PRMA system have accompanied the residential, commercial, and industrial development of these areas. These withdrawals have caused water levels to decline below sea level and the reversal of ground-water flow paths.

Table 3.--Data sources for the investigation of the hydrogeology of the Farrington aquifer in the Sayreville, South Amboy, and South River area

Data Description	Data Source
Geologists' logs prepared from test borings in the Raritan River, South River, and the Washington Canal for proposed bridges.	Technical reports prepared for the Army Corps of Engineers by Meredith Johnson, NJGS (unpublished worksheets, no date).
Geologists' logs and geologic cross sections prepared for the New Jersey Department of Transportation, and various industrial projects in the Sayreville, South Amboy, and South River area.	Professional records of Meredith Johnson on file at the NJGS from 1925-40.
Drillers' logs and lithologic data from foundation studies for utility projects in areas of Middlesex County.	Miscellaneous boring series along proposed sewer pipelines for Middlesex Co. Utility Authority.
Geologists' logs prepared for the New Jersey Department of Transportation near Raritan River.	Jon Lovegreen, (1974).
Geologists' logs prepared from test borings in the Raritan and South Rivers. A discussion of the distribution of these sediments is given. Hydraulic conductivities of river sediments were measured.	C. A. Appel (1962).
A data base, containing well records, lithologic, and geologic information maintained by the U.S. Geological Survey.	USGS, Watstore 1975, Ground-Water file.
Miscellaneous data pertaining to permitted wells on file at New Jersey Department of Environmental Protection.	The well records at the New Jersey Department of Environmental Protection.

Table 1.--A chronology of events and references on saltwater contamination of the Farrington and Old Bridge aquifers in Middlesex and Monmouth Counties--Continued

1943, In an effort to contain the problem of saltwater intrusion, limitations on ground-water withdrawals from the Farrington aquifer in Middlesex County were proposed.	
1943 and 1958 chloride concentration contours showed saltwater intrusion progressing into the Farrington aquifer.	C. A. Appel (1962).
1962, A tidal dam was proposed as a means of containing potential saltwater intrusion.	
1963, The effects of canal and river channel dredging on saltwater intrusion into the Farrington aquifer were examined using analog methods.	Irwin Remson and C. A. Appel, U.S. Geological Survey, written commun. 1963.
1969, To prevent saltwater intrusion into the Farrington aquifer, a freshwater reservoir was proposed at Crab Island in the Raritan River.	Irwin Remson and A. A. Fungaroli, U.S. Geological Survey, written commun. 1969.
1970, Saltwater encroachment into the Old Bridge aquifer was first reported in the vicinity of Keyport and Union Beach.	F. L. Schaefer and R. L. Walker (1981).
1985, Because of the threat of saltwater encroachment the New Jersey Department of Environmental Protection designated the Farrington and Old Bridge aquifers as "Critical Management Areas".	J. W. Gaston (1985).

Because of the reversal of the original ground-water flow paths, previous ground-water discharge areas in the estuarine regions of the Raritan and the South Rivers and Raritan Bay Basin have become recharge areas. Saltwater recharge from these water bodies has encroached into the two areas of the region's most important fresh ground-water source (fig. 1.).

Saltwater contamination also occurs north of the Raritan River in the Farrington aquifer outcrop from Woodbridge Creek. Saltwater maybe entering the Old Bridge aquifer where the South River and Raritan River flow over its outcrop (Schaefer, 1983). A discussion of these areas is not included in this paper because they do not pose a threat to major well fields. The migration of saltwater from these areas has been limited because of their location outside the narrow cones of depression in the unconfined region of the outcrops, and because of the countering effects of fresh, surface artificial recharge (Appel, 1962a).

As part of a 5-year investigation of the water resources of the Potomac-Raritan-Magothy aquifer system, the U.S. Geological Survey, in cooperation with the New Jersey Geological Survey (NJGS) has begun an investigation of the intrusion problems in the two areas of primary concern (fig. 1). Migration of the saltwater into the aquifer system will be simulated using a digital transport model. In order to improve the model's accuracy, the hydrogeology throughout the regional aquifer system will be refined. This will be especially important in the marine and estuarine areas, which have become the sources of the saltwater intruding into the regional aquifer system. This model will be used as a tool for understanding the intrusion process. The model results may be used by New Jersey Department of Environmental Protection (NJDEP) in its management of the water resources in these areas.

This paper presents a general description of the hydrogeology of the PRMA system in Middlesex and Monmouth counties of central New Jersey, and it describes the occurrence of the problem of saltwater intrusion in the two problem areas. Information which is being used to refine the hydrogeologic details is described separately for both intrusion areas. Finally, project efforts to interpret this information and to collect more information through a field program are summarized.

HYDROGEOLOGIC SETTING

The Potomac-Raritan-Magothy aquifer system within the New Jersey Coastal Plain has been divided into three aquifers: the upper, middle, and lower. However, the lower aquifer is absent in the study area. In the study area, the middle and upper aquifers are commonly known as the Farrington and Old Bridge aquifers (table 2). For historical consistency, the latter terminology will be used in this paper. The PRMA system is composed of Cretaceous unconsolidated clay, silt, sand, and gravel. These sediments form alternating beds of clay and

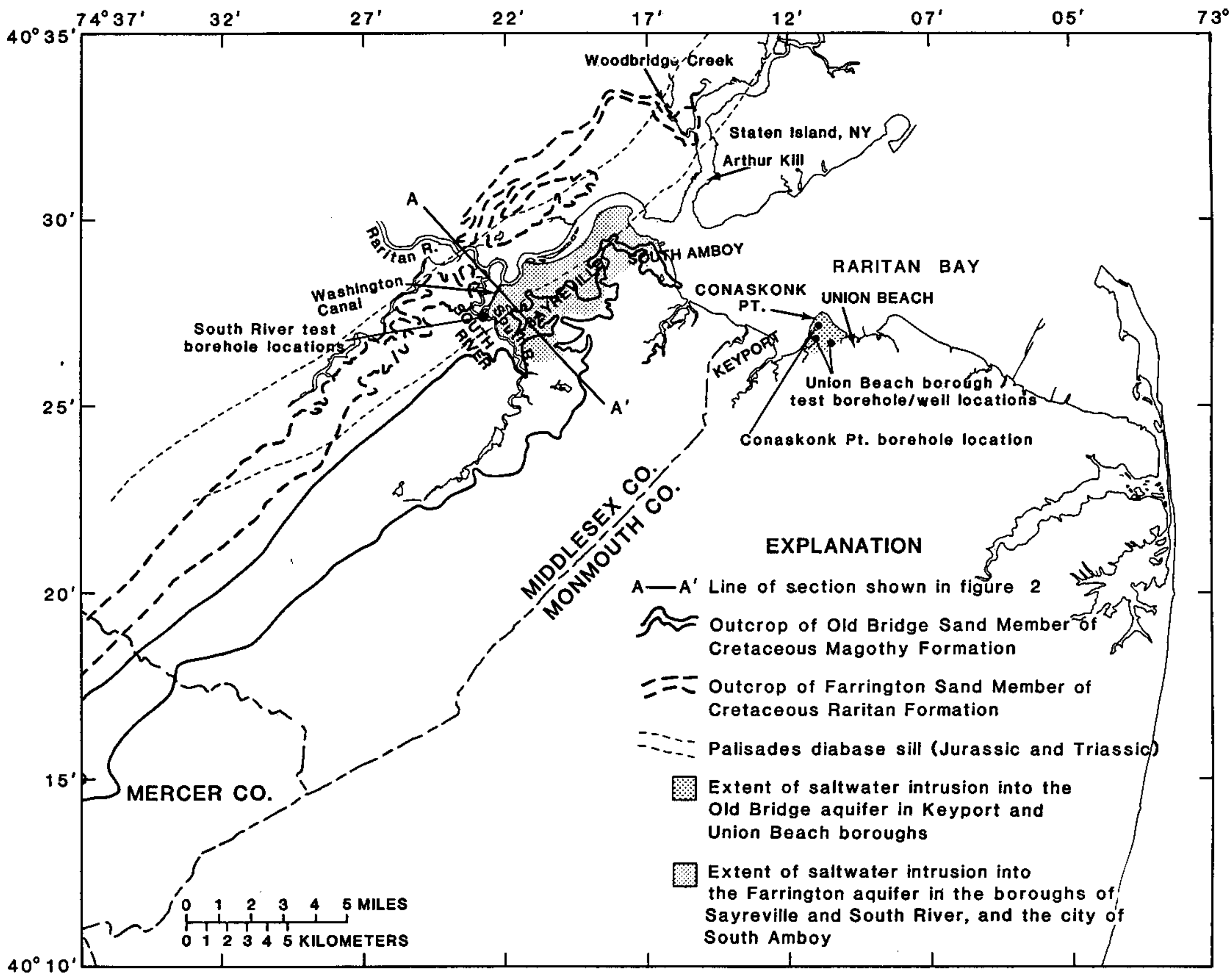


Figure 1.—Location of areas of saltwater contamination in Middlesex and Monmouth counties in New Jersey.

Table 2.--Geologic and hydrogeologic units in study area [1]

System	Geologic units		Hydrogeologic units	
Cretaceous	Woodbury Clay		Merchantville-Woodbury confining bed	Confining bed
	Merchantville Formation			
	Magothy Formation	Cliffwood beds	Potomac-Raritan-Magothy aquifer system	
		Morgan beds		
		Amboy Stoneware Clay member		
		Old Bridge Sand Member		Old Bridge aquifer [2]
	Raritan Formation	South Amboy Fire Clay Member		
		Sayreville Sand Member		
		Woodbridge Clay Member		Confining bed
		Farrington Sand Member		Farrington aquifer [2]
		Fire clay member		Confining bed
Jurassic and Triassic	Newark Supergroup and diabase intrusives		Bedrock	Bedrock
Lower Paleozoic and Precambrian	Igneous and metamorphic rocks			

1 Modified after O. Zapecza, 1984.
2 Using revised nomenclature, the Old Bridge aquifer is now known as the upper aquifer, the Farrington aquifer is now known as the middle aquifer as noted in this paper. The lower aquifer is not mappable within the area of concern for this paper.

sand that generally strike northeast-southwest and thicken as a wedge southeasterly from a featheredge at the outcrop to more than 1,000 feet in southeastern Monmouth County (Zapecza, 1984).

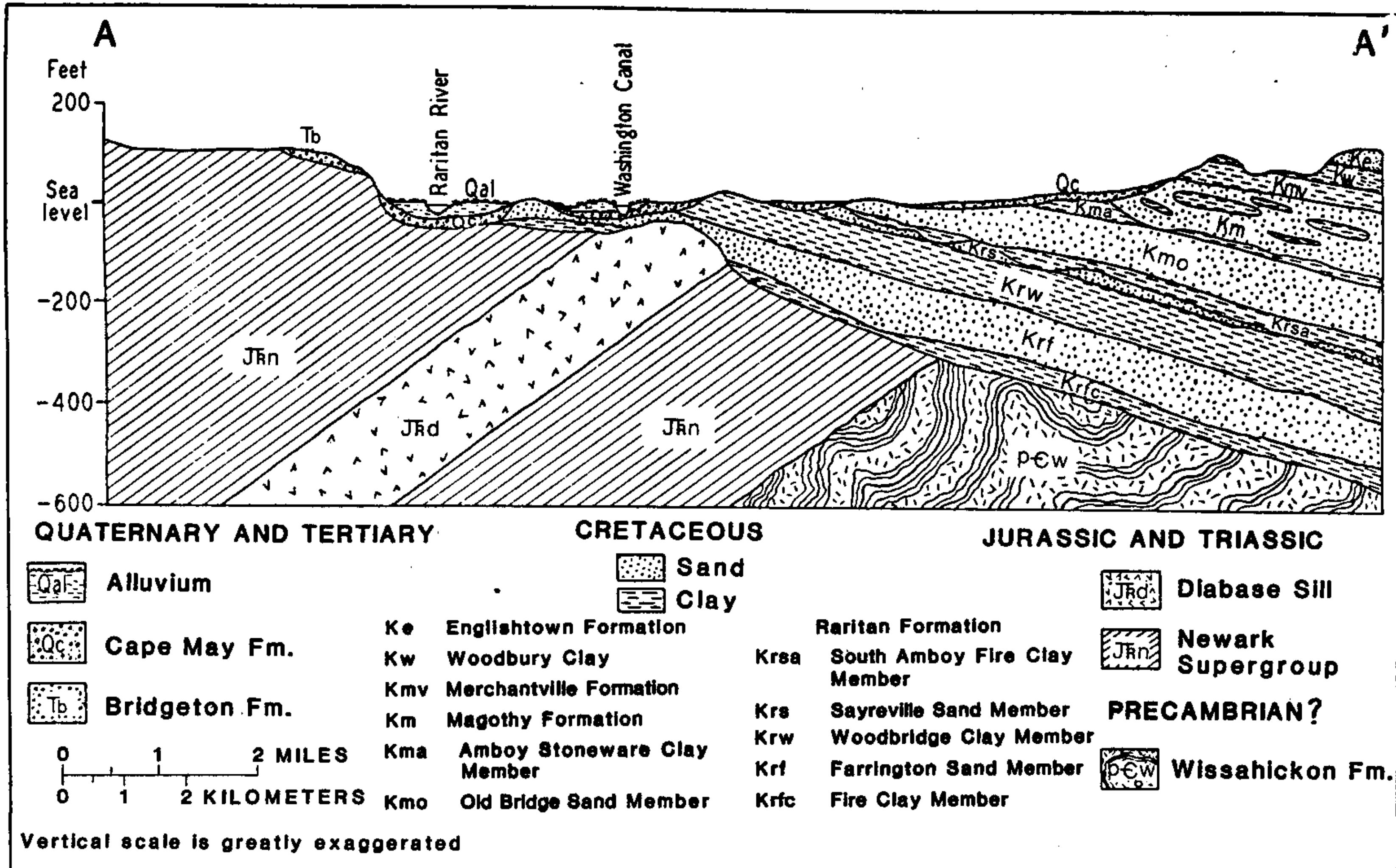
The Farrington aquifer, which consists of the Farrington Sand Member of the Raritan Formation, overlies a crystalline rock basement in the western part of the study area and the Raritan Fire Clay downdip of the outcrop area. In areas near its outcrop, the Farrington Sand Member also overlies the diabase Palisades sill (figures 1 and 2). The member consists of sands and gravels with clay lenses. The Farrington aquifer thickens from 50 feet in and near its outcrop to about 100 to 125 feet in the southeastern part of the study area (Zapecza, 1984). In the study area, the aquifer is overlain by the Woodbridge Clay Member of the Raritan Formation. Locally, this micaceous silt and clay confining bed includes sand and clay lenses of the Sayreville Sand and the South Amboy Fire Clay Members of the Raritan Formation (Farlekas, 1979). The confining-bed thickness increases from less than 50 feet in the outcrop area to more than 150 feet farther downdip in this area (Zapecza, 1984).

The Old Bridge aquifer, generally, is equivalent to the Old Bridge Sand Member, the basal unit of the Magothy Formation. Locally, where the South Amboy Fire Clay member of the Raritan Formation is thin or missing, the Old Bridge aquifer may include the Sayreville Sand Member as shown in figure 2 (Farlekas, 1979). The aquifer is composed of medium sands locally interbedded with clayey silts (Farlekas, 1979). From the outcrop, the unit thickens to about 125 feet downdip at a depth of 700 to 800 feet below sea level in the southeastern part of the study area. Localized interbedded sand, silt, and clay sequences pinch out and interfinger with the overlying confining bed downdip (Zapecza, 1984).

The Merchantville-Woodbury confining bed overlies the PRMA system throughout the study area. Zapecza (1984) described it as the most extensive confining bed in the New Jersey Coastal Plain. The confining bed thickness ranges from about 100 feet in the study area to approximately 300 to 350 feet toward the east (Zapecza, 1984).

Detailed discussions of geologic characteristics and stratigraphy of the Raritan and Magothy Formations and overlying Coastal Plain deposits are in Barksdale and others (1943), Gill and Farlekas (1976), and Zapecza (1984).

Figure 2.--



Modified from Barksdale et al, 1943

Figure 2.—Generalized geologic section along trace A-A' in figure 1.

PREVIOUS INVESTIGATIONS IN THE VICINITY OF SAYREVILLE, AND SOUTH RIVER BOROUGHS, AND THE CITY OF SOUTH AMBOY

Unpublished test-borehole data resulting from commercial development has provided most of the hydrogeologic information in the Boroughs of Sayreville, and South River and the city of South Amboy for this investigation. The earliest information comes from the pits that were dug into the clay beds near the South River and Raritan River. Meredith Johnson compiled U.S. Army Corps of Engineers (USACE) and New Jersey Department of Transportation test borings in the South and Raritan Rivers (M. Johnson, unpublished worksheets on file at NJDEP, 1925-40). Johnson's worksheets show that the Farrington aquifer pinches out against the Palisades diabase sill in some locations near the estuary waterways.

Barksdale and others (1943), reported on the regional hydrogeology and ground-water supply. His report included an areal delineation of the extent of the Palisades sill. Subsequent analysis on the extent and the depth of the sill from borings and well records was done by Steven Whitney of the NJGS (Whitney, S., New Jersey Geological Survey, written commun., 1969). An aeromagnetic survey of this area by the U.S. Geological Survey (1979) may indicate that the sill is present further to the west than previously determined by either Whitney or Barksdale.

Two projects proposed by the USACE in the 1960's concerned the hydrogeology of this area. The first was a proposal to dam the South River and form a freshwater reservoir (U.S. Army Corps of Engineers, 1962). Appel (1962) prepared a preliminary report for this project that included data on the permeability properties and distribution of the alluvium along the South and Raritan Rivers. Another study examined the potential effects of continued dredging of the rivers by the USACE (Appel, U.S. Geological Survey, written commun., 1962). This study shows the extent and location of the Farrington aquifer, and the confining alluvium above and the confining Palisades sill below the aquifer. The study also shows that the areal distribution of the chloride migration pattern is a function of both the sediment permeability beneath the estuary waterways and the irregular aquifer thickness. Table 3 summarizes the hydrogeologic data for this area.

Table 3.--Data sources for the investigation of the hydrogeology of the Farrington aquifer in the Sayreville, South Amboy, and South River area

Data Description	Data Source
Geologists' logs prepared from test borings in the Raritan River, South River, and the Washington Canal for proposed bridges.	Technical reports prepared for the Army Corps of Engineers by Meredith Johnson, NJGS (unpublished worksheets, no date).
Geologists' logs and geologic cross sections prepared for the New Jersey Department of Transportation, and various industrial projects in the Sayreville, South Amboy, and South River area.	Professional records of Meredith Johnson on file at the NJGS from 1925-40.
Drillers' logs and lithologic data from foundation studies for utility projects in areas of Middlesex County.	Miscellaneous boring series along proposed sewer pipelines for Middlesex Co. Utility Authority.
Geologists' logs prepared for the New Jersey Department of Transportation near Raritan River.	Jon Lovegreen, (1974).
Geologists' logs prepared from test borings in the Raritan and South Rivers. A discussion of the distribution of these sediments is given. Hydraulic conductivities of river sediments were measured.	C. A. Appel (1962).
A data base, containing well records, lithologic, and geologic information maintained by the U.S. Geological Survey.	USGS, Watstore 1975, Ground-Water file.
Miscellaneous data pertaining to permitted wells on file at New Jersey Department of Environmental Protection.	The well records at the New Jersey Department of Environmental Protection.

Table 3.--Data sources for the investigation of the hydrogeology of the Farrington aquifer in the Sayreville, South Amboy, and South River area--Continued

Contour maps of the top of the Palisades sill prepared from geologists' logs in the area of Sayreville, South River, and Perth Amboy.	Unpublished worksheets prepared by Steven Whitney, 1969, NJGS.
Uninterpreted aeromagnetic survey of central New Jersey and Delaware which indicates the location of the Palisades sill.	USGS (1979).

Saltwater contamination of 236 ppm (parts per million) was first reported for the Farrington aquifer in 1926 (Fairbanks, H. G., written commun. to Meredith Johnson, New Jersey State Geologist, 1936). The first investigations of the problem were done in the 1930's by Barksdale and others (1943). Their work showed the presence of saltwater in the Farrington aquifer southeast of the Washington Canal and south of the Raritan River, principally near the outcrop in the vicinity of the Boroughs of Sayreville, and South River and City of South Amboy in Middlesex County (fig. 1). Johnson (unpublished worksheets of the State Geologist from the period 1925-40, on file at New Jersey Department of Environmental Protection) identified a direct hydraulic connection between the salty surface water in the estuarine waterways and the underlying fresh ground water. Schaefer (1983) prepared graphs of chloride concentrations from wells in this area for the years 1965-81. His analyses indicate that saltwater concentrations were increasing, which indicates that saltwater is continuing to move from its source into the aquifer. In 1983, a chloride concentration of 2200 ppm was measured in a well approximately 2 miles southeast of the Washington Canal (U.S. Geological Survey, 1983, p. 311)

In an effort to minimize saltwater intrusion into the Farrington aquifer, both Barksdale (1936) and Johnson (unpublished worksheets on file at NJDEP, 1925-40) proposed constraints to the development of the area's water resources. Johnson recognized that proposed dredging of the alluvium from the channels of the Raritan River, the South River, and the Washington Canal would cause more saltwater to move into the Farrington aquifer. Barksdale proposed limiting ground-water withdrawals from the Farrington and Old Bridge aquifers in this area. These limitations would leave the ground-water system in equilibrium with natural recharge. The concerns of restricted ground-water development and careful management of the resource are reflected in the policies adopted by the NJDEP in 1985. Both aquifers have been designated by the Bureau of Water Allocation and the Division of Water Resources, NJDEP, as "Critical Water Supply Areas" (Gaston, 1985).

