INTRODUCTION

Bedrock in the Dover quadrangle consists mainly of Precambrian metamorphic and igneous rocks of the New Jersey Highlands (fig. 1). The quadrangle also includes part of the Green Pond Outlier, a downfaulted synclinal belt of Paleozoic sedimentary rocks extending southwesterly from Green Pond to Kenvil (fig. 1). The Precambrian rocks include interlayered hornblende granite, alaskite, quartz-feldspar gneiss, biotite gneiss, pyroxene syenite, quartz diorite, and minor amphibolite and granite pegmatite (Sims, 1958; Young, 1971). These rocks have a strong northeast-southwest foliation and strike, and are folded into plunging isoclines that are overturned in places (Sims, 1958; Young, 1971). The strike of the bedrock is expressed by northeastsouthwest trending uplands and ridges. Irregular upland topography occurs on thick units or where the strike of the units varies around fold noses.

The Paleozoic sedimentary rocks include quartzite, conglomerate, purple to red shale, dolomite, and gray siltstone of Cambrian to Silurian age, and gray siltstone, shale, and sandstone of Devonian age (Barnett, 1976). The units are tightly folded, steeply dipping and strike subparallel to the bordering Precambrian units. The quartzite and conglomerate units underlie the long, prominent ridges of Green Pond and Copperas Mountains. Berkshire Valley (the local name of the valley of the Rockaway north of Interstate Route 80), the valley at Kenvil, and the valley of Green Pond Brook in Picatinny Arsenal are underlain by shale and dolomite. Pre-glacial drainage was inferred from bedrock elevation contours based on approximately 400 well records selected from files of the New Jersey Department of Environmental Protection, Division of Water Resources; from records of wells in Picatinny Arsenal (Harte and others, 1986); and from several dozen seismic traverses (Canace and others, 1983; Stanford and Canace, unpub.). The pre-glacial drainage generally followed the present drainage lines. Major exceptions, first suspected by Cook (1880), are the pre-glacial valleys beneath Kenvil and Duck Pond. These drained northward to join the pre-glacial Rockaway near Lake June tion. From Lake Junction the combined drainage trended eastward across the strike of the Precambrian rocks. During the late Wisconsinan glaciation the valley at Kenvil was filled with as much as 300 feet of sediment deposited in glacial Lake Succasunna. These deposits blocked northward drainage. Surface drainage in this valley now is to the south down the Lamington River. At Dover the pre-glacial Rockaway valley was filled during the late Wisconsinan by till of the Terminal Moraine and by sand, gravel, and silt deposited in

weathered bedrock exhumed by glacial and post-glacial In places, excavation by glacial ice carved basins in the bottoms of pre-glacial valleys. The most prominent example is in Picatinny Arsenal, where a basin at least 50 feet deep was excavated in weathered dolomite flooring the valley of Green Pond Brook. Basins were also excavated in easily-eroded shale in Berkshire Valley near Woodstock. Shallow basins also occur at the surface on uplands, especially on Precambrian bedrock. Many of these surface basins are now occupied by swamps.

glacial Lake Dover. The post-glacial route of the Rock-

away is slightly south of the pre-glacial valley, and the

channel is now incised 10 to 20 feet into a spur of

GLACIAL HISTORY

the Dover quadrangle. The younger deposits are of late Wisconsinan age. The southernmost extent of this glaciation is marked by the Terminal Moraine, which extends across the southern part of the quadrangle from Rockaway Borough to Duck Pond. These deposits were first described in some detail by Cook (1880) and were mapped in more detail by Salisbury (1902) and Bayley and others (1914). The older deposits are from a pre-late Wisconsinan

Deposits of at least two glaciations are preserved in

placiation. They occur south of, and in places beneath the Terminal Moraine (as on sections BB' and DD'). The pre-late Wisconsinan deposits were first described by Salisbury (1892), who considered them to be post-Kansan and, in places, Wisconsinan, in age, in contrast to the more deeply-weathered Kansan-age glacial deposits further south in the state (Salisbury, 1902), Bayley and others (1914) designated the older glacial deposits "Jerseyan" but did not correlate them to the established stratigraphy in the Midwest. Leverett (1934) and Mac Clintock (1940) considered the less-weathered deposits, including those in the Dover quadrangle, to be of IIlinoian age. Ridge (1983) similarly postulated an Illinoiar age for glacial deposits south of the Terminal Moraine in the Great Valley to the west of the Dover quadrangle (fig 1). Further west, Sevon and others (1975) describe both Illinoian and early Wisconsinan deposits south of the late Wisconsinan border in northeastern Pennsylvania.

Pre-Late Wisconsinan Deposits

In the Dover quadrangle no exposures of undisturbed pre-late Wisconsinan deposits were observed. South of the limit of late Wisconsinan glaciation, a thin veneer of pre-late Wisconsinan till occurs at the surface in only one small area west of Lake Estling in Denville Township. Elsewhere, till that formerly mantled bedrock hills has moved downslope and mixed with the underlying weathered bedrock to accumulate in aprons of colluvium along slopes. Exposures show that the colluvium consists of an orange-brown silty sand to sandy silt containing many angular pebbles and cobbles derived from local weathered bedrock, and scattered erratic pebbles and cobbles. Crystalline erratics generally show some weathering of feldspar minerals; sandstone and quartzite erratics are unweathered. In contrast, erratics in late Wisconsinan till are unweathered and the matrix is more yellow. However, in the absence of an undisturbed weathered profile, no definitive age can be assigned to the pre-late Wisconsinan deposits Pre-late Wisconsinan stratified sediment is exposed at the surface at two locations. In Kenvil, pebbly sand

forms a low ridge about 20 feet higher than the late Wisconsinan outwash surface. This deposit may be a remnant