PREVIOUS INVESTIGATIONS IN THE VICINITY OF KEYPORT AND UNION BEACH BOROUGHS

Lithologic data and borehole geophysical data in this area have been recovered from the well-record archives at NJDEP, from records of borings for municipal projects, and from the U.S. Geological Survey data base (Murashige, J.E. and others, U.S. Geological Survey, written commun., 1985). Schaefer and Walker (1981) reported on the hydrogeology of the area; however, their analysis did not include hydrogeologic information from Raritan Bay. Based on the altitude of the top of the Old Bridge aquifer (from well logs in Middlesex and Monmouth Counties), they predicted that a submerged outcrop of the aquifer in Raritan Bay was the source of saltwater intrusion in this area.

Several sources of marine test-borehole data for Raritan Bay have been located. In 1931, a preliminary study to determine the feasibility of building a bridge between Union Beach, New Jersey, and Staten Island, New York, was done for the Port of New York Authority in 1931 (Berkey, 1955). The data used in this study included geologist logs of borings from Raritan Bay. Berkey's geologic section from Union Beach northward to Staten Island does not show an outcrop of the Old Bridge aquifer. The USACE, as part of its program to prevent beach erosion (1963), also investigated the bay sediments. Lithologic logs were made at 86 sites in Raritan Bay along the New Jersey shore. Bokuniewicz and Fray (1979) investigated the feasibility of mining sand from the Raritan Bay and collected shallow cores and seismic-reflection data on the sediments beneath the bay. Their study provided information on the type, thickness, and distribution of the shallow sediments of the bay bottom. Their data suggests the presence of discontinuous confining units over the Old Bridge aquifer beneath the bay, near Keyport and Union Beach. Transcontinental Pipeline Company (Edgerton, Germeshausen, & Grier, Inc., 1965) and the U.S. Geological Survey at Woods Hole, Massachusetts, also provided uninterpreted marine seismic data from Raritan Bay. These various hydrogeologic data references are given in table 4.

Schaefer and Walker (1981) investigated the saltwater-intrusion problem in the Keyport and Union Beach area. They state that the intruding saltwater is moving to the south of Keyport inlet and Conaskonk Point in Union Beach (figure 1). They also reported a rapid increase of chloride concentrations in wells from this area from 1970-77. Background level chloride concentrations are reported prior to 1970 (Schaefer and Walker, 1981). In 1983, chloride concentrations of 1700 ppm were found in water samples from the Union Beach Water Department Well #2 (U.S. Geological Survey, 1984 p. 319). Although these reports provide some data, there is insufficient information to determine whether the path of saltwater intrusion into the Old Bridge aquifer is through the submerged outcrop of the aquifer, several miles to the northwest of Keyport and Union Beach, or through the confining beds.

FIELD DATA COLLECTION PROGRAMS IN THE TWO AREAS OF SALTWATER INTRUSION

Current data-collection programs include marine seismic geophysics, test-borehole and observation-well drilling, surface geophysics, and aquifer tests. During the summer of 1984, marine seismic-reflection data were collected by the U.S. Geological Survey in the Raritan River, South River, Washington Canal, and off Conaskonk Point in Raritan Bay. These data will be used to correlate the sediments beneath the waterways in the study area. The interpretation of all marine seismic-reflection data by the U.S. Geological Survey is ongoing and concurrent with the on-shore drilling and geophysics programs.

Table 4.--Data sources for the investigation of the hydrogeology of the Old Bridge aquifer in the Keyport and Union Beach area

Data Description	Data Source
Geologists' logs from eight test borings in Raritan Bay between Conaskonk Point, New Jersey and Staten Island, New York with a geologic cross section.	C. P. Berkey, 1931.
Lithologic logs from 86 marine test borings in Raritan Bay along the shoreline of Middlesex and Monmouth Counties, New Jersey.	U.S. Army Corps of Engineers, 1963.
Marine seismic records of submerged sediments in Raritan Bay along a track from Morgan, New Jersey to Long Island, New York.	Edgerton, Germeshausen & Grier, Inc. (1965).
Uninterpreted logs from borings collected in the vicinity of Keyport and Union Beach Boroughs.	Miscellaneous soil boring reports prepared for Bay Shore Regional Sewerage Authority (1972).
A map of the type and distribution of bottom sediments in Raritan Bay prepared from various data, including shallow borings and marine seismic data.	H. J. Bokuniewicz and C. T. Fray, 1979.
A data base containing well records, lithologic and geologic information maintained by the USGS.	U.S. Geological Survey, WATSTORE, 1975, Ground-water File.
Uninterpreted marine seismic reflection data from Raritan Bay, collected by the USGS, Woods Hole, Massachusetts.	Unpublished data on file at U.S. Geological Survey at Woods Hole, Massachusetts.

In the summer of 1985, the NJGS drilled a test borehole in South River Borough, and another near the northern extreme of Conaskonk Point, in Union Beach Borough. The South River borehole penetrated to 140 feet below land surface and located the top of the Farrington aquifer. The Conaskonk Point borehole was completed to basement at a depth of 550 feet below land surface. Lithologic samples from each borehole were collected; cores were examined for mineralogy; and gamma-ray, spontaneous potential, resistivity, and caliper logs were run. A down-hole seismic test was run to help interpret the marine seismic-survey data collected nearby. The Conaskonk Point borehole was completed as a monitoring well. The well is screened in the Old Bridge aquifer at 200 to 210 feet below land surface.

Six saltwater-monitoring wells will be constructed by the NJGS at locations in both intrusion areas. Two of the wells will be used to monitor an aquifer test in Union Beach. The aquifer test may yield information on the proximity of the saltwater recharge boundary to the Keyport and Union Beach area.

The U.S. Geological Survey surface-geophysics programs will be done in cooperation with the NJGS and will include transient electromagnetic, resistivity, gravimetric and seismic surveys. This program will refine the hydrogeologic data base in both areas of saltwater intrusion, and specifically delineate the extent of the Palisades sill in the Sayreville, South Amboy, and South River area. Surface geophysics in Union Beach will complement geologic sections developed from the marine geophysical data collected off Conaskonk Point, from the logs of the Conaskonk Point borehole, and from the two Union Beach monitoring wells.

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GROUND-WATER RESOURCES OF THE ATLANTIC CITY REGION, NEW JERSEY: PLAN OF STUDY, WORK COMPLETED, AND PRELIMINARY RESULTS

Gary N. Paulachok[1]

INTRODUCTION

Overview

Ground water is the principal source of water supply in the Coastal Plain of New Jersey, and, in many areas, it is an abundant resource. However, large withdrawals in the coastal resort communities of the Atlantic City region have resulted in declining ground-water levels and an attendant reduction in the volume of water in storage. Consequently, these conditions have increased the potential for water-supply shortages and for contamination of freshwater aquifers by encroaching saltwater. The Statewide Water-Supply Master Plan (New Jersey Department of Environmental Protection, 1981) indicates that a steady increase in ground-water pumpage, as well as contamination of ground water by saltwater and leachate from disposal sites, will likely accompany the redevelopment of the Atlantic City region. This development began in 1977 with the introduction of legalized gambling in Atlantic City (fig. 1).

In November 1981, the voters of New Jersey authorized a $350 million Water Supply Bond Issue. This Bond Issue, administered by the New Jersey Department of Environmental Protection (NJDEP), provides funding for (1) upgrading and consolidating privately owned water-supply systems; (2) constructing or improving system interconnections and surface-water storage facilities; (3) constructing various state-owned water-supply facilities and acquiring additional facilities; and (4) conducting studies of water supply and management to aid in the prudent development of surface-water and ground-water resources. The Atlantic City region was selected for a comprehensive study of its ground-water resources, as were the localities near South River in Middlesex and Monmouth Counties, and the Camden metropolitan area (New Jersey Department of Environmental Protection, 1981). The U.S. Geological Survey, in cooperation with the New Jersey Department of Environmental Protection, Division of Water Resources, Geological Survey (NJGS), will conduct these studies over a period of approximately 5 years.

The chief purposes of this report are to (1) summarize the principal geohydrologic problems of the Atlantic City region; (2) define the objectives of the present study; (3) outline the

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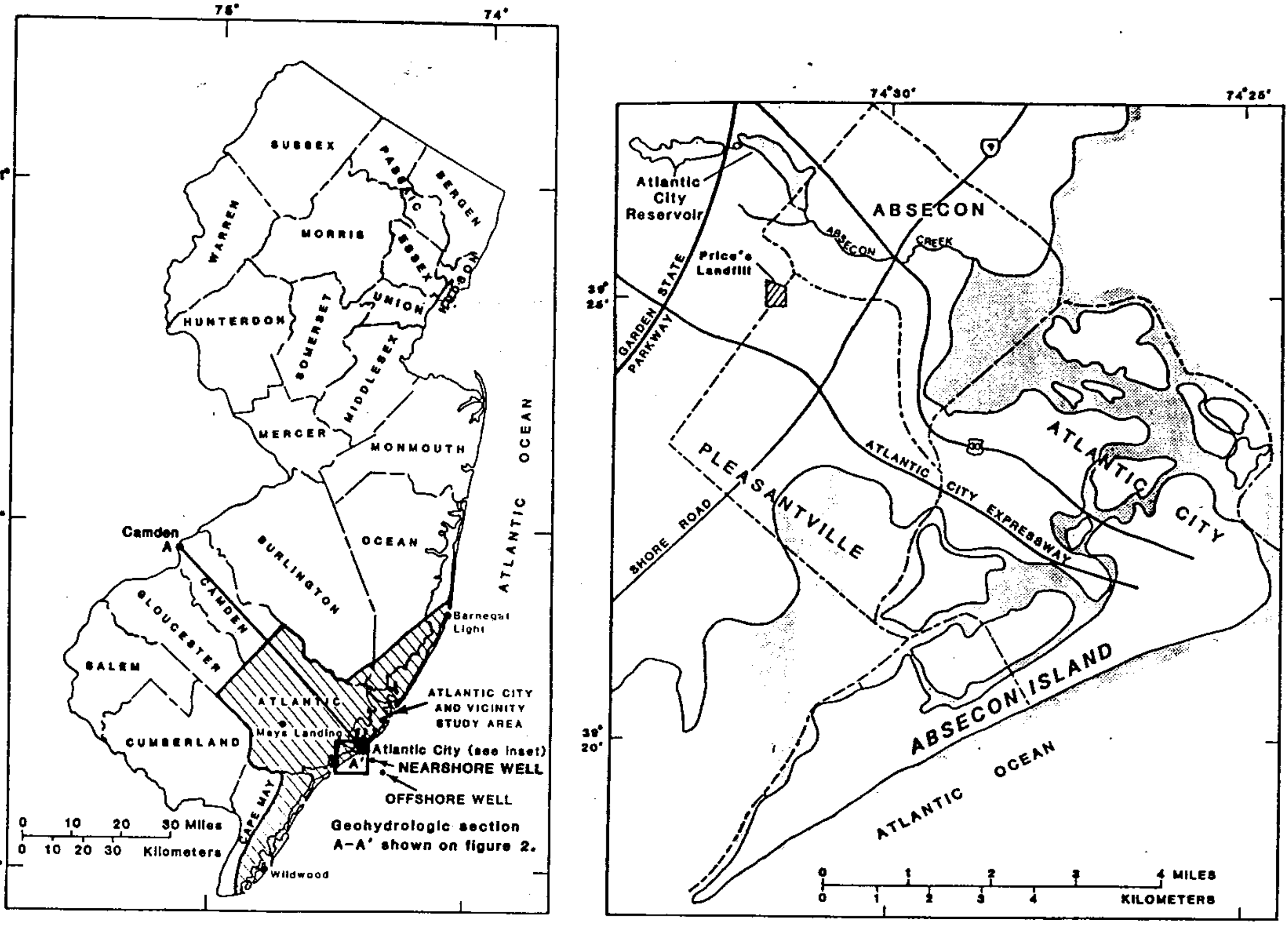

Figure 1.--Location of the Atlantic City region, New Jersey.

technical approaches that have been implemented or that will likely be used to investigate the various problems; and (4) present selected preliminary results of the study.

Previous Investigations

Reports by Woolman (1890-1902) on artesian wells in New Jersey recorded much of the original information on the geology and ground-water hydrology of the study area. Woolman correlated water-bearing zones penetrated by wells in the Coastal Plain of New Jersey and Delaware. Thompson (1928), who reported on the ground-water supplies of the Atlantic City region, presented a general outline of the hydrology of the various freshwater aquifers, and discussed the potential problem of saltwater encroachment into the Atlantic City 800-foot sand of the Kirkwood Formation. According to Thompson (1928, p. 115), the prepumping location of the freshwater-saltwater interface in the 800-foot sand was approximately 4 miles offshore of Atlantic City. Barksdale and others (1936), in a more comprehensive treatment, defined the ground-water hydrology of the Atlantic City region and concluded that saltwater was probably being induced landward toward pumping wells in the 800-foot sand because of a steep hydraulic gradient in that direction. More recently, Leggette, Brashears, and Graham, Inc. (1982) re-emphasized the probable shoreward migration of the saltwater and suggested its possible landward arrival within a few years. May (1985) proposed the use of injection wells to recharge the 800-foot sand at Absecon Island (fig.1). These wells would be used to supplement water supply and to reduce the likelihood of saltwater intrusion by arresting or reversing present ground water-level declines.

As part of the Regional Aquifer System Analysis (RASA) program of the U.S. Geological Survey, the geohydrologic framework, geochemistry, and nature of ground-water flow in the principal aquifers of the northern Atlantic Coastal Plain are being investigated in detail (Meisler, 1980). The aquifers under study by the New Jersey subregional RASA modeling program (Meisler, 1980) include those in the Atlantic City region. Zapecza (1984) defined the geohydrologic framework of the New Jersey Coastal Plain and illustrated with a series of cross sections and maps the stratigraphic relations among the component geohydrologic units.

Gill (1962) described the occurrence, available quantity, and chemical quality of ground water in Cape May County (fig. 1), and delineated areas of existing or potential saltwater intrusion into the freshwater aquifers. Clark and others (1968) presented a general summary of the geohydrology of Atlantic County (fig. 1); this report lists records of selected wells and contains results of 36 laboratory inorganic determinations on water samples from some of those wells. Schaefer (1983, p. 29-30) presented information on chloride concentrations in water from selected monitoring wells in the coastal parts of Atlantic County and concluded "that although (presently) there is no evidence in the Atlantic City area of lateral saltwater intrusion in the 800-foot sand from a seaward direction,...the probability of this occurrence is as significant today (1983) as it was in the 1930's." Prior to the present study, the sparse data in these reports constituted the majority of information available on the quality of ground water in the Atlantic City region.

Location of Study Area

The area of study encompasses approximately 1,200 square miles including all of Atlantic County and parts of Ocean, Burlington, Cumberland, and Cape May Counties; it includes barrier-island communities from Barnegat Light on the north to Wildwood on the south (fig. 1). In this report, the study area is commonly referred to as the Atlantic City region. Atlantic City and neighboring municipalities on Absecon Island are the localities of principal interest.

Geohydrologic Framework

The study area is in the Coastal Plain of New Jersey, which is composed chiefly of unconsolidated deposits of gravel, sand, silt, and clay. The principal freshwater aquifers formed by these deposits are of Tertiary age and in descending order include the surficial Kirkwood-Cohansey aquifer system and the Atlantic City 800-foot sand of the Kirkwood Formation, which is commonly called the 800-foot sand. The Rio Grande water-bearing zone of the Kirkwood Formation is situated midway within the confining bed that separates the Kirkwood-Cohansey aquifer system from the 800-foot sand. Throughout most of the study area, however, the Rio Grande is an aquifer of minor importance. In the Atlantic City region, aquifers deeper than the 800-foot sand have not been developed for water supply, as they may contain brackish or saline water. In descending order, these undeveloped units include the Piney Point aquifer of Tertiary age, and units of Cretaceous age including the Wenonah-Mount Laurel aquifer, the Englishtown aquifer system, and the Potomac-Raritan-Magothy aquifer system. Figure 2 shows a generalized section of these geohydrologic units. Table 1 presents information on the lithology and hydrologic characteristics of the units, and shows the relations between geologic units and geohydrologic units.

Within the study area, the Cohansey Sand and the underlying upper part of the Kirkwood Formation form the Kirkwood-Cohansey aquifer system (fig. 2). Although these two units are components of this composite aquifer system, they are not differentiated individually because of their similar geologic and hydrologic properties. The Kirkwood-Cohansey aquifer system thickens toward the southeast and near Atlantic City it is approximately 400 ft (feet) thick (Zapecza, 1984). This aquifer system is the principal source of water supply in parts of the study area on the mainland. However, on the barrier islands and along the coastal fringe, the system contains brackish or salty water and cannot be used as a source of water supply.

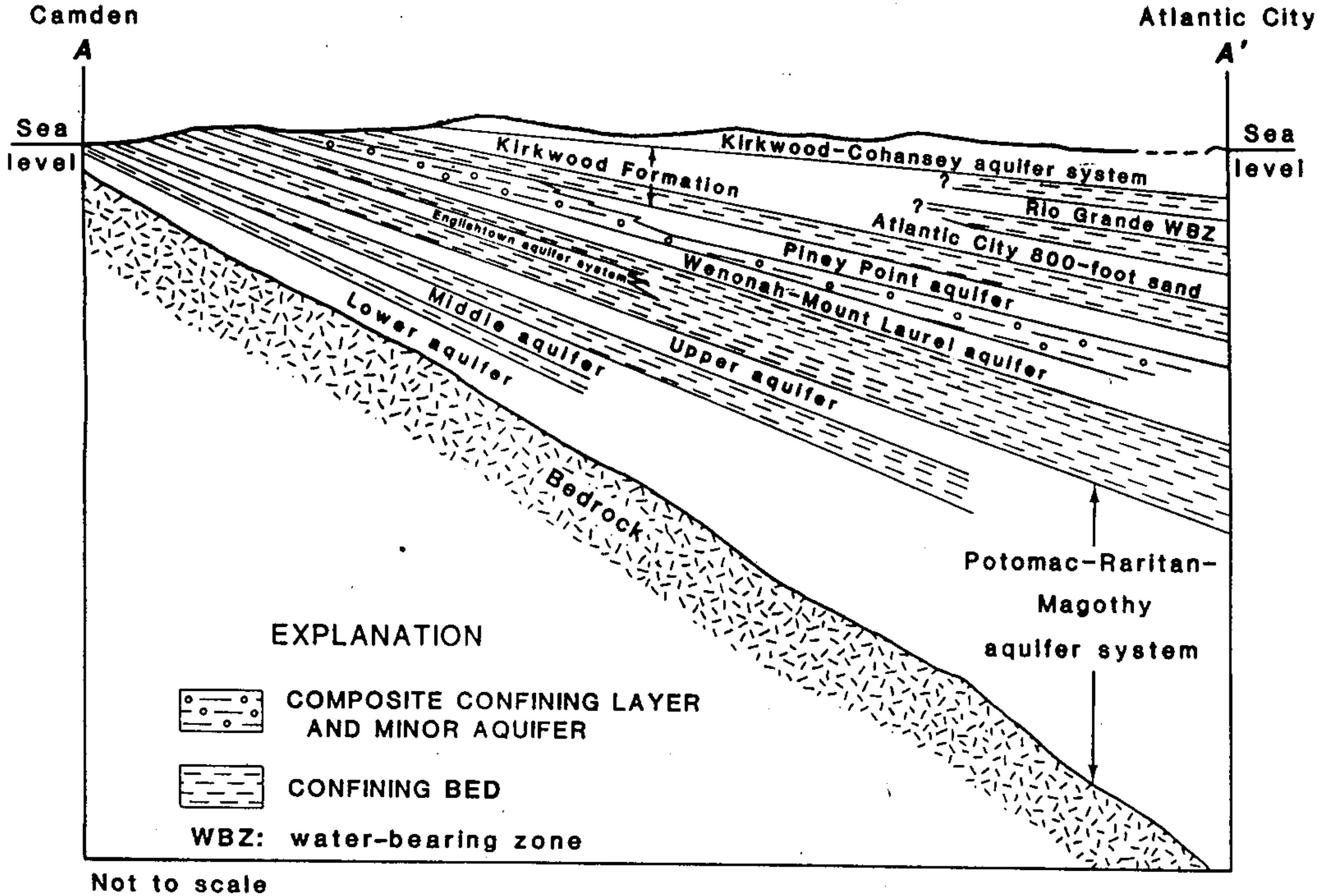

Figure 2.-- Generalized geohydrologic section of the Coastal Plain of New Jersey (Location of section shown on figure 1).

Table 1.--Relations between geologic units and geohydrologic units of the Coastal Plain of New Jersey.

SYSTEM	SERIES	GEOLOGIC UNIT	LITHOLOGY	HYDROGEOLOGIC UNIT	HYDROLOGIC CHARACTERISTICS
Quaternary	Holocene	Alluvial deposits	Sand, silt, and black mud.	Undifferentiated	Surficial material, often hydraulically connected to underlying aquifers. Locally some units may act as confining beds. Thicker sands are capable of yielding large quantities of water.
		Beach sand and gravel	Sand, quartz, light-colored, medium- to coarse-grained, pebbly.		
	Pleistocene	Cape May Formation	Sand, quartz, light-colored, heterogeneous, clayey, pebbly.		
Tertiary	Miocene	Pensauken Formation			
		Bridgeton Formation			
		Beacon Hill Gravel	Gravel, quartz, light colored, sandy.	Kirkwood-Cohansey aquifer system	A major aquifer system. Ground-water occurs generally under water-table conditions. In Cape May County the Cohansey Sand is under artesian conditions.
		Cohansey Sand	Sand, quartz, light-colored, medium to coarse-grained, pebbly; local clay beds.		
		Kirkwood Formation	Sand, quartz, gray and tan, very fine- to medium-grained, micaceous, and dark-colored diatomaceous clay.	confining bed Rio Grande w-bz[1] confining bed	Thick diatomaceous clay bed occurs along coast and for a short distance inland. A thin water-bearing sand occurs within the middle of this unit.
				Atlantic City 800-foot sand	A major aquifer along the coast.
				Composite confining bed	Alloway Clay member or equivalent
	Eocene	Piney Point Formation	Sand, quartz and glauconite, fine- to coarse-grained.	Piney Point aquifer	Yields moderate quantities of water locally.
		Shark River Formation	Clay, silty and sandy, glauconitic, green, gray and brown, fined-grained quartz sand.		Poorly permeable sediments.
		Manasquan Formation			
	Paleocene	Vincentown Formation	Sand, quartz, gray and green, fine- to coarse-grained, glauconitic, and brown clayey, very fossiliferous, glauconite and quartz calcarenite.	Vincentown aquifer	Yields small to moderate quantities of water in and near its outcrop area.
		Hornerstown Sand	Sand, clayey, glauconitic, dark green, fine- to coarse-grained.		Poorly permeable sediments.
Cretaceous	Upper Cretaceous	Tinton Sand	Sand, quartz, and glauconite, brown and gray, fine- to coarse-grained, clayey, micaceous.		
		Red Bank Sand		Red Bank sand[2]	Yields small quantities of water in and near its outcrop area.
		Navesink Formation	Sand, clayey, silty, glauconitic, green and black, medium- to coarse-grained.		Poorly permeable sediments.
		Mount Laurel Sand	Sand, quartz, brown and gray, fine- to coarse-grained, slightly glauconitic.	Wenonah-Mount Laurel aquifer	A major aquifer.
		Wenonah Formation	Sand, very fine- to fine-grained, gray and brown, silty, slightly glauconitic.		
		Marshalltown Formation	Clay, silty, dark greenish gray, glauconitic quartz sand.	Marshalltown-Wenonah confining bed	A leaky confining bed.
		Englishtown Formation	Sand, quartz, tan and gray, fine- to medium-grained; local clay beds.	Englishtown aquifer system	A major aquifer. Two sand units in Monmouth and Ocean Counties.
		Woodbury Clay	Clay, gray and black, micaceous silt.	Merchantville-Woodbury confining bed	A major confining bed. Locally the Merchantville Fm. may contain a thin water-bearing sand.
		Merchantville Formation	Clay, glauconitic, micaceous, gray and black; locally very fine-grained quartz and glauconitic sand.		
		Magothy Formation	Sand, quartz, light-gray, fine- to coarse-grained; local beds of dark-gray lignitic clay.	Potomac-Raritan-Magothy aquifer system: upper aquifer	A major aquifer system. In the northern Coastal Plain the upper aquifer is equivalent to the Old Bridge aquifer and the middle aquifer is the equivalent of the Farrington aquifer. In the Dela. River Valley three aquifers are recognized. In the deeper subsurface, units below the upper aquifer are undifferentiated.
		Raritan Formation	Sand, quartz, light-gray, fine- to coarse-grained, pebbly, arkosic, red, white, and variegated clay.	conf bd middle aquifer	
	Lower Cretaceous	Potomac Group	Alternating clay, silt, sand, and gravel.	conf bd lower aquifer	
Pre- Cretaceous		Bedrock	Precambrian and lower Paleozoic crystalline rocks, metamorphic schist and gneiss; locally Triassic basalt, sandstone and shale.	Bedrock confining bed	No wells obtain water from these consolidated rocks, except along Fall Line.

[1] Rio Grande water-bearing zone.

[2] ------ Minor aquifer not mapped in this report.

Modified from Seaber, 1965, table 3.

conf bd: confining bed

The Atlantic City 800-foot sand of the Kirkwood Formation is a highly permeable artesian aquifer. It is situated between an overlying thick massive confining bed and an underlying relatively thin confining bed (fig. 2). At Atlantic City, the overlying confining bed is approximately 300 ft thick, the 800-foot sand is more than 150 ft thick, and the underlying confining bed is approximately 125 ft thick (Zapecza, 1984). The 800-foot sand is, with few exceptions, the sole source of freshwater supply for the barrier-island communities in the study area. The Piney Point aquifer lies beneath the basal confining layer of the 800-foot sand (fig. 2). Little is known about the hydraulic properties and quality of water in this deeper aquifer.

GEOHYDROLOGIC PROBLEMS

Overproduction

Figure 3 illustrates the trend in withdrawals from the 800-foot sand from 1956 to 1980 in Atlantic, Ocean, and Cape May Counties, and shows that pumpage more than doubled during that 25-year period. In 1980, withdrawals from the 800-foot sand averaged 21 million gallons per day, with pumpage in Atlantic County accounting for almost half of that total (Vowinkel, 1984, p. 24). According to the Atlantic County 208 Water Quality Management Planning Agency (1979, page II-34), the demand for water in Atlantic and Cape May Counties is likely to increase by nearly 22 percent during the period from 1975 until the year 2020. This rate of increase is approximately 6 percent higher than the corresponding rate expected overall for the state of New Jersey.

Under prepumping conditions, it is likely that water in the 800-foot sand flowed chiefly southeastward toward discharge areas offshore. However, subsequent large withdrawals of water caused the development of a regional cone of depression and altered the local rate and direction of ground-water flow. In late 1978, water levels in the deepest part of the cone were more than 70 ft below sea level (fig. 4). These levels can be expected to decline further if larger volumes of water are pumped from the aquifer to meet the increasing demands.

The majority of municipal water purveyors in the coastal parts of the Atlantic City region withdraw their supplies from the 800-foot sand. In addition, two casino hotels in Atlantic City are currently satisfying their total requirements for water with their own wells in that aquifer, and several other casinos have applied to the NJDEP for diversion rights to withdraw water from the 800-foot sand. Because little is known about the various possible effects of increasing pumpage, the future status of these existing and requested diversion rights is uncertain. However, increasing pumpage probably will accelerate the rate of saltwater migration from areas offshore toward the pumping centers. Contamination of the 800-foot sand by saltwater would have disastrous consequences throughout the Atlantic City area,

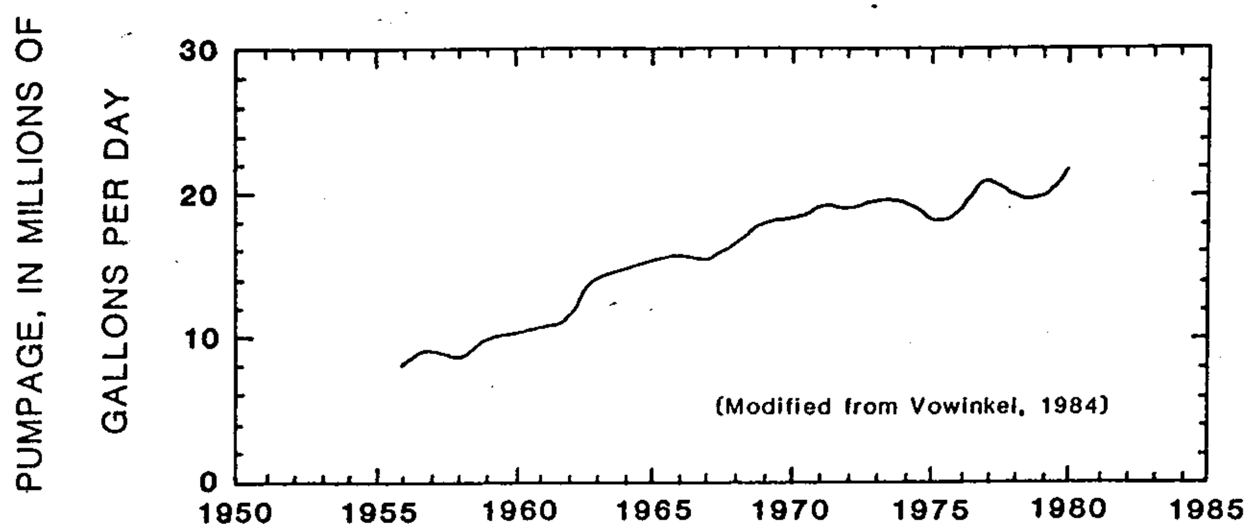

Figure 3.-- Pumpage from the Atlantic City 800-foot sand of the Kirkwood Formation in Atlantic, Ocean, and Cape May Counties, New Jersey, 1956-80.

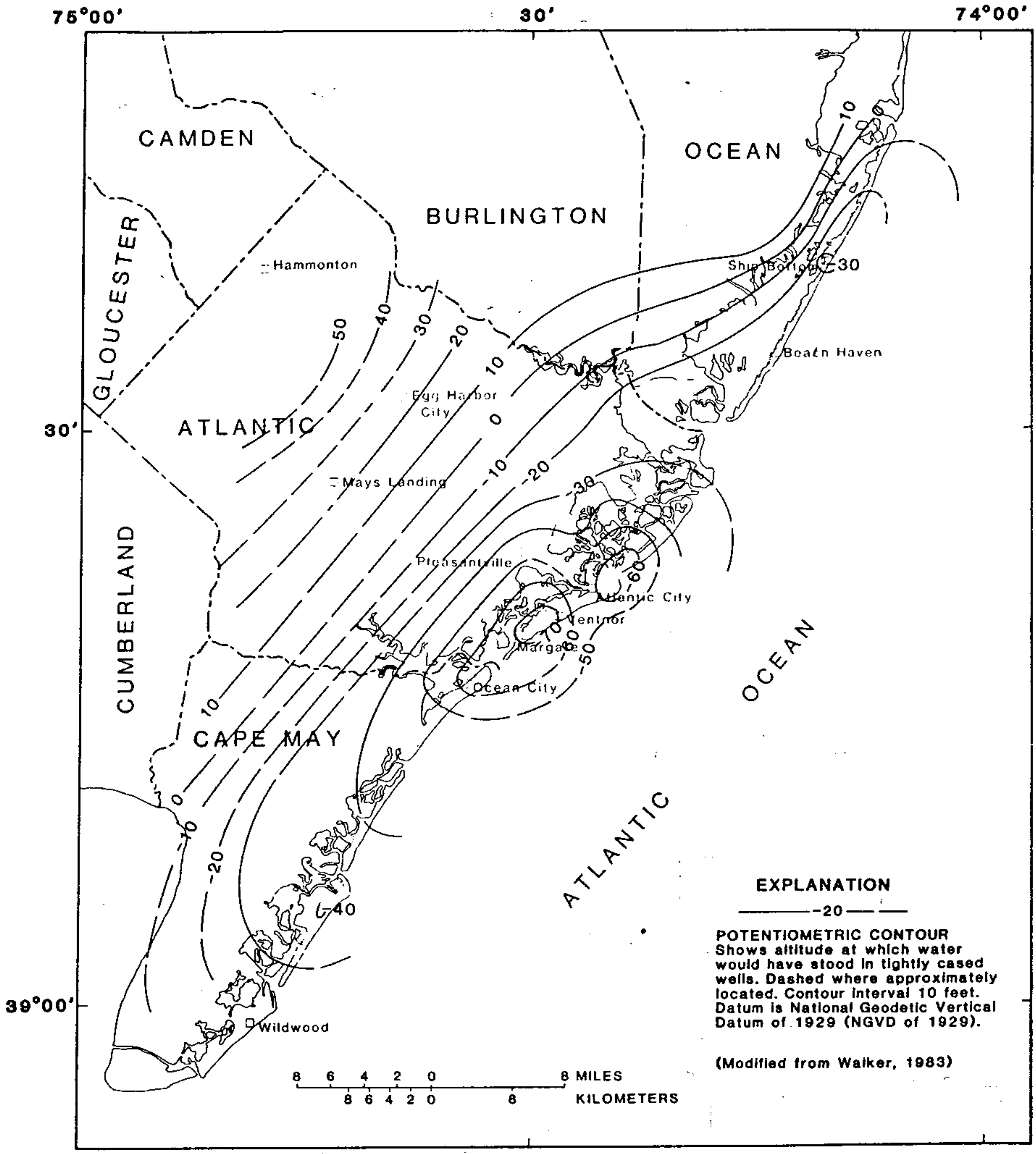

Figure 4.--Potentiometric surface of the Atlantic City 800-foot sand of the Kirkwood Formation, October-December 1978.

as none of the coastal resort communities except Atlantic City and Wildwood have direct emergency interconnections with water supplies from the mainland.

Degradation of Ground-Water Quality

At several localities in the study area, water in the Kirkwood-Cohansey aquifer system has been contaminated by leachate from landfills and by toxic chemical liquids and sludges that were disposed of improperly. Many of these landfills are in abandoned gravel pits with relatively high water tables. Because the contents of many landfills are at or below the water table, there is a likelihood of local ground-water contamination. At several sites, leachate has contaminated ground water with volatile organic compounds and inorganic chemical species including trace elements.

From May 1971 through November 1972, millions of gallons of uncontained industrial wastes were disposed of at Price's Landfill[2] (fig. 1) in Pleasantville (New Jersey Department of Environmental Protection, 1984, p. 103). Through the use of a digital flow model, Gray and Hoffman (1983, p. 9) concluded that these contaminants were migrating in the ground water of the Kirkwood-Cohansey aquifer system toward the nearby public-supply wells of the Atlantic City Municipal Utilities Authority (ACMUA). As a precautionary measure, and at significant expense, the ACMUA relocated their well field to the site of the Atlantic City Reservoir (fig. 1), nearly 3 miles northwest of Pleasantville, and terminated withdrawals from the Pleasantville well field. Because the toxic wastes at this landfill and at several other disposal sites in the study area have yet to be recovered and disposed of properly, they continue to threaten the quality of local ground-water supplies. As pointed out by these examples, the Kirkwood-Cohansey aquifer system is particularly vulnerable to contamination resulting from activities at the land surface.

Very little is known about the background quality of water in the Kirkwood-Cohansey aquifer system in the study area, except in the few localities where site-specific investigations have been conducted. More information is needed on the quality of shallow ground water in order to prepare and implement prudent water-management strategies for the Atlantic City region. Because of existing or potential shortages and contamination of ground water, in 1985 the NJDEP solicited from private firms a request for proposals to evaluate supply and institutional problems related to the ground-water resources of the region.

PLAN OF STUDY

The chief purposes of the present study are to (1) define the nature of ground-water flow in the Kirkwood-Cohansey aquifer system and in the Atlantic City 800-foot sand of the Kirkwood Formation; and (2) ascertain the likelihood of saltwater

[2] The use of firm names in this report is for location purposes only, and does not impute responsibility for any present or potential effects on the natural resources.

intrusion into the 800-foot sand in the Atlantic City area. Selected results of the study will be used to prepare a detailed, calibrated model of regional ground-water flow. This model may be used subsequently by the NJDEP to guide decisions regarding ground-water diversions and water management in the Atlantic City region.

Objectives

The principal objectives of the study are to:

1. Define the geohydrologic framework, particularly the thickness and extent of the confining layer overlying the 800-foot sand of the Kirkwood Formation.

2. Ascertain the hydraulic properties of the Kirkwood-Cohansey aquifer system, the 800-foot sand, and associated confining layers.

3. Bracket the position of the freshwater-saltwater interface in the offshore part of the 800-foot sand near Atlantic City.

4. Prepare a detailed conceptual model of regional ground-water flow.

5. Assess regional water-quality conditions in the Kirkwood-Cohansey aquifer system and in the 800-foot sand, as well as local conditions in the Piney Point aquifer.

6. Prepare and maintain standardized data bases for hydrologic information.

Approach

The present study will address the objectives stated by assessing and compiling geologic and hydrologic data from various sources and by collecting additional data as required. These data will then be used to analyze and interpret hydrologic processes and to evaluate water-quality conditions. The results of this investigation will be released in published reports, oral presentations, and in various other media.

Assessment of Geologic and Hydrologic Data

Few comprehensive reports have been released on the geology and ground-water hydrology of the Atlantic City region. Regardless, the basic information contained in the previously cited reports and that from several other sources will constitute the starting point for the more comprehensive present investigation. Initially, data from various sources on the geology and ground-water hydrology of the study area will be evaluated and compiled. The principal sources of such information are the files of the U.S. Geological Survey, particularly those on ground-water levels, water quality, water use, and well records. The contents of ancillary files, chiefly those containing borehole geophysical logs and data on aquifer system lithology, stratigraphy, and hydraulic properties, also will be assessed.

The files of the NJDEP, along with those of other governmental agencies and private entities, will be examined for additional geologic and hydrologic data. Selected information from these sources will be evaluated, compiled, and entered into the various data bases for subsequent use during the interpretive phase of the study.

The objective of standardized information management will be met by using appropriate computer software developed or purchased by the U.S. Geological Survey. This software will be used to create new data bases, upgrade or modify existing data bases, and to facilitate computations involving data files. Eventually, other governmental agencies probably will be granted direct access to these data bases.

Collection of Additional Data

During the second phase of the study, various data will be collected to define the geohydrologic framework of the Atlantic City region and to characterize the ground-water flow system. Information on the geohydrologic framework will be gathered by reviewing well records and logs, and by conducting an inventory of selected water wells in Atlantic County and vicinity. This inventory will be an important aspect of the investigation because data are sparse on ground-water levels, well yield, and quality of ground water in the study area.

Present knowledge of the geohydrologic framework is inadequate to evaluate the hydraulic interrelationships of the principal aquifers and their associated confining layers. Of particular interest to this study is the determination of the thickness and extent of the confining bed overlying the 800-foot sand. Where this bed is present, it impedes ground-water flow between the Kirkwood-Cohansey aquifer system and the 800-foot sand; where it is absent, the subject aquifers are hydraulically connected and behave as a single unconfined aquifer. Information of this type will be obtained for this study by drilling exploratory boreholes in areas where such information is sparse, then logging and analyzing drilled or cored lithologic samples. Various geophysical surveys will also be conducted in the boreholes. Several of these boreholes will be finished as wells for monitoring ground-water levels and water quality. The NJGS will conduct comprehensive surface geophysical investigations for this study. Results of these investigations, particularly those involving seismic and electrical techniques, will be correlated with data from the borehole surveys so that lithology and aquifer system hydraulic properties in areas not drilled can be assessed.

In selected parts of the study area, the hydraulic properties of the Kirkwood-Cohansey aquifer system and the 800-foot sand will be evaluated with single-well pumping tests and multiple-well aquifer tests. The results of these tests will be used to calibrate the ground-water flow model, and, in conjunction with data on ground-water levels, will be used to refine the present concept of regional ground-water flow.

Because the freshwater-saltwater interface in the 800-foot sand is offshore of Atlantic City, little is known about its present location and width. Existing digital models, particularly the New Jersey subregional RASA model, have been unable to address with certainty the nature of this interface. These models have been constrained by the lack of information on water levels, hydraulic properties, and quality of water in the offshore extension of the 800-foot sand and its associated confining layers.

A marine well-drilling program is planned as a major component of the present study. The primary objective of this program is to bracket and monitor the position of the freshwater-saltwater interface in the 800-foot sand near Atlantic City. Such monitoring will enable advance warning of landward saltwater encroachment to be issued, if necessary. Secondary objectives are to obtain the geologic and hydrologic information required to adequately represent with a digital model the offshore part of the flow system. Plans are to construct two wells, each approximately 1,000 ft deep, to address these and other subordinate objectives.

Because data are sparse on the quality of ground water in much of the Atlantic City region, a substantial number of water samples will be collected and analyzed for this study. Enough samples will be gathered so that the regional distribution of various chemical species in the Kirkwood-Cohansey aquifer system and in the 800-foot sand can be characterized. As part of the exploratory drilling program, plans are to construct one well in the Piney Point aquifer near Atlantic City. Samples from this well and a few other wells in the study area will be collected to ascertain local water-quality conditions in the Piney Point aquifer. If the aquifer contains water of poor quality, then it is possible that this water may leak upward through the confining bed and eventually contaminate local freshwater supplies in the 800-foot sand. However, if the Piney Point contains a sufficient quantity of freshwater, then the aquifer would be an attractive alternative source of water supply.

The study of water-quality conditions in the Kirkwood-Cohansey aquifer system and in the 800-foot sand will focus on the spatial distribution of major ions, nutrients, selected trace elements, volatile organic compounds, and, in agricultural areas, pesticides. The investigation of conditions in the 800-foot sand will also look into any time-dependent changes in water quality that may be caused by pumping stress on the aquifer. Sampling of water from the Kirkwood-Cohansey aquifer system and the 800-foot sand will be conducted in a synoptic manner. Water samples from the Piney Point aquifer will be analyzed for the same categories of constituents cited previously, excluding pesticides.

Analysis and Interpretation of Hydrologic Processes

The various geologic and hydrologic data from previous studies and those collected for this study will be used to refine the present concept of ground-water flow in the Atlantic City region, and to prepare a calibrated ground-water flow model. This model will be designed to simulate flow in the Kirkwood-Cohansey aquifer system, in the 800-foot sand, and in the Piney Point aquifer. The use of areal and cross-sectional models is planned as a means of understanding the complex behavior of the regional flow system. The lateral boundaries of the areal model will be represented by boundary fluxes from the New Jersey subregional RASA model. After the model prepared for the present study has been calibrated, it can be used to assess how the various aquifers will respond to development. Consequently, the model should provide managers and planners with a rational means for making prudent water-allocation decisions for the Atlantic City region.

The water-quality data will be interpreted with various statistical and analytical techniques. Data on the Kirkwood-Cohansey aquifer system will be interpreted statistically to ascertain the general relations between land use and ground-water quality. Data on the 800-foot sand will be interpreted in terms of the evolution of ground-water quality. This evolution will be described by the concept of hydrochemical facies (Back, 1960), which states that the facies present reflect the overall effects of chemical processes occurring between the ground water and the minerals of the lithologic framework. Because the ground-water flow patterns modify the facies and their distribution (Back, 1966, p. 11), the results of the facies analysis will be interpreted in conjunction with the flow-velocity field computed by the calibrated model. This interpretation may thus provide some insight into the nature of mass transport in the aquifer system. The simulated ground-water flow field near landfills and other disposal sites will likewise form the basis for estimating the local rate and direction of contaminant migration.

Planned Products

The various written products expected to result from the study of the Atlantic City region can be classified as data reports and interpretive reports. Anticipated principal reports on the study include a compilation of verified records of wells and ground-water quality; maps of the synoptic water table in the Kirkwood-Cohansey aquifer system; maps of the synoptic potentiometric surface in the 800-foot sand representing conditions of minimum and maximum pumping stress; and reports on the marine-drilling program, including a description of logistical and planning aspects of the program, and a summary of scientific findings. Preparation of interpretive reports summarizing the principal aspects of the study, especially the results of the model simulation of regional ground-water flow, is planned during the later stages of the investigation.

WORK COMPLETED AND PRELIMINARY RESULTS

Presently (1986), data-collection activities for this study are concluding, and the investigation is entering the phase of analysis and interpretation of hydrologic processes. Selected work items completed and preliminary results to date are summarized in this section.

Because marine test wells are the only direct means for bracketing and monitoring the position of the freshwater-saltwater interface in the 800-foot sand and for collecting related data, they formed the basis for this aspect of the study. From July through September 1985, two wells were drilled offshore at sites 1.9 miles (nearshore site) and 5.3 miles (offshore site) southeast of Atlantic City (fig. 1). At the nearshore and offshore sites, an 11-inch diameter borehole was drilled by the hydraulic rotary method to depths of 933 ft and 1,025 ft, respectively, below the seafloor. Lithologic samples drilled or cored from the boreholes have been submitted to various laboratories for analysis of mineralogy, paleontology, palynology, pore-water quality, and hydraulic properties. Borehole testing included vertical seismic profiling and collecting complete suites of geophysical logs. Subsequently, these boreholes were completed as wells with 4-inch diameter screens and casings; then, each was pumped for approximately 6 days. Water samples were collected during the later stages of pumping and were analyzed for major ions, nutrients, trace elements, volatile organic compounds, stable isotopes, and dissolved gases. Following pumping and sampling, three differential pressure transducers and three conductivity electrodes were permanently installed in a redundant arrangement in each marine well. Measurements of head and specific conductance are being made periodically by retrieving the sensor connectors that are stored on the seafloor, attaching them to the appropriate instruments aboard ship, and monitoring the downhole sensors. These measurements will continue to be made until all the sensors become inoperative.

The nearshore well was pumped continuously at 40 gal/min (gallons per minute) for 6 days, and the specific conductance eventually stabilized at 220 uS/cm (microsiemens per centimeter at 25° Celsius). Following this pumping, four nearby wells onshore were pumped continuously at a combined rate of 2,500 gal/min for 6 days while drawdown was measured in the nearshore well and in two observation wells onshore. By the conclusion of onshore pumping, water levels had declined about 6 ft in the nearshore well.

Subsequently, the offshore well was pumped continuously at 50 gal/min for 6 days. The specific conductance stabilized at 502 uS/cm. Water samples were collected for complete chemical analysis from the nearshore and offshore wells during the final stages of pumping. Chloride concentrations were 15 mg/L (milligrams per liter) in water from the nearshore well and 77 mg/L in water from the offshore well. These concentrations are significantly less than the Federal drinking-water standard of 250 mg/L (U.S. Environmental Protection Agency, 1977). Results of analysis for tritium (^{3}H) in water samples from both wells show no detectable concentrations; accordingly, it is likely that this water entered the 800-foot sand well before 1953. In 1953, thermonuclear testing introduced large quantities of tritium into the environment, some of which entered hydrologic systems worldwide.

Chemical analyses of ground-water samples collected in the study area from northeast to southwest (parallel to strike), and from northwest to southeast along the principal flow path (down dip), illustrate the general trends and characteristics of the quality of water in the 800-foot sand. Increases in specific conductance and pH from north to south and from west to east are thought to be related to (1) an increase in the amount of carbonate matter in the sediments underlying present-day coastal areas and (2) areal variations in cation exchange. These increases are accompanied by changes in hydrochemical facies from a predominantly calcium bicarbonate sulfate water to a sodium bicarbonate water. The facies changes are believed to be caused by the interaction of ground water with sediments deposited in an increasingly marine environment. These fine-grained sediments of marine origin may promote the opportunity for increased rates of cation exchange. With increasing distance offshore, the ground water acquires a predominantly sodium bicarbonate chloride character, due possibly to the increasing proximity to the freshwater-saltwater interface. Preliminary results of this study suggest that a large body of freshwater is present in inland parts of the 800-foot sand and that it extends several miles seaward from Atlantic City. Analytical results also indicate that throughout the Atlantic City region, water from the Kirkwood-Cohansey aquifer system and the 800-foot sand is of a quality suitable for most purposes.

SUMMARY

In the Coastal Plain of New Jersey, ground water is the principal source of water supply. In many areas it is an abundant resource, but, in others including the Atlantic City region, large withdrawals have resulted in declining ground-water levels and an accompanying reduction in the volume of water in storage. These conditions have increased the potential for water-supply shortages and for contamination of freshwater aquifers by encroaching saltwater. In order to address these critical problems, the U.S. Geological Survey, in cooperation with the New Jersey Department of Environmental Protection, instituted a comprehensive 5-year investigation of the ground-water resources of the region.

Additional development of the ground-water resources of the Atlantic City region is unwarranted until more is known about the volume, hydraulic properties, flow patterns, potential yield, and the quality of water in the principal freshwater aquifers. Inadequate information of this type has hampered regional water-resources planning and management and has led to imprudent development, thereby resulting in various existing and potential problems. Overproduction and degradation of water quality by human activities are the most serious of these problems. Proper management of these ground-water supplies requires data sufficient to characterize the flow systems and analytical techniques that satisfactorily represent and enable model simulation of system behavior. Prior to the present study, available information on the ground-water system, as well as an understanding of the various stresses acting on this system, were inadequate for proper analysis and management of the water resources of the region.

The principal objective of the Atlantic City region ground-water resources investigation is to provide officials of the NJDEP with the hydrologic data and analyses necessary for effective water-resources management. This objective is being accomplished by upgrading the geologic and hydrologic data bases; by developing a detailed understanding of the ground-water flow system behavior, mainly through the use of digital models; and by implementing a standardized information management system. The overall approach to the study consists chiefly of (1) assessment of available data on the geology and hydrology of the study area; (2) collection of additional data, partly through the construction of two test wells offshore; and (3) analysis and interpretation of hydrologic processes. Planned products of the study include data reports and interpretive reports.

Preliminary results of the study include the documentation that water from two wells offshore of Atlantic City had chloride concentrations that were significantly less than the Federal drinking-water standard of 250 mg/L; and the characterization of fresh ground water in the Atlantic City region as being of a quality suitable for most purposes.

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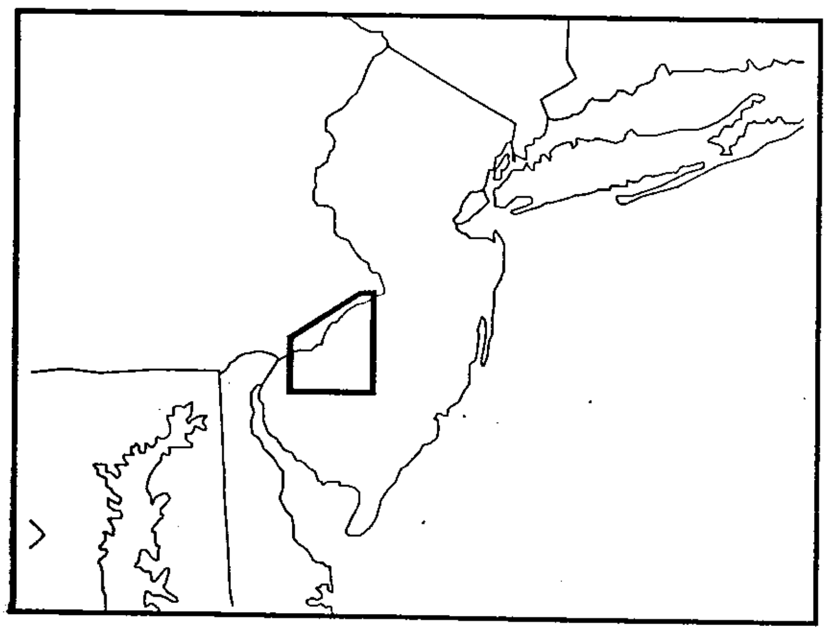
THE POTOMAC-RARITAN-MAGOTHY AQUIFER SYSTEM IN THE CAMDEN METROPOLITAN AREA: CULTURAL IMPACT ON AN OUTCROP AREA

by

Anthony S. Navoy



New Jersey District Office
Water Resources Division
U.S. Geological Survey

The Potomac-Raritan-Magothy Aquifer System in the Camden New Jersey Metropolitan Area: Cultural Impact on an Outcrop Area

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ABSTRACT

The Potomac-Raritan-Magothy aquifer system forms the lower part of a southeast-dipping wedge of Cretaceous to Holocene Coastal Plain sediments. The aquifer system is the major source of water supply for Camden, New Jersey, and its surrounding metropolitan area in southwestern New Jersey. Prior to the development of ground-water supply in the area, the aquifer system was recharged chiefly by precipitation on the outcrop area to the northeast of Camden and was depleted by ground-water discharge to the Delaware River in the vicinity of Camden.

The development of ground-water supplies has affected the ground-water flow system. Withdrawal by wells began in 1898, and presently approaches 100 million gallons per day. These withdrawals have created a large regional cone of depression in the potentiometric surface of the aquifer system, and have caused hydrologic conditions in the outcrop area near Camden to change from a discharge area to a recharge area. This change threatens potable ground-water supplies by: (1) increasing the potential for movement of saline water towards the metropolitan area, (2) inducing contaminated recharge water from the outcrop, and (3) inducing recharge of saline Delaware River water during extreme drought conditions.

INTRODUCTION

The Camden metropolitan area, in southwestern New Jersey, incorporates parts of Burlington, Camden, and Gloucester Counties. The Potomac-Raritan-Magothy aquifer system is the principal source of water supply for the area. The Camden area has the coincidental situation of high ground-water use and proximity to saline ground water, as well as being the location of industrial and commercial land-use. These and associated contamination problems in the outcrop area have affected the quality of the area's major source of water supply, and has resulted in a complex situation of water-supply and water-quality problems. This paper briefly describes the hydrogeology and impact of water-supply development on the Potomac-Raritan-Magothy aquifer system in the Camden, New Jersey Metropolitain area.

HYDROSTRATIGRAPHY

The greater Camden metropolitan area is situated on the outcrop area of a southeast-dipping wedge of Coastal Plain sediments that range in age from Cretaceous to Holocene. The oldest sediments of the Coastal Plain belong to the Potomac Group and the Raritan and Magothy Formations, and are fluvial-marginal marine in origin, overlying pre-Cretaceous crystalline rocks. Table 1 shows the geologic relationships and properties of these units as well as their hydrologic characteristics. These units comprise the highest-yielding aquifers in the Coastal Plain. The outcrop area of the undifferentiated sediment mass formed by the Potomac Group and the Raritan and Magothy Formations trends from the southwest to the northeast and extends from the Fall Line in Pennsylvania, southeastward through the Camden area to approximately 1 to 4 miles southeast of the Delaware River (figure 1). Situated on this outcrop area are the major urban areas of metropolitan Camden and southeastern Philadelphia, and the Delaware River. In some places, a veneer of Quaternary sediments is present at the land surface (U.S. Geological Survey, 1967).

The stratigraphy of the Potomac Group and the Raritan and Magothy Formations in New Jersey has been examined in detail in the Raritan embayment, located in the northeastern part of the New Jersey Coastal Plain. The subdivisions of the Raritan and Magothy Formations as represented in the Raritan embayment are not evident in the stratigraphy of the Camden area (Owens and Sohl, 1969). Therefore, in the Camden area, these formations have generally been considered as stratigraphically undifferentiated. Contained within the Potomac Group and the Raritan and Magothy Formations is the Potomac-Raritan-Magothy aquifer system, the most productive source of ground water in the Camden metropolitan area. This aquifer system has been subdivided on a hydraulic basis into three aquifers, designated as lower, middle, and upper, through the use of geologic and borehole geophysical logs (Zapecza, 1984). Cross-sections of these aquifer units are shown along the traces in figure 2. The various units dip towards the southeast and thicken in that direction (figure 3), and are fairly consistent along strike (figure 4), except for the lower aquifer, which thins out and terminates against bedrock in central Burlington County. The units also show a regional trend of decreasing sediment size downdip.

The hydrostratigraphy of the aquifer units becomes rather complex in the outcrop area. The lower aquifer extends beneath the bed of the Delaware River and crops out in Philadelphia. The middle aquifer extends under, but in places contacts the river. The upper aquifer crops out only in New Jersey. The confining beds, which are composed predominantly of clay, are fairly continuous in the downdip, but become discontinuous in the outcrop area where they provide only local confinement.

Table 1.-- Geologic and Hydrogeologic Units of the Potomac-Raritan-Magothy Aquifer System in New Jersey.

SYSTEM	SERIES	GEOLOGIC UNIT	LITHOLOGY	HYDROGEOLOGIC UNIT		HYDROLOGIC CHARACTERISTICS
Cretaceous	Upper Cretaceous	Woodbury Clay	Clayey, gray and black, micaceous silt.	Merchantville-Woodbury confining bed		A major confining bed. Locally the Merchantville Fm. may contain a thin water-bearing sand.
		Merchantville Formation	Glauconitic, gray and black, micaceous clays and clayey silts; locally very fine-grained quartz and glauconitic sand.			
		Magothy Formation	Sand, quartz, light-gray, fine- to coarse-grained; local beds of dark-gray lignitic clay.	Potomac-Raritan-Magothy aquifer system	upper aquifer	A major aquifer system. In the northern Coastal Plain the upper aquifer is equivalent to the Old Bridge aquifer and the middle aquifer is the equivalent of the Farrington aquifer. In the Dela. River Valley three aquifers are recognized. In the deeper subsurface, units below the upper aquifer are undifferentiated.
		Raritan Formation	Sand, quartz, light-gray, fine- to coarse-grained, pebbly, arkosic, red, white, and variegated clay.		conf bd	
					middle aquifer	
	Lower Cretaceous	Potomac Group	Alternating clay, silt, sand, and gravel.		conf bd	
					Lower aquifer	
Pre- Cretaceous		Bedrock	Precambrian and lower Paleozoic crystalline rocks, metamorphic schist and gneiss; locally Triassic basalt, sandstone and shale.	Bedrock confining bed		Except along Fall Line, no wells obtain water from these consolidated rocks.

Modified from Zapecza, 1984, Table 2.

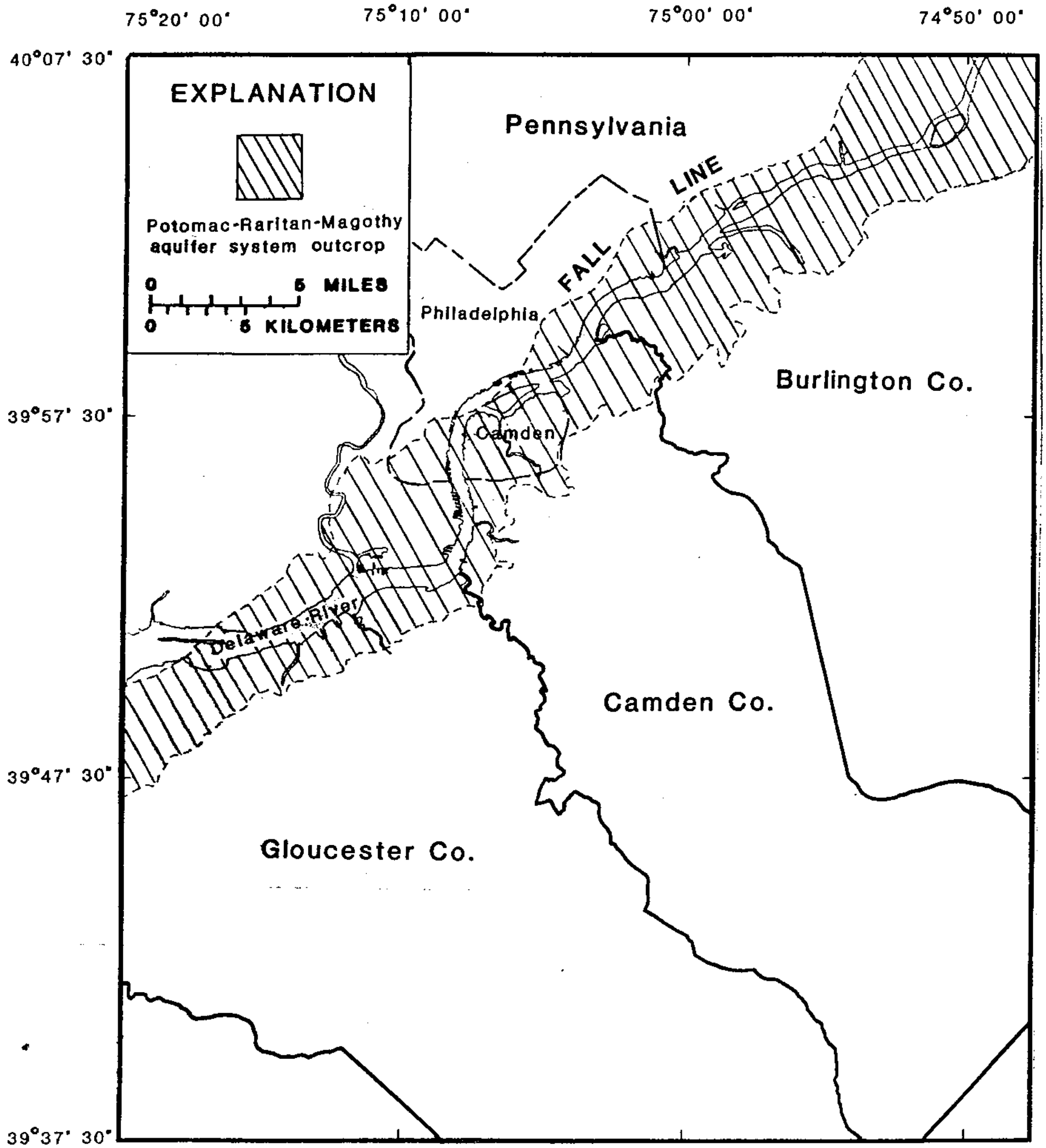

Figure 1. -- The outcrop of the Potomac-Raritan-Magothy aquifer system in the Camden metropolitan area.

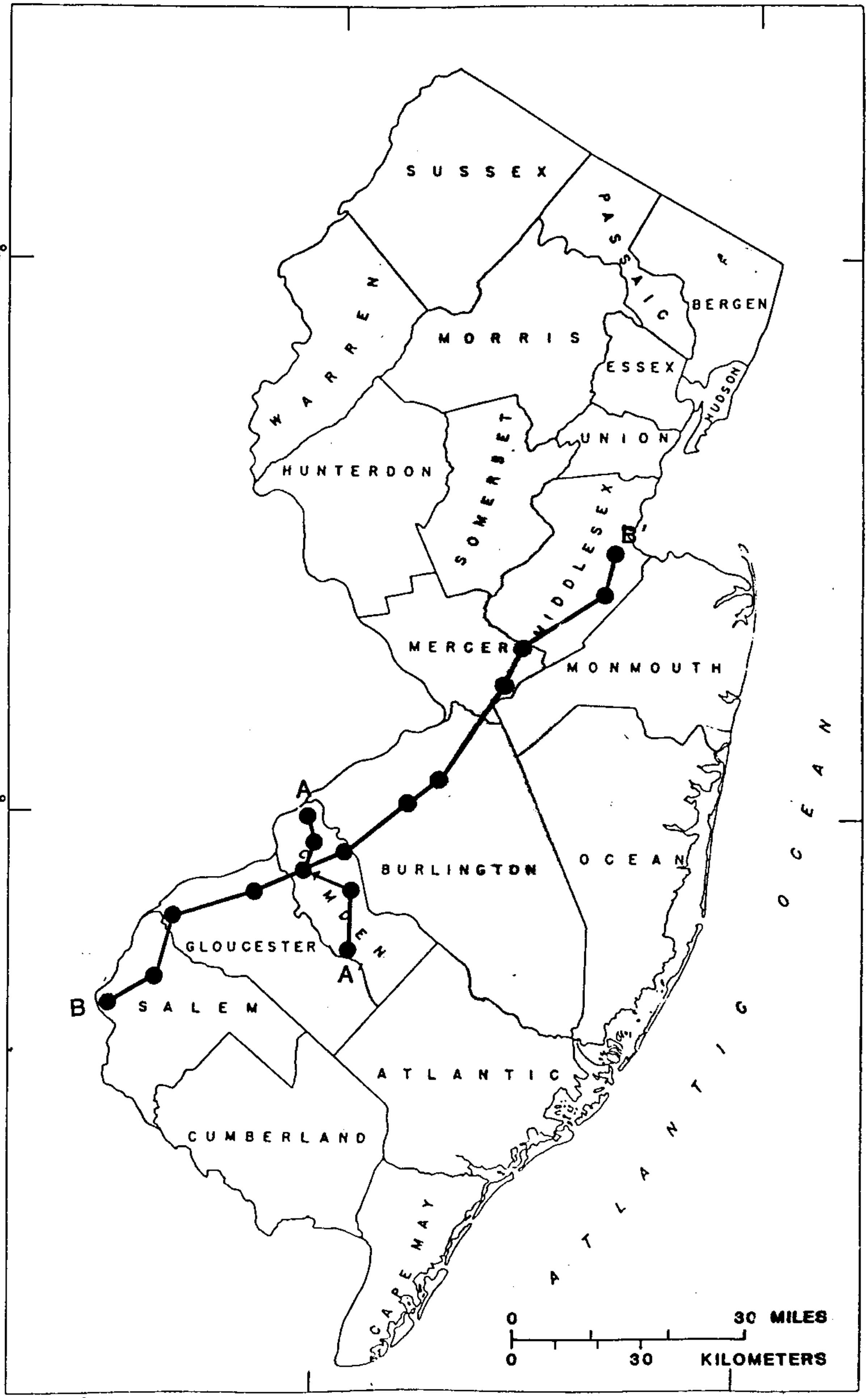

Figure 2. -- Location of hydrostratagraphic cross-sections.

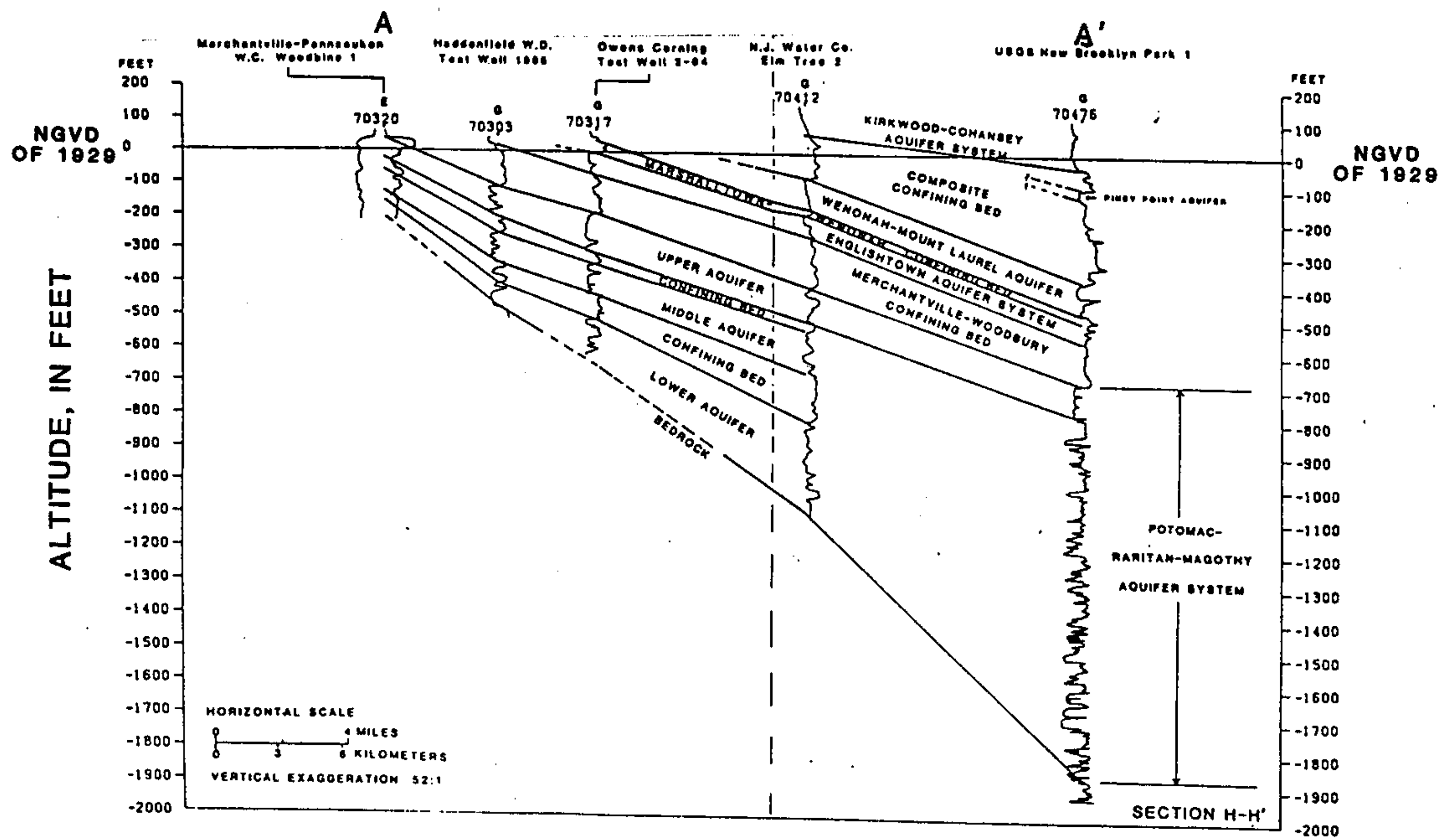

Figure 3.--Downdip cross section A-A' of hydrostratigraphic units. See figure 2 for location of section. (modified from Zapecza, 1984).

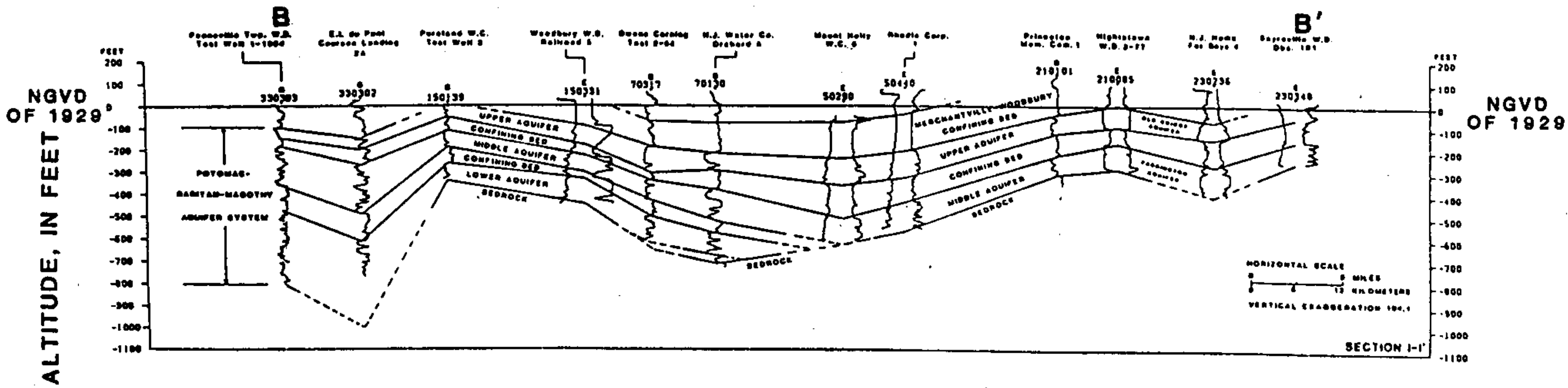

Figure 4.--Cross section B-B′ of hydrostratigraphic units parallel to strike. See figure 2 for location of section.(modified from Zapecza, 1984).

PREDEVELOPMENT GROUND-WATER FLOW SYSTEM

During predevelopment times (prior to 1900), the outcrop along the Delaware River near Camden was a discharge area for the regional ground-water flow system. Recharge, chiefly as precipitation, entered the system in the outcrop to the northeast in Burlington, Mercer, and Middlesex Counties (figure 5). To a lesser extent, recharge occured locally as vertical leakage from overlying aquifers. Figure 5 shows the potentiometric surface of the undifferentiated confined aquifer system prior to its development for water supply. In a simplistic sense, both discharge and recharge occur in the outcrop area of the aquifer system. Because of this orientation, ground-water-flow velocities decrease downdip, resulting eventually in negligible rates of flow.

The flow regime in the vicinity of Camden appears to be controlled chiefly by the location and rate of ground-water discharge to the Delaware River. The amount of ground-water discharge as leakage to the river, under predevelopment conditions, will be controlled by river-bottom permeability, to some extent by the proximity of crystalline bedrock beneath the riverbed, and by the head gradient in the area. The river bottom downstream (approximately 10 miles) from Philadelphia and Camden becomes predominantly clayey and silty, and coincidentally, the crystalline bedrock is present at shallow depths (approx. 10 feet) in the same river reach (Duran, 1986). Just downstream of this reach, the saline-water interface in the aquifer is nearest the river (see the hatchured line in figure 5), perhaps indicating a low-flow velocity zone. This change to less-permeable river-bottom material and shallowness of bedrock may preclude relatively high rates of discharge to the river, and thus limit the extent of vigorous ground-water flow. Furthermore, such conditions may have fixed the location of the downdip saline-water interface under predevelopment conditions.

The occurence of saline ground water in the downdip areas may be a manifestation of lower flow velocities downdip, as noted earlier. The saline water, most likely introduced into the aquifer during an earlier, higher stand of sea level, may not have been flushed completely by freshwater. The chemical character of the saline water shows evidence of ion-exchange reactions that are indicative of freshwater flushing the saline water from the aquifer (Fusillo and others, 1984). Chapelle and Knobel (1983) studied a similar ion-exchange phenomenon in glauconitic sediments in Maryland. With montmorillonite acting as the exchange medium within the Potomac-Raritan-Magothy aquifer system (L. L. Knobel, 1985, U.S. Geological Survey, written commun.), calcium would replace sodium on the exchange sites as freshwater flushes saltwater from the aquifer. This process enriches the fresh ground water with sodium as chemical equilibrium between ground water and exchange media is maintained during the flushing.

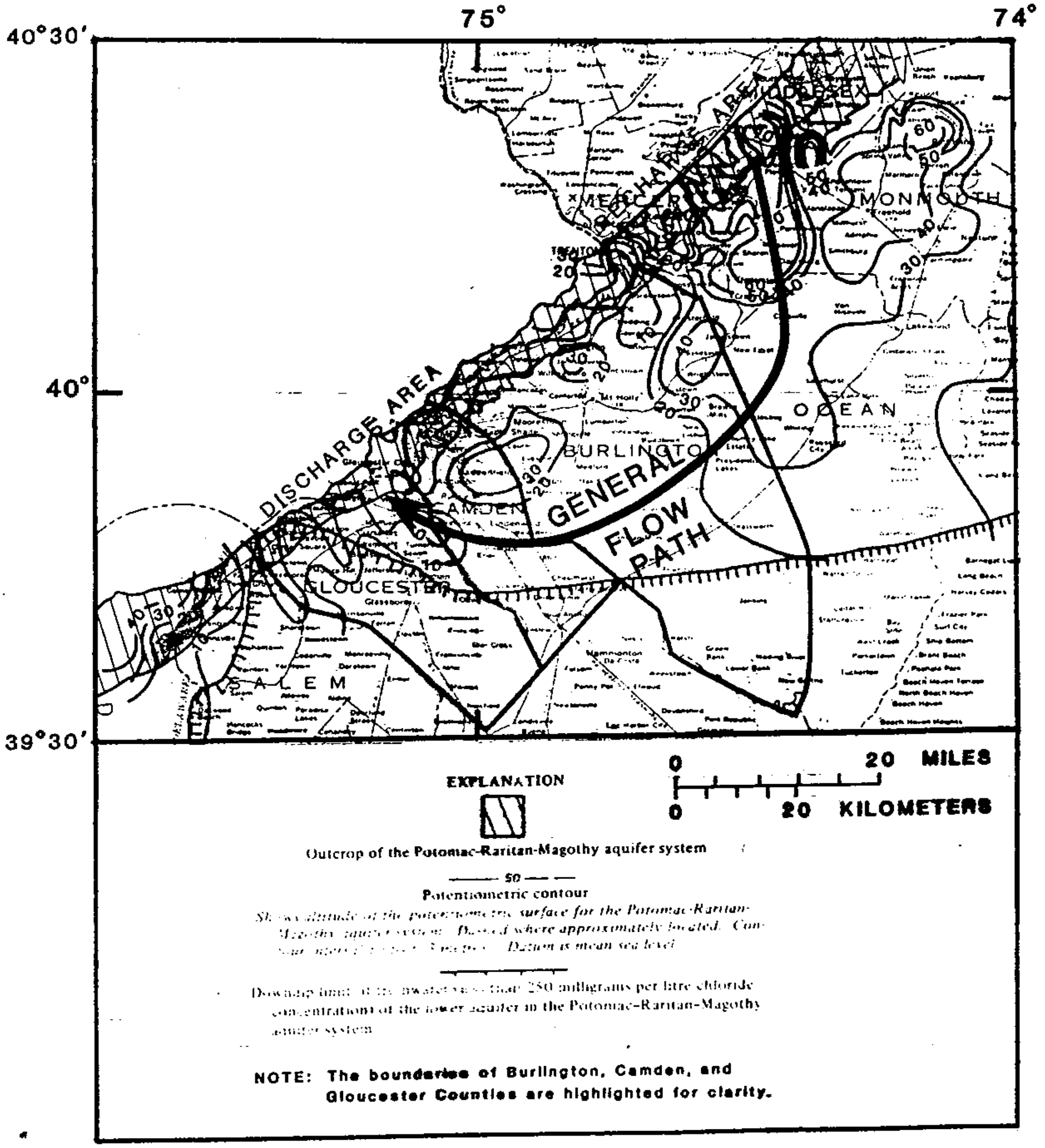

Figure 5 -- Predevelopment (1900) potentiometric surface of the Potomac-Raritan-Magothy aquifer system (modified from Gill and Farlekas, 1976).

IMPACT OF CULTURAL DEVELOPMENT ON GROUND-WATER RESOURCES

Flow in the Potomac-Raritan-Magothy aquifer system has undergone significant local changes since the advent of ground-water-supply development in the Camden area. Significant ground-water use in the metropolitan Camden area began in 1898 and is presently approaching an average rate of 100 million gallons per day (Camp Dresser & McKee, Inc., 1984). Figure 6 shows the continuously increasing trend of water use in Camden County.

Water-supply development has produced large cones of depression in the potentiometric surface of the aquifer system, resulting in heads in excess of 80 feet below sea level. The main regional cone of depression as measured in 1978 is depicted on the potentiometric surface map in figure 7. The decline of the potentiometric surface from predevelopment times to 1968 exceeded 100 feet in places, as shown in figure 8.

The decline in potentiometric surface of the aquifer system, in response to pumping, has locally changed the hydrologic significance of the outcrop area along the river from that of a discharge area to a recharge area. Results of ground-water-flow modeling by Luzier (1980) indicated that, in 1978, approximately 68 million gallons per day of recharge flowed from the Delaware River into the aquifer system in the Camden metropolitan area. Because of this induced infiltration, extreme decline of the potentiometric surface near the river has not occurred. Figure 9 shows the distribution of ground-water pumpage in 1980, by township. The greatest pumpage is from wells located near the river, but these pumping centers do not coincide with the main regional cone of depression (figure 7). This is additional evidence that the majority of the ground water pumped from wells near the river is actually induced river-water recharge.

A cone of depression forms in response to pumping stress. The formation of a regional cone of depression centered around Camden threatens ground-water quality in several ways. First, the regional cone of depression has produced a potentiometric gradient toward the center of the cone that is conducive to the movement of the deep, downdip saline-water interface toward the Camden metropolitan area. Figure 10 shows the location of the saline-water interface in relation to the regional cone of depression. Water-quality samples from production wells near the interface have shown slight increases in dissolved solids (Fusillo and others, 1984), suggesting that there has been some updip movement of the interface. This threat would have its greatest effect on ground-water supplies in Gloucester County.

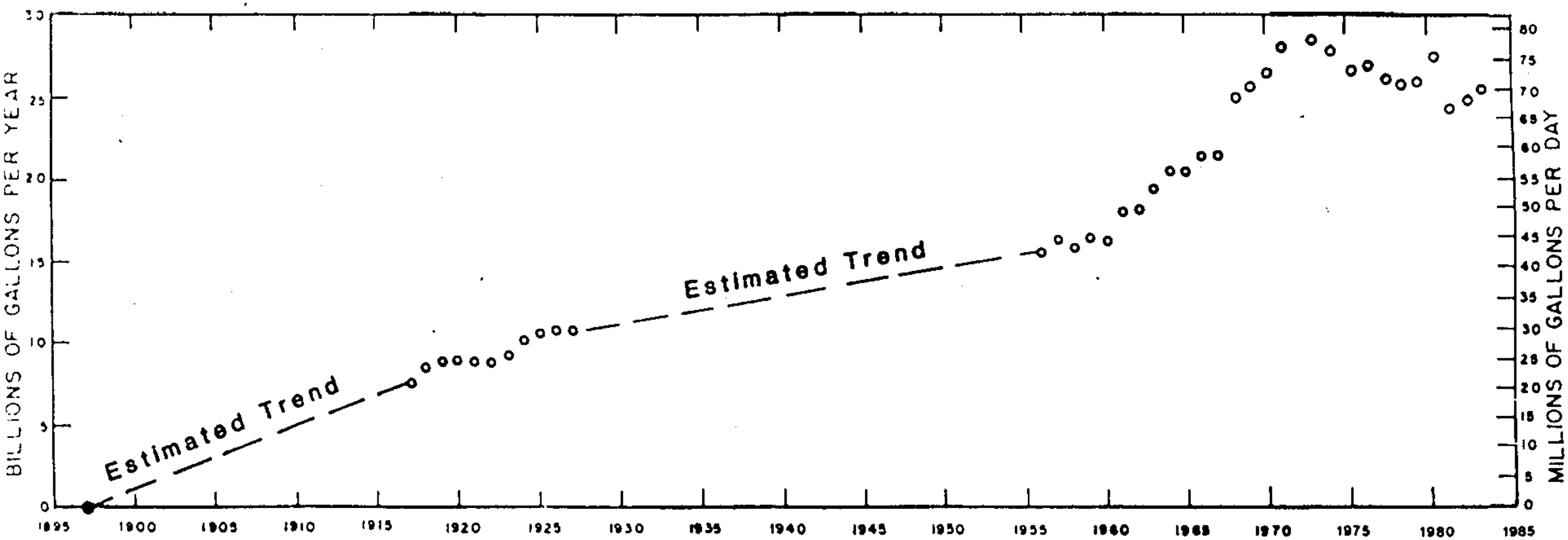

Figure 6.--Pumpage from the Potomac-Raritan-Magothy aquifer system in Camden County, 1897-1983 (modified from Farlekas and others, 1976).

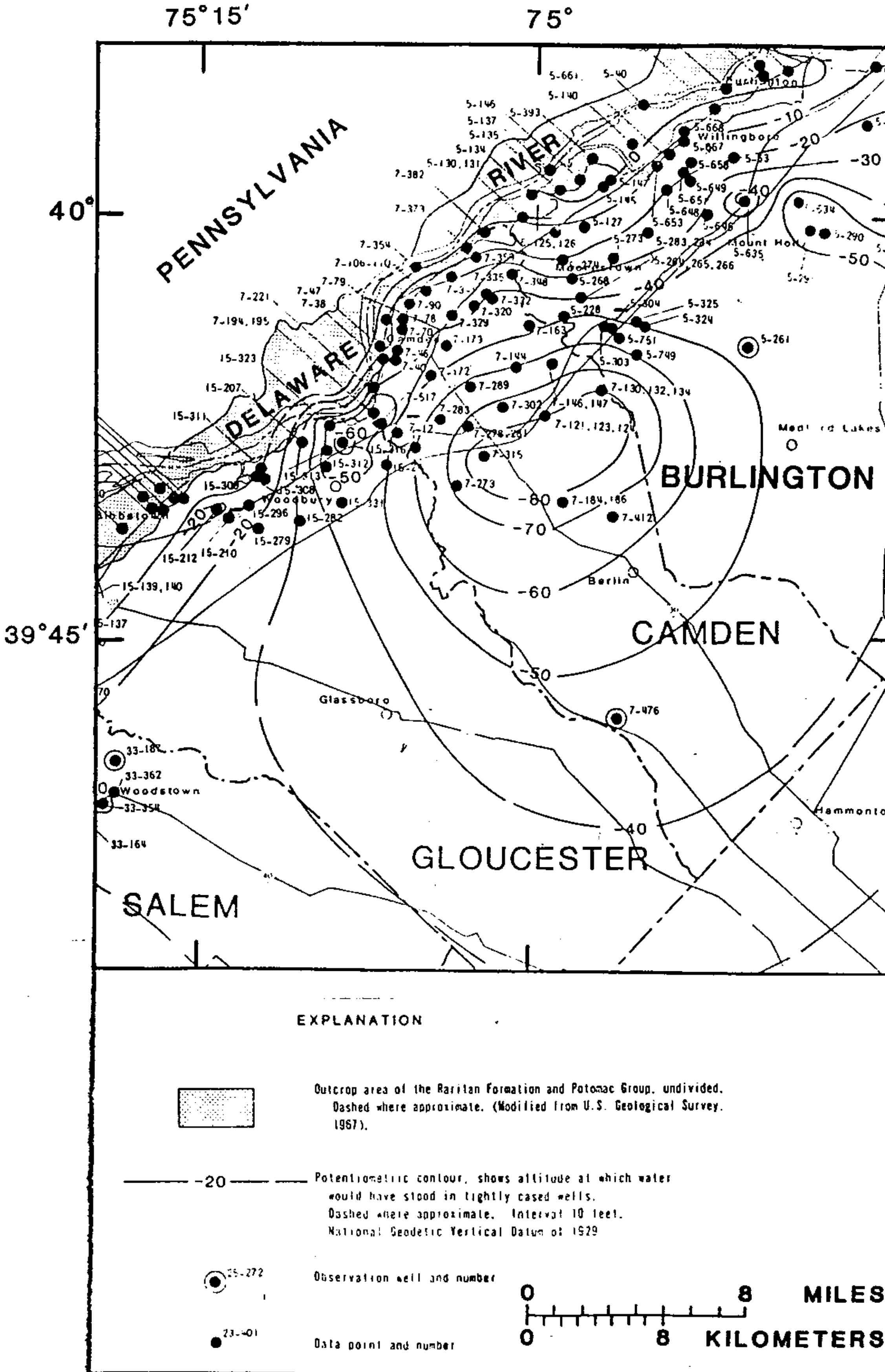

Figure 7 -- Potentiometric surface map of the lower aquifer of the Potomac-Raritan-Magothy aquifer system, 1978 (modified from Walker, 1982).

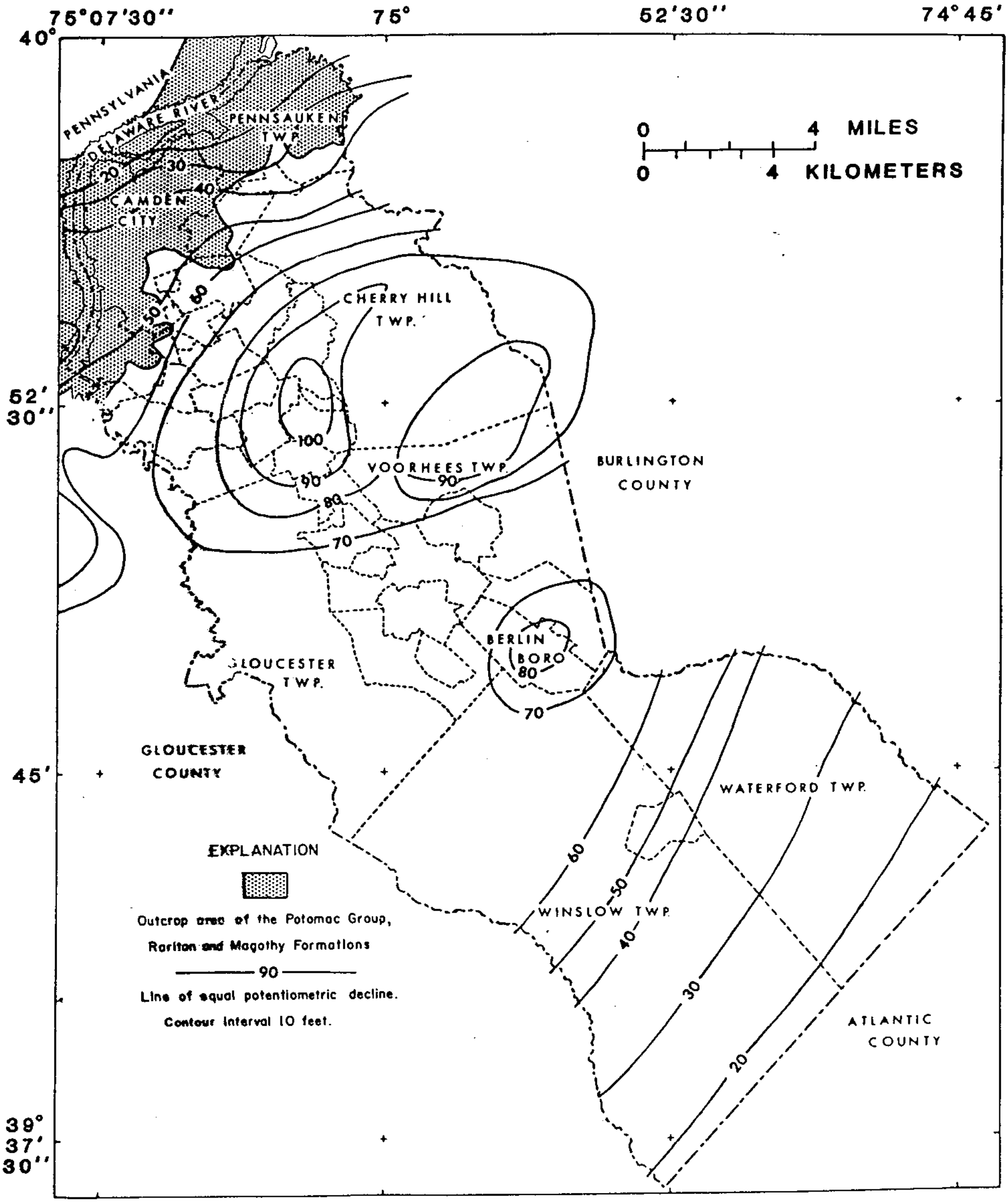

Figure 8. -- Potentiometric decline of the Potomac-Raritan-Magothy aquifer system in Camden County, 1900-68 (from Farlekas and others, 1976).

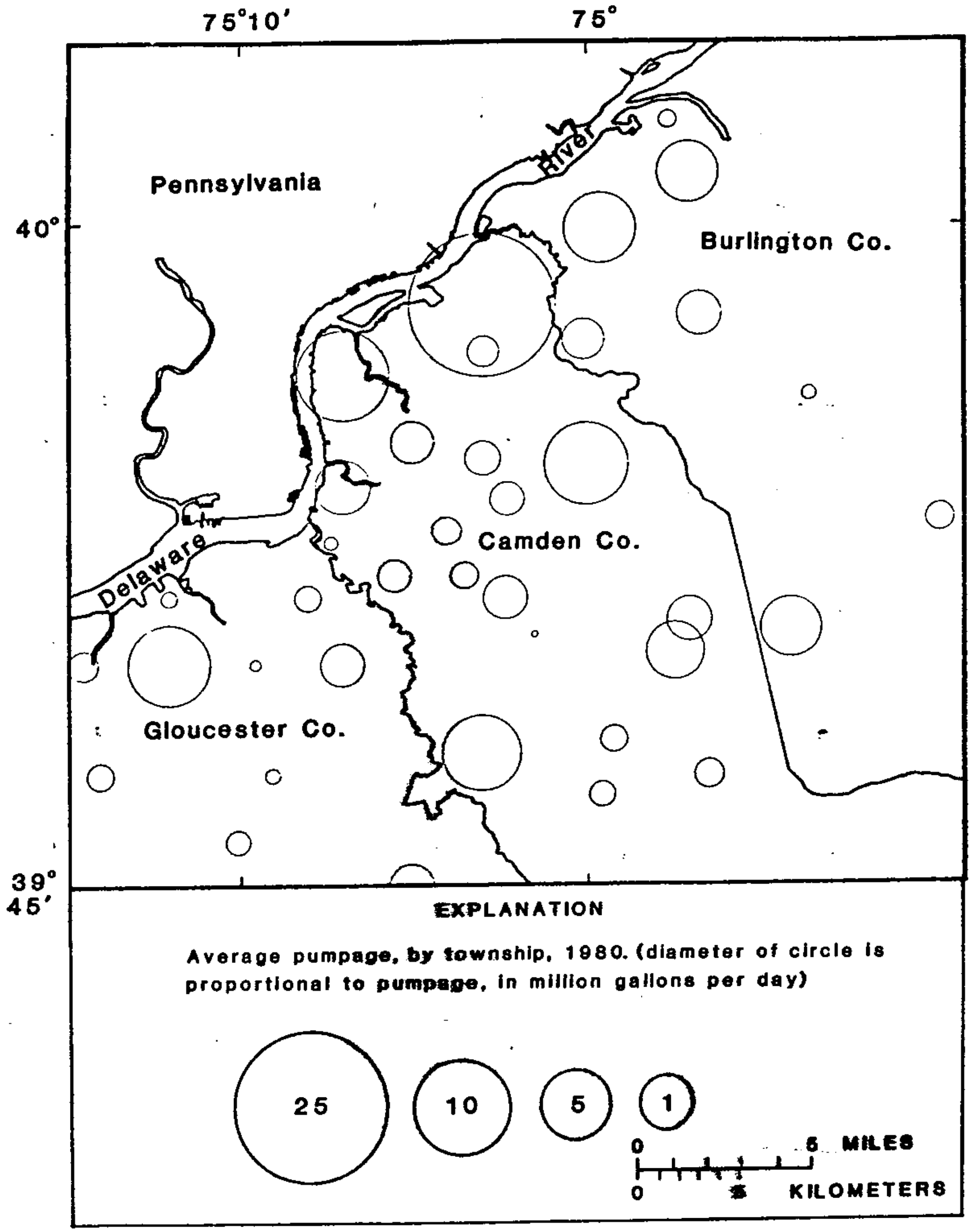

Figure 9. -- Ground-water use in the Camden metropolitan area, 1980, by township.

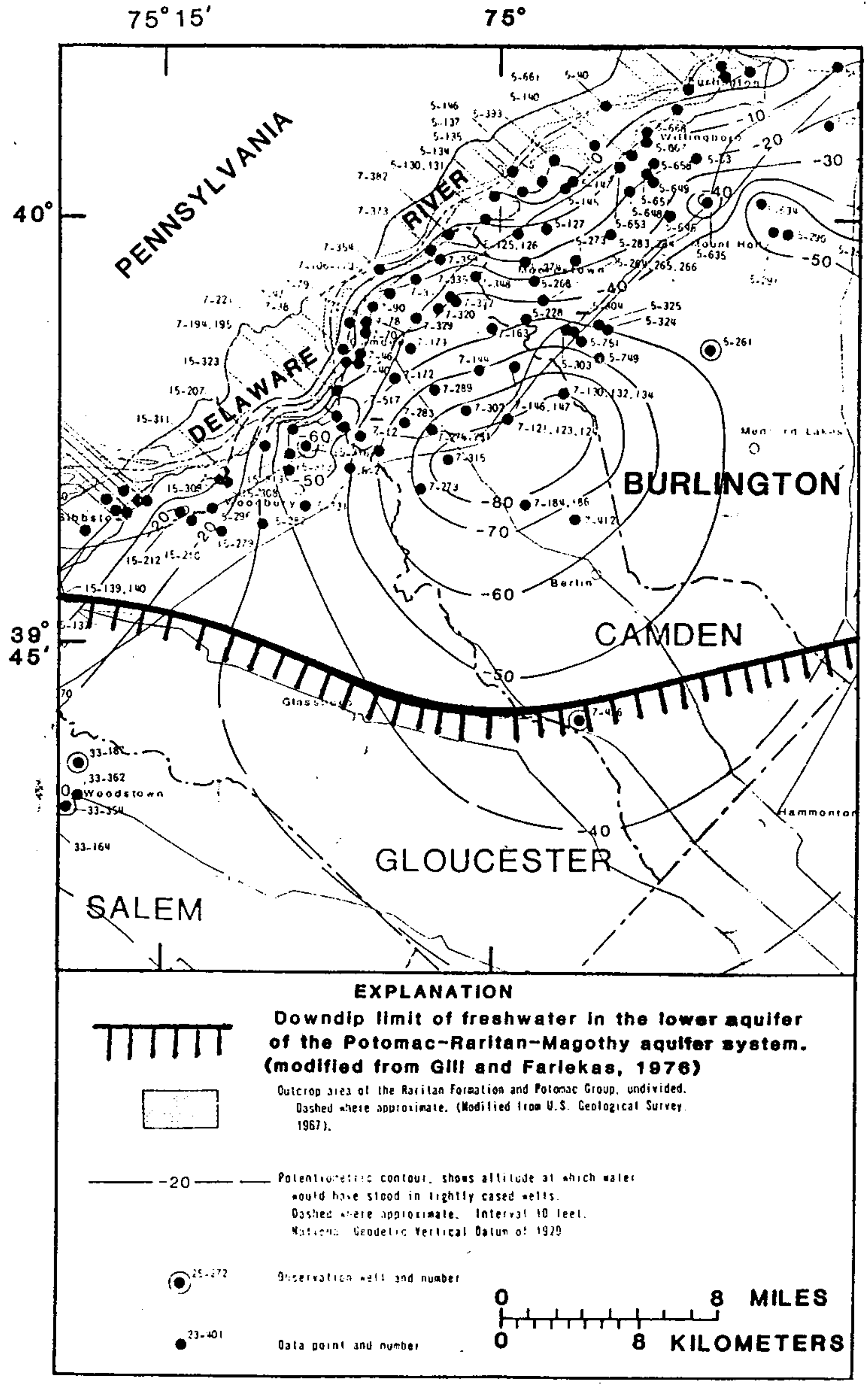

Figure 10. -- Relative location of downdip saline water to regional potentiometric cone of depression in the lower aquifer of Potomac-Raritan-Magothy aquifer system, 1978 (modified from Walker, 1982).

Second, the reversal in the hydrologic function of the aquifer system outcrop in the metropolitan area from a discharge area to a recharge area has increased the likelihood of induced infiltration of contaminated water from surface sources. Concomitant with the development of ground-water supplies in the area has been the development of heavy industry and commerce. The location of industrial and commercial wastes on the recharge area has degraded water quality in some parts of the aquifer system. This is evidenced by the prevalence of organic chemicals and heavy metals found in water-quality samples (Fusillo and others, 1984). The Camden metropolitan area has 10 "Superfund" sites (U.S. Environmental Protection Agency National Priorities List, 1984) and 96 other known environmentally hazardous sites (figure 11). The potential effect of the hazardous sites is not limited to areas on the outcrop of the aquifer system, for any contaminated effluent that discharges to a stream system that flows across the outcrop of the aquifer system can contribute contaminants (although probably diluted) to ground water through natural or induced infiltration.

Third, the reversal in the hydrologic function of the outcrop area has also allowed induced infiltration of water from the Delaware river. Under conditions of normal streamflow, this recharge is beneficial. Under conditions of low streamflow it could result in recharge of saline river water. The saltwater interface in the estuary is normally located approximately 20 miles downstream from Camden. However, during a drought, the interface in the estuary may move far enough upstream to be adjacent to the aquifer system outcrop in the Camden area, creating the possibility that this saltwater could enter into the aquifer system and contaminate near-river wells. The Delaware River Basin Commission maintains and operates reservoirs for augmenting low flow in the river to prevent the upstream migration of saltwater. Therefore, this threat would affect the ground-water system only if the drought was severe enough to exhaust the augmentation capacity.

SUMMARY

The flow regime in the Potomac-Raritan-Magothy aquifer system has been altered by pumpage for water supply in the Camden metropolitan area. The cones of depression that have developed have resulted in several potential threats to the potability of the water supply of the area including: (1) movement of the downdip saline-water interface toward pumping centers, (2) induced infiltration of contaminated water from the outcrop area, and (3) induced infiltration of salty water from the Delaware estuary during conditions of low streamflow. Continuing development and increasing demand for water will require sound management policies that minimize the deleterious effects on the ground-water supplies of the Camden metropolitan area.

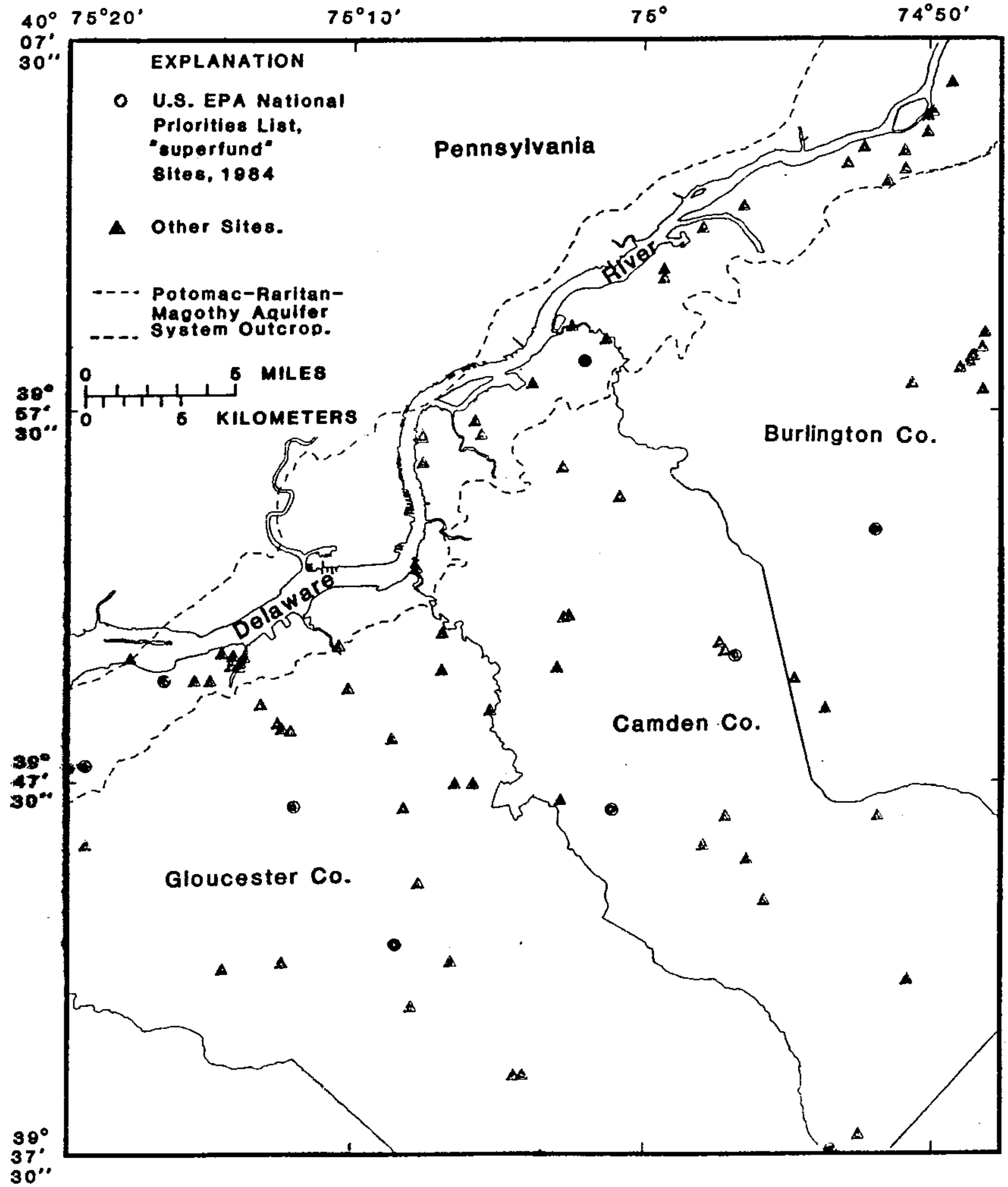

Figure 11. -- Environmentally hazardous sites in the Camden metropolitan area.

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The Role of the Geologist in Today's Ground Water Problems

Haig F. Kasabach,
State Geologist

When I first began to work with the State of New Jersey in 1960, there were only 6 people who held geologist titles working for the State. The shift in the economic situation and environmental regulations have made the state the largest employer of geologists in New Jersey(over 90 people). Specialists are now required in hydrogeology, geophysics, and soil science to handle the complex environmental problems and especially those related to ground water. New Jersey's colleges and universities must prepare their students for these new challenges. Virtually every major project in New Jersey, which may have an impact on ground water, requires input from a geologist either during its inception or in the regulation process.

The Role of the Geologist in Today's Ground-Water Problems

When I first started work with the State of New Jersey in 1960 the State Geologist and 5 geologists residing in a Department called Conservation and Economic Development were the only geologists working for the state. (D.O.T. had a couple of geological engineers for materials). At that time, no one thought that there was any conflict between economic development and conservation.

Geologists in state service were then primarily engaged in the traditional tasks associated with geological surveys - that is mineral exploration, geologic mapping, and providing the public with information on geology and ground water.

The petroleum geologists were the glamour boys of the profession in the 50's but recession had taken its toll on employment by 1960. However, uranium exploration was continuing and a few prospects even had been discovered in New Jersey. A few years later a combination of abundant supply, increasing regulations and environmental concerns also had curtailed uranium exploration. So it has been with the geologic profession. For the past 50 years geologists in exploration and mineral development have been the first victims of economic downturns. In fact, exploration geology is one of the few professions where the reward for doing a good job is unemployment.

During the 50's a few consulting engineering firms also employed a handful of geologists to assist in subsurface investigations. Only one geological consulting firm in the area specialized in ground-water problems and a second one began in the early 60's.

Several things occurred during the late 60's and early 70's which forever changed the role of geologists employed by the State of New Jersey. First a project had been proposed and designed by the Division of Water Policy and Supply called the South River Tidal dam. We were told that this project would recharge the Raritan aquifer all the way to Asbury Park. After all the borings and preliminary design had been completed the N.J. Geological Survey was asked to look at the data. It became obvious that this project would primarily benefit two municipalities and flood many basements by elevating the water table. The project was soon dropped but the Division decided they had better have a geologist on the staff before any more projects got this far. Soon after this incident I was asked by the Stream Encroachment section to look at plans for a landfill in an old gravel pit in the flood plain. I called the State Bureau of Solid Waste Management, which was then part of the

Health Department, and indicated that the placement of garbage and industrial waste in a gravel pit would surely contaminate the ground water of the area. The reply I received was: "So What"] At that point I got several Division Directors involved and no landfills were sited again without a review from a state geologist.

These incidents and another where phamaceutical wastes were being dumped in the Pinelands with state approval suddenly made two Commissioners and the Governor aware of the fact that there were two Departments regulating water, for different purposes. The Health Department was issuing permits to dispose of wastewater to streams and on the ground and the Department of Conservation and Economic Development was issuing permits for the consumption of ground water and surface water. Communications between the two Departments was minimal. Even more bizarre was the fact that one agency was planning reservoirs and water intakes on streams while the other was planning huge trunk sewers to carry wastewater to the ocean, making that water unavailable.

On Earth Day in 1970 the State of New Jersey began a new era where it was recognized that the natural resources and environment of this state could not be protected by the existing hodge-podge of environmental agencies, each with its own narrow mission. And so the Department of Environmental Protection was born. Within the Department all former agencies dealing directly with water merged into the Division of Water Resources.

The early 70's brought the rediscovery of ground-water contamination. Polluted wells had been reported since biblical times however the contamination usually was due to poor sanitary practices resulting in bacterial and viral contamination. Now complaints regarding taste, odor, strange rashes and illness began to increase and by 1974 the Division of Water Resources had 5 geologists investigating polluted well reports and spills.

The comprehensive New Jersey pollution laws passed in the late 1970's were among the most stringent in the country and included the regulation of ground-water discharges, something the Federal laws did not cover. Therefore, geologists were needed to regulate and clean-up ground water discharges. However, in 1979 the State could not even analyze for the exotic chemicals which had become so prevalent in our daily lives since World War II. Once the laboratories began analyzing for these chemicals we began finding them everywhere. The myths about a few feet of soil being able to filter the ground water were obviously invalid but it was hard for the layman to comprehend how he was part of the problem. Chemicals were dumped into septic systems and household products were flushed away and then showed up in people's wells. With funding from a Federal grant we found hundreds of so-called "evaporation lagoons" in a state where precipitation and evaporation rates are about equal. Where were the contents going?

By 1982 twenty four (24) geologists were involved with ground-water pollution and regulation of discharges. The establishment of ground-water-discharge-permit program required more geologists and soil scientists since New Jersey's program regulates all actual or potential discharges to ground water including lined and unlined lagoons, landfills, sludge farms, spray irrigation of effluent and underground injection.

By 1983 additional positions were required to complete ground-water supply evaluations mandated by the 1981 Water Bond Act and State Water Supply Master Plan including the Atlantic City, Camden, and South River areas and the buried valley aquifers of northern New Jersey. In addition a program was initiated with the U.S.G.S. to produce a modern geologic map of the state which could be used for land use and water-supply planning.

By now it had become obvious that certain skills were necessary to accomplish all of the ground-water related tasks mandated by Federal and State legislation. The Division of Water Resources had by this time made great strides in hydrogeology and geophysics and probably had one of the most comprehensive state ground-water programs in the country. However, not all of those graduating with geology degrees could accomplish the tasks at hand. After a year-long battle with civil service the Department was able to establish 3 new titles in addition to the geologist title which had been in existence for 40 years. The new titles are: hydrogeologist, geophysicist and pedologist (soil scientist).

Armed with these new titles the Division of Water Resources began a massive recruitment drive which included special hiring rates competitive with private industry. By the spring of 1985 the number of geologist positions in the Division of Water Resources, including the Geological Survey, had risen to 89 and by September, four additional hydrogeologist positions were added to investigate the cases required by the new Environmental Cleanup Responsibility Act (ECRA) and five more were approved from the Spill Fund to evaluate accidental spills, Superfund and abandoned Coal Gas sites.

Funding for these new positions are supported by permit fees and taxes on petroleum and bulk chemicals. About 75% of the Division of Water Resources geological staff is either in a regulatory program or directly supporting regulatory programs.

In the private sector I estimate that the percentage of geologists employed in the northeast, as a result of ground-water related regulations (CERCLA, RECRA, ECRA, TOSCA, NJPDES, Spill Fund, etc.) is probably about 70%. Clearly geology faculty must continuously shift emphasis to assure that graduates are employable. For example, a recent survey of the petroleum industry indicated that there will be 20% to 50% fewer independent companies by the 1990's and fewer positions in exploration. However, demand will increase for development geologists, hydrogeologists and soil geologists. At the University of Tulsa, where most geology students seek careers in the petroleum industry, curriculum shifts are in the areas of geophysics, computers and engineering geology.

That is not to say that geology students must give up the basics. On the contrary, a strong understanding of field and basic geology is necessary to be able to apply some of the more sophisticated techniques in modeling, geophysics, and computer graphics. I have seen mathematical geniuses actually create physically impossible models because they became so enamoured with the math that they ignored the geologic and hydrologic realities. However, to prepare for the new challenges facing the geologic profession, an advanced degree has become more necessary in order to obtain the courses needed in a flexible job market. Geologists today require a good foundation in geophysics, hydrogeology, mathematics, chemistry and fundamental computer literacy as well as basic geology. Grades may not mean much after one has been working 5 years but most prospective employers, including the state and federal government do consider grades. The outstanding student has a distinct advantage in the geologic job market.

In summary, in the densely populated northeast, there is no doubt that geologists with the proper training are playing a vital role in solving many of the state's environmental problems including waste-water disposal, clean-up of hazardous waste and the development of ground-water supplies. Whereas 15 years ago the majority of projects impacting ground water had little input from geologists, today virtually every major undertaking in New Jersey requires input by geologists either during its inception or during the regulation process.

Ground-water contamination in an outcrop area of a coastal plain aquifer system : Logan Township, Gloucester County, New Jersey

Joseph J. Hochreiter Jr., Jane Kozinski, Pierre J. Lacombe, & Jean C. Lewis

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Sulfide Mineral Distribution of Northern New Jersey Rock Formations and Their Surface and Ground-water Induced Acid Generating Capacity

by

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Abstract

Sulfide minerals are distributed throughout the various Northern New Jersey rock formations in widely varying concentrations and can form acid according to the following reaction:

$$FeS_2 + 7O_2 + 2H_2O = 4H^+ + 2Fe^{2+} + 4SO_4^{-2}$$

Of the various rock formations exposed throughout the New Jersey Highlands, amphibolite occurrences contain the highest average sulfide mineral concentrations (typically 1-3 volume percent). Rock samples collected at several abandoned New Jersey mines are also enriched in sulfide and in combination with oxidizing bacteria are capable of generating pHs as low as 2.9. Laboratory data indicates that the combined acid generating potential of both sulfide and oxidizing bacteria is far more influential than the potential influence of either sulfide or bacteria in isolation of each other. Although the amphibolitic rocks have the highest average sulfide concentrations, the pH of lake waters resting on them is not particularly low. This is probably due to the buffering effect of the carbonates and glacial material present within the watersheds of such lakes. There is little indication that low pH values are directly related to lithology except on a highly localized basis.

Introduction

There is strong evidence that acid rain is a principal cause of acidification of some northern New Jersey lakes. Another contributing factor, however, may be the sulfuric acid generating capacity of sulfide bearing bedrocks. Hydrolysis of sulfide minerals exposed to surface and groundwater will generate acids that may significantly affect environmentally sensitive bodies of water. Pyrite, (FeS_2) for example, is distributed throughout the various rock formations in New Jersey in widely varying concentrations and can form acid by the oxidation of sulfide to sulfate (reaction I), by the oxidation and hydrolysis of iron (reaction II) and by the oxidation of pyrite by ferric iron (reaction III).

$$2FeS_2 + 7O_2 + 2H_2O = 4H^+ + 2Fe^{2+} + 4SO_4^{2-} \qquad (I)$$

$$Fe^{2+} + 5/2H^2O + 1/4O_2 = Fe(OH)_3(s) + 2H^+ \qquad (II)$$

$$14Fe^{3+} + FeS_2 + 8H_2O = 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \qquad (III)$$

Pyrite weathering is known to be the principal cause of acid mine drainage with particularly severe problems at several sulfide mining districts such as Sudbury, Ontario and Ducktown, Tenn. (Cathles, 1982; Kleinman et al.; 1980; Silverman, 1967). The pyrite content of most New Jersey Highland bedrock is less than that of typical active sulfide mining locations but nevertheless seems to be causing similar, although lower level, effects. The principal objectives of this project are threefold:

1. Determination of the average sulfide mineral concentrations of the nine principal rock formations that constitute the bedrock of the northern New Jersey Highlands area.

2. Determination of the sulfide mineralogy of selected highly localized sulfide showings located within the Highlands area.

3. Determination of the buffering or acid generating capacities of the various bedrock formations with particular attention paid to the selected sulfide concentrations.

Buffering Capacity:

Most published references to the buffering capacity of rocks and soils recognize the importance of carbonate mineral constituents. With regard to soils, the total cation exchange capacity (CEC) is a commonly measured parameter (McFee, 1980, Wood, 1979). For example, McFee (1980), rates the sensitivity (CEC) of most of the soil of the New Jersey Highlands areas to acid precipitation as slightly sensitive.

Schmidt and Faust (1984) determined the buffer capacity of seven fresh water lakes in two different lithologies in New Jersey. In doing so, they showed that the ability of a water body to resist change in pH, called the buffer capacity, is one of the critical parameters in determining the sensitivity of fresh water systems to acidification.

In the northeastern U.S., many areas are sensitive to mineral acidity. Acid sensitive watersheds are generally underlain by granitic bedrock and have small pools of readily available basic cations (Driscoll and Newton, 1985). Complete neutralization of acidity can be accomplished by the dissolution or exchange of basic cations within the soil.

The carbonate content and several complex soil properties are clearly important controls on the buffering capacity of the acid rain buffering capacity of the lithosphere. We suggest, however, that the sulfide content of bedrock may be another important acid generating factor.

Sulfides and carbonates are unstable in the presence of acid groundwater, and are typically absent from New Jersey soils. Just as the carbonate in the bedrock below the soils continues to exert an important influence on the pH of water supplies, we suggest that sulfides are also generating significant quantities of sulfuric acid within portions of the New Jersey Highlands area.

Analytical studies to determine the acidity, composition and corrosivity of acid mine water were conducted under the auspices of the Bureau of Mines (Krickovic, 1965; Lorenz, 1962; Mihok and Moebs, 1972). Sources of and variation in acid mine drainage, the effect of pyrite content, rock dusting and chemical neutralization were also investigated.

Recent research has been directed towards several other areas such as improving prediction of acid potential, improving control of acid formation at abandoned mines and waste piles (Perrotti and Snyder, 1981), improving reclamation technique to controlling acid drainage and assessment of groundwater contamination in major mining districts (Geidel and Caruccio, 1982; Good et al., 1970; Welsh and Mitchell, 1975; Kleinman et al, 1982; Olem, et al., 1983).

The role of bacteria:

The kinetics of acid generation are dependent on the availability of oxygen, the surface of pyrite exposed, the activity of sulfur and iron-oxidizing bacteria (genus Thiobacillus), and the chemical characteristics of the influent water (Kleinmann et al, 1983). The role of bacteria in the release of sulfate and iron and in the formation of sulfuric acid from pyrite was first reported in 1919 by Parr and Powell, who determined that coal inoculated with an unsterilized ferrous sulfate solution produce drainage with high concentrations of sulfate than did sterile controls (Lorenz and Stephan, 1969).

Iron pyrite consists of both iron and sulfur in the reduced state. The initial oxidation of pyrite is a process that could be either microbial or non-biological according to equation I. At pH value of above about 4.0, ferrous iron is easily oxidized non-biologically. Abiotic acid production becomes self-limiting once this pH is attained. Below this pH, biological oxidation, mainly carried out by thiobacilli, becomes the major contributing factor to acid production (Alexander, 1977).

Norton et al (1982), classified our area of study in the New Jersey Highlands as having low buffering capacity. Whenever drainage pH of less than 5.0 (with a corresponding interstitial pH of approximately 3.0) are found to occur it is, therefore, probable that the biological mechanisms of pyrite oxidation are of more importance than the non-biological ones.

Acid mine drainage:

Our study includes monitoring of acid drainage through several abandoned mine locations in the northern New Jersey area (Fig. 1). Field data indicate acid generation due to reaction of both surface water and ground water with sulfide mineral concentrations exposed by the mining activity (Table 4b).

Methods and Procedures

The first phase of the research assessed the average sulfide concentration of each of the principal rock formations in the Precambrian Highlands province of northern New Jersey that includes several formations possessing low to negative acid neutralizing capacity. The Precambrian terrain described by Puffer (1980) primarily consists of hornblende granite, quartz-oligoclase gneiss, amphibolite-pyroxenite, marble, and syenite. Statistically representative samples of each of these major rock units were collected and analyzed for sulfide content with reflected light microscopic, x-ray diffraction, and chemical analytical techniques. We focused our rock sampling efforts within the area of the New Jersey Highlands bounded by Rt. 15, Rt. 23, and Rt. 80 (Figure 1) where exposures of unweathered and unaltered bedrock exist.

The second phase of the research focused on local concentrations of sulfide minerals. Sulfide concentrations are associated with several of the iron ore deposits of northern New Jersey (Puffer, 1980). Three such sulfide mineral concentrations were examined. The Sulfur Hill iron mine (Fig. 1a), the Edison iron mine (Fig. 1b), the Cranberry Lake uranium mine (Fig. 1c) and the International Trade Zone Site (Fig. 1t) are sulfide occurrences that are each associated with springs and ponds that we monitored.

The third phase of the research was an assessment of the buffering or acid generating capacities of the various bedrock formations with particular attention paid to selected sulfide concentrations. This involved both laboratory and field studies.

The laboratory studies focused on the development of a model of pH, and sulfate activity as affected by temperatures, biologic activity, and a variety of mineral constituents. We measured the pH, and sulfate ion activity (within a 0 to 30 C° range) of water mixed, digested and equilibrated with: a. pure iron sulfides, b. various bedrock types of northern New Jersey, and c. sulfide oxidizing bacteria (Table 5).

We tested the viability of our laboratory model in the field by examining pH, sulfide, and sulfate levels of ponds, streams, and springs within the New Jersey Highlands particularly where high sulfide levels are known to occur such as abandoned sulfide mine locations. We measured pH, and sulfate ion concentrations of pond, stream and spring water samples at several sites (Fig. 1) on a by-monthly basis from May 1, 1985 to March 20, 1986. Temperature levels and precipitation levels were

Figure 1 Geologic Map of the New Jersey Highlands with lake locations and preliminary sample site locations.

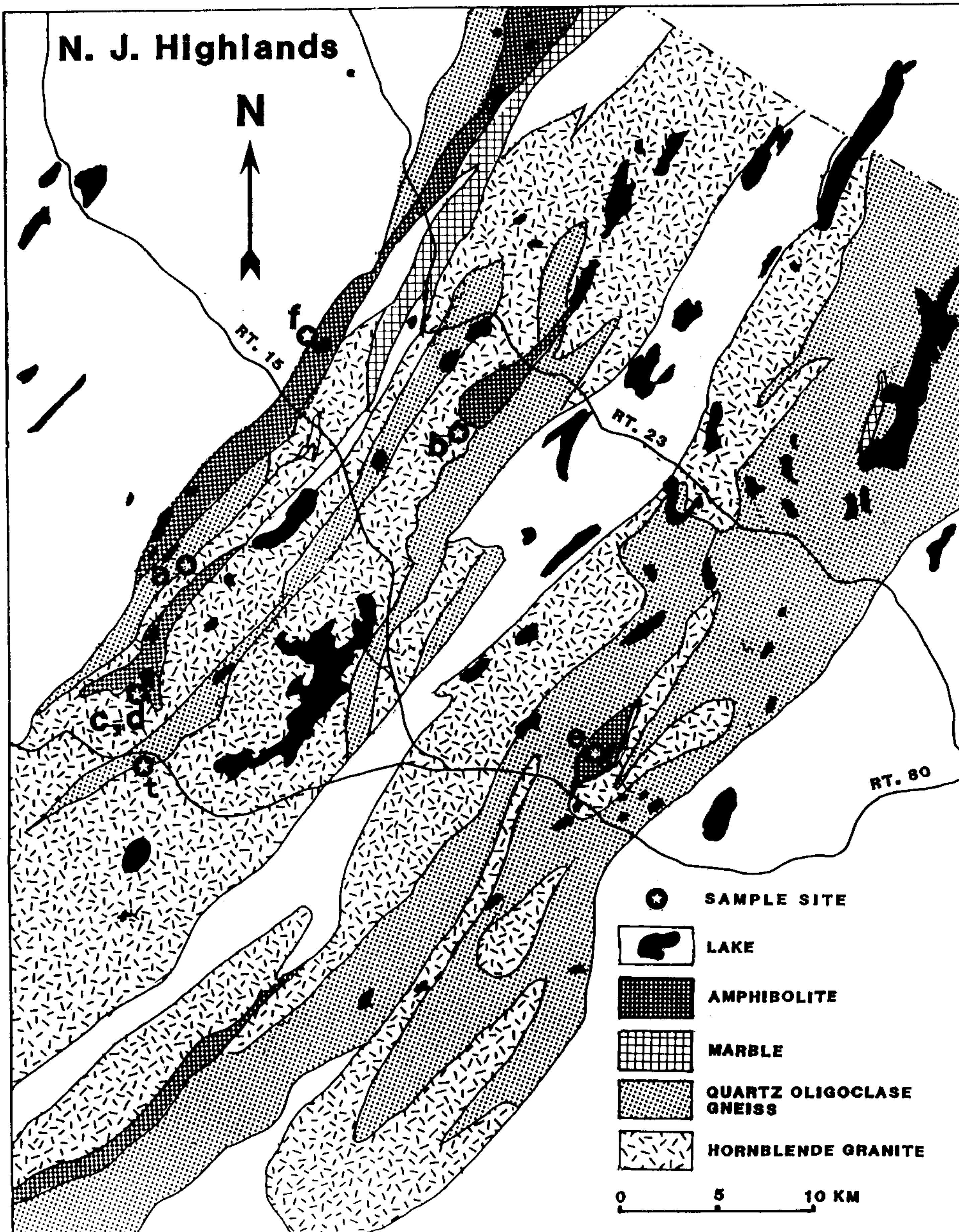
Survey of bedrock sulfide content will be focused on the area founded by Rt. 15, Rt. 23 and Rt. 80.

Preliminary concentrated sulfide site and acid mine drainage site locations are:

a. Sulfur Hill Iron Mine
b. Edison Iron Mine
c. Cranberry Lake Uranium Mine

Preliminary lake locations that rest in sulfide enriched amphibolite are:

d. Cranberry Lake
e. Cedar Lake
f. Lake Grinnell



N. J. Highlands
N
RT. 15
RT. 23
RT. 80
f
b
c
d
t
e
SAMPLE SITE
LAKE
AMPHIBOLITE
MARBLE
QUARTZ OLIGOCLASE GNEISS
HORNBLENDE GRANITE
0
5
10 KM

recorded as they relate to seasonal cycles and variation in biological activity.

Laboratory determination of pH was performed with a Beckman Century SS-1. Field determination were performed with Corning Model 103 Portable pH Meter.

Rock and water sampling procedures followed the recommendation of the EPA Handbook for Sampling and Sample Preservation...(1982). We collected representative grab samples of rocks, stream water, and pond water at several sites within the central New Jersey Highland area (Figure 1). Three kinds of samples were taken:

1. Representative samples of each of the bedrock formations within the portion of the New Jersey area bounded by Rt. 15, Rt. 23, and Rt. 80 (Fig. 1).
2. Samples of sulfide enriched rock at several sulfide concentrations such as (a) Sulfur Hill (Fig. 1a), (b) The Edison Iron Mine (Fig. 1b), (c) the Cranberry Lake Uranium Mine (Fig. 1c), and (d) the International Trade Zone Site (Fig. 1t).
3. Samples of water from small lakes located on bedrock known to contain high sulfide concentrations were taken bi-monthly. Cranberry Lake (Fig. 1d), Lake Grinnell (Fig. 1e), Cedar Lake (Fig. 1f) are each located in sulfide enriched amphibolite and were carefully monitored. The pH, and sulfate ion activity of these lake waters are compared with published values of average New Jersey lake water.

EPA standard analytical methods were used for our rock and water analysis. (Standard Methods, 1974.) The sulphide mineral content of the bedrock samples were analyzed using petrographic, x-ray diffraction and chemical analysis. The chemical analytical technique chosen is a spectrophotometric method following the decomposition of rock samples by acid digestion (Maxwell, 1968). The sulfate analytic method used for the water samples is an EPA recommended spectrophotometric method that measures the absorbance of barium sulfate suspension. The sulfide method we used for our water samples is a methylene blue photometric method. The sulfate and sulfide measurements were conducted at the Rutgers Geochemistry laboratory.

Bedrock Petrology and Sulfide Content of New Jersey Highlands

The major rock units that make up the New Jersey Highlands include: 1. Granite; 2. Hypersthene-Quartz-Oligoclase Gneiss (or Quartz Diorite?); 3. Quartz-Oligoclase Gneiss (or Tonalite); 4. Syenite Gneiss; 5. Amphilbolite; 6. Pyroxene Gneiss; 7. Marble; and 8. Quartzofeldspathic Metasedimentary Rocks. Each of these rock units, except for the Hypersthene-Quartz-Oligoclase Gneiss are exposed along Route 15.

Radiometric data (Long and Kulp, 1962; Tilton and others, 1960; Mose and Helenk, 1976) suggest that the New Jersey Highlands underwent metamorphic recrystallization during the Grenville about 1100 Ma and was then invaded by Granites about 840 Ma. The metamorphic setting invaded by the granites was very deep seated and was within the hornblende granulite facies (Drake, 1969; Smith, 1969; and Young, 1971) or at least within the sillimanite-almandine-orthoclase subfacies of the amphibolite facies (Baker and Buddington, 1970) of Turner and Verhoogen (1960).

1. Granites

Granites are the most abundant rock type in the New Jersey Highlands. Buddington (1959) uses the granites of the Highlands as an example of his "catazonal" level of granite emplacement. He also describes the granites as phacoliths, the most striking feature being the lack of large scale discordant features between the granites and the metamorphic rocks that contain them. The two major granite types exposed in the Highlands are Hornblende Granite and Pyroxene Granite.

a. Hornblende Granite and Alaskite.

Drake (1984) has reintroduced the name "Byram Intrusive Suite" to apply to the hornblende granite and alaskite. The granite is pinkish buff to greenish buff with a distinct gneissoid structure. It contains numerous xenoliths and large amphibolite schlieren and numerous pegmatites. The average composition of the granite is 46.5 percent microperthite and microcline, 26.9 percent quartz, 8.9 percent hornblends, 16.3 percent plagioclase with accessory and trace magnetite, ilmenite, apatite, zircon, sphene, biotite, fluorite and pyrite (Puffer, 1980). The hornblende, biotite, magnetite and pyrite contents are highly variable. The granite is mapped as an alaskite by Baker and Buddington (1970) and Sims (1958) where the mafic mineral content is less than five volume percent. The alaskite facies is closely associated with most of the magnetite ore deposits found in the New Jersey Highlands. The magnetite iron ore deposits of the New Jersey Highlands are typically enriched in sulfides, particularly pyrite and pyrrhotite.

The sulfide content of the Hornblende Granite ranges from 0.01 to 1.45 volume percent averaging 0.18 percent (Table 1). At least 90 percent of the sulfide content consists of pyrite the remainder consisting of pyrrhotite, and chalcopyrite.

b. Pyroxene Granite and Pyroxene Syenite.

Pyroxene bearing granite is less common than hornblende granite. The Pyroxene Granite is light to dark green and displays a gneissoid structure that Baker and Buddington (1970) interpret as resulting from magmatic flowage. The granite contains numerous amphibolite schlierien and magnetite bearing pegmatites. The average composition of the granite is 61.6 percent perthite, 21.1 percent quartz, 8.4 percent plagioclase and antiperthite, 5.6 percent pyroxene, 0.6 percent hornblende with accessory opaque oxides, sulfides, apatite, zircon, and sphene (Puffer, 1980).

Table 1

Sulfide Mineral Concentrations in New Jersey Bedrocks

Rock type	Number of Samples	Range (Vol. %)	Mean	Median
Hornblende Granite	8	0.01 to 1.45	0.18	0.10
Pyroxene Granite	7	0.01 to 1.25	0.15	0.09
Hyper.-Otz.-Olig. Gneiss	3	0.08 to 0.53	0.24	0.14
Quartz-Oligoclase Gneiss	18	0.00 to 45.	3.42	0.07
Syenite Gneiss	4	0.01 to 1.50	0.38	0.03
Amphibolite	23	0.31 to 5.2	2.13	1.13
Marble	15	0.00 to 3.8	0.41	0.02
Biotite-Qtz.-Feld. Gneiss*	11	0.00 to 1.15		
Potassic Feldspar Gneiss	6	0.02 to 5.50	1.32	0.29

The pyroxene is typically intergrown with opaque oxides and hornblende. Both clino- and orthopyroxenes occur in the granite but clino-pyroxene predominates. The ortho-pyroxene component has been identified as ferrohedenbergite by Baker and Buddington (1970) and as hypersthene by Rhett (1977). The clino-pyroxene component is probably calcic augite (Rhett, 1977). Rhett has observed that the clino-pyroxene typically displays varying degrees of replacement by hornblende.

The sulfide content of the pyroxene granite ranges from 0.01 to 1.25 volume percent averaging 0.15 percent (Table 1).

2. Hypersthene-Quartz-Oligoclase Gneiss

About one-half of what is referred to as the Losee Gneiss on the Geologic Map of New Jersey (Lewis and Kummel, 1912) is mapped by Smith (1969) as a Hypersthene-Quartz-Andesine Gneiss; by Baker and Buddington (1970) and Dodd (1962) as a Hypersthene-Quartz-Oligoclase Gneiss; and by Sims (1958) and Drake (1969) as a Quartz Diorite. Minor portions of the "Byram Gneiss" are also remapped as Hypersthene-Quartz-Andesine Gneiss (Smith, 1969). The rock is foliated and is characterized by alternating light buff or light green and dark greenish gray or brownish gray bands. It contains numerous amphibolite schlieren and pegmatites. The average mineral composition is 63.8 percent plagioclase, 17.8 percent quartz, 8.2 percent orthopyroxene, 1.5 percent clinopyroxene, 1.9 percent biotite, 1.7 percent hornblende, 1.2 percent potassium feldspar, with accessory opaque oxides, zircon, apatite, sulfide, and graphite. The dark layers contain more mafic minerals than the light layers. The clinopyroxene is a diopside (Smith, 1969) that is intergrown with hypersthene, and hornblende as mafic clusters. The plagioclase component is typically an antiperthitic andesine that ranges from An_{33} to An_{50}, Or $_{2.4}$ to Or $_{6.9}$ (Vogel and others, 1968).

The sulfide content of the Hypersthene-Quartz-Oligoclase Gneiss ranges from 0.08 to 0.53 volume percent averaging 0.24 percent (Table 1b) and consists primarily of pyrite.

3. Quartz Oligoclase Gneiss

Drake (1984) has reintroduced the name Losee Metamorphic Suite to refer to the quartz-oligoclase gneisses of the New Jersey Highland.

Quartz-Oligoclase Gneiss is widely distributed throughout both the northern and southern blocks of the New Jersey Highlands. On Smith's (1969) map of the Highlands, Quartz-Oligoclase Gneiss constitutes roughly one half of what is referred to as the Losee Gneiss on the Geologic Map of New Jersey (Lewis and Kummel, 1912). It is exposed along Route 15 near the type locality of the Losee Gneiss (Losee Pond renamed Beaver Lake). The Quartz-Oligoclase Gneiss appears white to light green, is medium grained and foliated. It contains numerous pegmatites some of which are conformable to the foliation of the gneiss and some of which are discordant. The mineral component of the Quartz-Oligoclase Geniss averages 62.7 percent plagioclase, 29.7 percent quartz and 2.1 percent biotite with accessory garnet, hornblende, pyroxene, chlorite, epidote, orthoclase, apatite, zircon sillimanite, opaque oxides and sulfides (Puffer, 1980). A large portion of the Losee Suite has melted to form a plagoclase rich igneous rock or tonalite.

The sulfide content of the Quartz-Oligoclase Gneiss ranges from absent to 45 volume percent averaging 3.42 percent (Table 1c) but the mean value of 18 samples measures only 0.07 percent. Although most samples contain less than 0.1 percent sulfide material a few exposures are highly enriched. The highest values were found in shear zones where the sulfides appear to have precipitated as secondary minerals along fracture surfaces and shear planes. The sulfide mineralization consists principally of pyrite with minor chalcopyrite. The highest sulfide values were found at the International Trade Zone site (Fig. 1) but several enriched zones were also found associated with magnetite concentrations and pegmatites.

4. Syenite Gneiss

A large mass of Syenite Gneiss envolopes the Quartz-Oligoclase Gneiss of the northern block of the New Jersey Highlands and is exposed along Route 15 about one mile south of Sparta (Fig. 1). The Syenite Gneiss is described as an orthogneiss by Baker and Buddington (1970) and is not to be confused with the igneous pyroxene syenite that is associated with the pyroxene granite. The Gneiss is green medium grained, and granoblastic. It is associated with numerous concordant pegmatites. The mineral composition averages 47.8 percent microcline perthite, 39.0 percent oligoclase, 2.5 percent quartz, 4.3 percent hornblende, 3.8 percent clinopyroxene and accessory opaque oxides and sulfides, zircon, sphene, epidote,chlorite and apatite (Puffer, 1980). The hornblende is a ferrohastingstie (Hinds, 1921) but is typically partially altered to chlorite. The pyroxene is ferroaugite (Baker and Buddington, 1970). Drake (1984) suggests that the syenite is probably anatectic and perhaps melted at a level deeper than the Byram Suite.

The sulfide content of the Syenite Gneiss ranges from 0.01 to 1.50 volume percent averaging 0.38 percent (Table 1). The sulfides consist primarily of pyrite with minor chalcopyrite.

5. Amphibolite

Amphibolite is very ubiquitous throughout the Highlands, occurring in small amounts as layers or schlieren in each of the metamorphic and igneous rock units, and less commonly veined with pegmatites or granitic rock and locally contain some magnetite iron ore. The mineral composition averages 27.9 percent hornblende, 49 percent plagioclase, 12.1 percent clinopyroxene, 4.4 percent orthopyroxene, 1.6 percent biotite, with accessory epidote, apatite, sphene, garnet, calcite, scapolite, quartz and sulfides (Puffer, 1980). The plagioclase component is typically andesine but ranges from An_{86} to An_{16} (Maxey, 1971).

The sulfide content of the Amphibolite ranges from 0.31 to 5.2 volume percent averaging 2.13 with a median of 1.13 percent (Table 1). The median value is clearly higher than any of the other New Jersey Highlands rock types. Sulfides are consistently a significant component of each exposure of amphibolite that we examined and in a few cases makes up more than four volume percent of the rock. Enriched sulfide values seem to correlate with high oxide concentrations and with the occurrence of pegmatites. The principle sulfides include both pyrite and pyrrhotite with minor chalcopyrite.

6. Marble

The Franklin Marble is concentrated near the northern edge of the northern structural block of the New Jersey Highlands although thin layers of marble also occur in the southern block. The rock is white, very coarse to locally fine-grained, slightly impure marble, and contains numerous irregular shaped blocks, lenses, boudins, and layers of amphibolite and a variety of gneisses, and is intruded by numerous pegmatites. It is composed of dolomite or calcite with accessory graphite, phlogopite, clinopyroxene, and tremolite. The dolomite marble is by far the more abundant variety. At the Franklin and Sterling Hill zinc mining district the marble contains considerable franklinite, willemite, and zincite in addition to over 230 accessory and trace minerals (Frondel and Baum, 1974). Outside of the mine area the zinc minerals are very rare to absent. Some of the marble has been almost completely altered to serpentine and (or) talc and (or) tremolite perhaps throughout some kind of metasomatic process.

Sulfides were absent from samples collected at most Marble exposures that we examined but occur in some samples in trace amounts. Lenses and veins of sulfide enriched material are not rare at Marble exposures and are associated with magnetite concentrations such as the Sulfur Hill Iron Mine (Figure 1) and with pegmatites. The sulfide content ranges from absent to 3.8 volume percent averaging 0.41 percent but the median value is only 0.02 percent (Table 1). Pyrite is the principle sulfide but pyrrhotite, chalcopyrite, spalerite, and galena occur at a few exposures.

Calcareous rocks of probably related metasedimentary affinity include minor exposures of pyroxene gneiss, epidote-scapolite-quartz gneiss, quartz-epidote gneiss and skarn typically occurring near or within exposures of marble.

7. Quartzofeldspathic Metasedimentary Rocks

Of the several varieties of quartzofeldspathic rocks exposed throughout the highlands the two dominant varieties are (a) biotite-quartz-feldspar gneiss and (b) potassic feldspar gneiss.

Biotite-quartz-feldspar gneiss typically contains more plagioclase than K-spar but contains highly variable concentrations of biotite in layers or bands that grade into a biotite schist. Graphite is commonly found in the gneiss in concentrations high enough to justify the term "graphitic gneiss" as used by Buckwalter (1962). Highly variable concentrations of garnet and magnetite are also characteristics with minor sillimanite, pyrite, rutile, zircon, epidote, chlorite, and apatite. The pyrite content ranges from trace amounts up to 1.1 percent averaging about 0.3 percent in the eleven samples listed by Drake (1984).

Drake (1984) suggests that the biotite-quartz-feldspar gneiss is a metamorphosed potassium rich graywacke.

Localized Sulfide Concentration

Localized sulfide concentrations are found in various lithologies in the N.J. Highland which tends to suggest that factor(s) other than lithology could be the controlling parameter. Scattered grains of disseminated sphalerite, charcopyrite, pyrite and galena were noted in the mineralized skarn of the Sulfur Hill Mine (Table 2). Pyrrhotite is the most abundant sulfide in the Sulfur Hill deposit (Sims & Leonard, 1952). It replaces both magnetite and pyrite. The sphalerite is marmalite and it contains scattered blebs of exsolved charcopyrite and replaces pyrite, pyrrhotite and magnetite. Pyrite is the common sulfide form in the Biotite Quartz-Oligoclase gneiss at the International Trade Zone Site. The percent concentration pyrite ranged from 1-50% based on field observation. This location has the highest known local concentration of sulfide in New Jersey. The sulfide present in the Edison Iron Mine sample are found to be in association with the magnetite. The sulfide associated with Cranberry Lake Uranium mine range from a trace to about 3% in some places.

Laboratory pH Model

Samples of the six major rock type of the New Jersey Highland were grounded and mixed with pure pyrite at varying proportions and then digested in distilled water. Six samples were prepared for each bedrock type. Five out of each sample set were innoculated with 4 ml of *T. ferroxiation*. pH readings were taken after seven days (Table 3a). Generally the pH value decreased with increase in the amount of pure pyrite added to the sample. There is a significant drop in pH of samples innoculated with sulfur oxidizing bacteria *T. ferroxiation* as opposed to the sterile ones. Pure pyrite digested in distilled water read 3.7 in contrast to a pH reading of 3.0 in a sample of pure pyrite innoculated with *T. ferroxiation*. Another set of samples innoculated with iron

TABLE 2

LOCALIZED SULFIDE CONCENTRATION OF N.J. HIGHLANDS

(Percent Sulfide Content)

	International Trade Zone Site					Sulfur Hill Mine					Edison Hill Mine					Cranberry Lake Uranium Mine (Charlotte Mine)				
	1	2	3	av.%	*Range%	1	2	3	av.%	*Range%	1	2	3	av.%	*Range%	1	2	3	av.%	*Range%
Pyrite	5	6	9	6.66	1-50	4	3	6	4.3	1-10	2	3	5	3.3	1-8	2	4	3	3.0	1-15
Pyrrhotite	.05	.04	.01	.03	0-.05	6	4	8	6.0	1-20	1	1	1.5	1.16	1-1.8	0	0	1	.33	0-1
Chalcopyrite	.01	.05	.04	.03	0-.05	6	8	7	7.0	1-15	2	4	5	3.6	1-4	1	3	2	2.0	1-10
Magnetite	0	0	0	0	0	1	3	4	2.6	1-5	4	6	8	6.0	1-30	0	0	1	.33	0-1
Sphalerite	0	0	0	0	0	2	3	5	3.3	1-5	0	1	2	1.0	1-1.5	0	0	0	0	0

* Based on field observations

Table 3a

	S	S+B	S+1/4P+B	S+1/2P+B	S+3/4P+B	S+P+B
Hornblend Granite	7.9	4.55	3.7	2.9	2.8	3.50
Pyroxene Granite	8.3	5.8	5.0	5.0	5.1	4.7
Amphibolite	8.5	4.9	4.1	3.55	3.5	3.6
Syenite	8.1	3.2	3.15	2.95	2.90	3.1
Franklin Marble	8.7	7.2	5.5	5.5	5.7	5.5
Lossee Gneiss	8.1	4.1	3.2	3.2	3.0	3.5

S = Sample (8 gm)

S+B = Sample + Bacteria

S+1/2P+B = Sample + 1/2 pyrite (4 gm) + Bacteria

oxidizing bacterial, S. natans, showed relatively high pH reading as compared to those innoculated with T. ferroxidian (Table 3b). Thiobacillan ferroxidians therefore, is the bacteria principally involved in the oxidation of pyrite in acid formation.

Table 3b

	S+1/2P+FeB	S+1/2P+SB	S+1/2P
Hornblende granite	5.6	2.9	5.2
Pyroxene granite	7.0	5.3	5.8
Amphibolite	6.5	3.55	5.2
Syenite	4.8	2.90	4.5
Franklin Marble	7.3	5.55	7.4
Lossee gneiss	6.0	3.20	4.9

S+1/2P+FeB = Sample (8 gm) + Pyrite (4 gm) + Iron oxidizing, bacterial. S. Natans.

S+1/2P+SB = Sample (8 gm) + Pyrite (4 gm) + Sulfur oxidizing bacterial. T. ferroxidian.

Our laboratory data indicates that the combined acid generating potential of both sulfide and bacteria addition is far more influential that the potential influence of either sulfide or bacteria in isolation of each other. It may be anticipated, therefore, that wherever natural sulfides in bedrock are exposed to an environment condusive to the growth of sulfide oxidizing bacteria, pH's as low as 3 (Table 3) may be generated. The pH reading for the marble mixed with pyrite and inoculated with T. ferroxidian is relatively low, although higher than those of other rock types (Table 3a). A control experiment with the same proportion of sample to pyrite but without bacteria had a pH of 7.4 (Table 3B). This pH value is similar to the pH readings at the Sulfur Hill Iron Mine (Table 5) where sulfides are found in calcareous pyroxene-garnet skarn with variable amounts of marble.

Acid Generating Capacity of Bedrock

Crystalline terrains have been known to possess low to negative buffering or neutralizing capacity to acidification of surface and groundwater. The data presented in Table 4a were the results of digested bedrock leachate of typical Highland bedrocks (Table 4a) and the digested bedrock leachate of selected localized sulfide concentrations (Table 4b). The pH measurement for the latter except for the Sulfur Hill Mine sample is quite acidic, as low as 3.30. The sulfate measurement for the International Trade Zone site sample reads a little over 200 mg/l as opposed to non-measurable sulfate reading for the typical Lossee gneiss of the New Jersey Highland, even though they are both of the same lithology (Biotite-quartz-oligoclase gneiss). The differences in the alkalinity reading are quite noticeable. At the Sulfur Hill Mine disseminated sulfides are found in calcareous pyroxene-garnet skarn with variable amounts of marble. This carbonate content is responsible for the high pH value measured for the Sulfur Hill sample despite its high sulfide content.

Acid Generating Capacities of Highland Bedrocks

TABLE 4a

*sulfate, and alkalinity

pH of digested bedrock leachate

	Pyroxene (granite)	a & b Granite	Amphibolite	Lossee gneiss	Franklin Marble	Pyroxene Syenite
pH	7.7	7.4	7.25	7.5	8.1	7.4
sulfate (mg/1)	0	5	0	0	0	0
alkalinity (mg/1)	54.4	47.6	54.4	40.8	115.6	47.6

Table 4b

ph, Sulfate and Alkalinity of selected localized sulfide concentration (digested bedrock leachate)

	Andover/Sulfur Hill Mine	Edison Iron Mine	International Trade Zone Site
pH	7.6	4.6	3.30
Sulfate	45 mg/1	24 mg/1	200 mg/1
Alkalinity	92.2 mgl/	6.8 mg/1	0

Although the New Jersey Highland lakes and streams are generally more sensitive to acidification than midwestern water bodies, they display a remarkable degree of variability in physical and chemical characteristics such as area, depth, productivity, elevation and watershed acid neutralizing capacity, Each of these factors helps to determine the sensitivity of a water body to acidification. Cedar Lake, Lake Grinnelle, and Cranberry Lake were each chosen for examination because they are sited on amphibolite bedrock which we have found to be enriched in sulfides. If sulfides in bedrock are capable of influencing the pH of water systems as suggested by Table 3 & 5 it might be anticipated that pH values less than typical of New Jersey would be expected at these lakes. The diversity of the bedrock geology of the various drainage basins, however, makes it very difficult to isolate the effect of the bedrock underlying the various lakes. Lake Grinnelle and Cedar Lake (Table 5), for example, are located within the Wallkill River watershed. The drainage area for the Wallkill River watershed is about 140 square miles. It has its leadwater in the precambrian crystalline rocks, then flows in valleys underlain by Precambrian Franklin (marble) Formation, the Kittatiny formation and glacial deposits, and also drains a large area of underlain by Martinburg Formation (Miller, Jr. 1974). The exposure to carbonates presumably account for the relatively neutral to alkaline pH readings for these lakes. Cranberry lake, however, with a surface area of only 296.00 acres within the Musconetcong drainage area receives water from a much more restricted watershed. There is high variation in the pH value (Table 5) but during periods of low precipitation (August-September 1985) there seems to be a distinctly low pH development that may be related to bedrock sulfide effects. The sulfides associated with a uranium mine located just

Table 5

pH of selected New Jersey Lake and Mine Drainage (1985-1986)

Location	May		June		July		August		Sept.		Oct.		Nov.		Dec.	Feb.		Mar.	
Cedar Lake	5.10	5.80	6.2	6.75	8.41	7.11	7.13	6.8	7.06	6.98	6.9	6.2	6.8	6.9	6.7	6.8	6.9	6.6	6.8
Cranberry Lake	8.19	7.95	7.29	7.31	7.84	7.2	7.1	6.67	6.4	6.4	6.5	6.3	6.4	6.6	6.5	6.5	6.4	6.7	6.5
Lake Grinnelle	5.05	6.9	8.66	8.70	9.05	8.71	7.8	8.2	8.4	7.8	7.5	7.6	7.8	7.7	7.6	7.8	7.7	7.5	7.2
Edison Iron Mine Pond	5.5	5.9	6.25	6.8	5.6	5.8	6.3	5.9	5.1	5.6	5.7	5.6	5.5	5.4	5.8	5.2	5.1	5.6	5.4
Cranberry Lake Uranium Mine (Charlotte Mine)	6.81	7.07	7.09	6.90	6.23	6.18	6.4	6.24	6.4	6.6	6.24	6.4	6.6	6.34	6.7	6.4	6.3	6.9	7.1
Sulfur Hill Iron Mine	7.9	7.8	7.6	7.4	7.9	7.6	7.2	7.6	6.95	7.6	6.95	6.8	7.3	7.6	7.8	7.1	7.2	7.2	7.4

*Sampling took place every 5th and 20th of each month south of the lake may be significant contributors and further work is planned to quantify this possibility.

Conclusions

1. Most of the sulfides contained within the bedrocks of the New Jersey Highlands occur as disseminated pyrite and to lesser degree as pyrrhotite.

2. Of the various bed-rocks, the highest concentration of sulfide are contained within the amphibolite. Local concentration, however are contained with the Byram Pyroxene granite, the Byram hornblende granite, the Lossee Gneiss. Relatively minor concentration are found in the Franklin Marble and Syenites.

3. There is a close association of pyrite with most of the several iron mines in the New Jersey Highlands area. There is also distinct association of pyrite and pegmatite occurrences.

4. The combined acid generating potential of both pyrite and sulfur oxidizing bacteria, T ferroxidian is far more influential than the potential influence of either pyrite or bacteria in isolation of each other.

5. Although the amphibolitic rock contain the highest average sulfide concentration, the pH of lake waters resting on them are not particularly low. This is probably due to the buffering effect of carbonate and glacial material exposed within the watershed of most such lakes.

6. There is a strong evidence that sulfide mineral concentrations, particularly those at several abandoned New Jersey mines, are measurably affecting the pH of streams and mine drainage associated with them.

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PART 2:

Paleontologic and Other Investigations

Depositional Environment of a Cenomanian (Upper Cretaceous) Flora from the Raritan Formation of New Jersey.

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Excavations in the Raritan Formation (Cenomanian, Upper Cretaceous) at the Linden Sand Pit in Sayresville, New Jersey have revealed fluvial deposits including levee, channel, and oxbow lake facies. The best exposure reveals a north dipping set of non-rooted, flaser-bedded alternating sands and clays probably representing cyclic subaqueous deposition on a tidally influenced levee. These beds are truncated by a south-dipping fine-medium grained, light gray channel sand that contains large clay clasts derived from the eroded levee. The channel sand is overlain by a thin oxidized yellow-brown clayey silt unit that contains numerous well-preserved fossil leaves. The flora consists of ferns such as "Asplenium" Foersteri, conifers including "Sequoia" heterophylla and Elatides sp., and a variety of early angiosperms including the Platanaceous Protophyllum sp. and entire-margined, elongate forms that have been previously misidentified as Eucalyptus. The flora-bearing silt unit is immediately overlain by a well-bedded dark gray silty clay (clay plug) that thickens to the south and apparently contains no fossils. The beds dip to the south (11 degrees) at the thin northern margin of the unit but are essentially flat-lying as the unit thickens towards the channel's center. The plant-bearing beds appear to represent a transition from free-flowing channel conditions to a sluggish flow typical of a meander cut-off oxbow lake. Plant material was washed into the partially cut-off transitional unit during flooding episodes. The absence of fossils in the clay plug, presence of flaser bedding and lack of rooting in the levee sediments, and the presence of a marine molluscan fauna slightly higher in the section indicates that the fossil plants were probably allochthonous and were deposited in a coastal margin channel system that was not well vegetated.

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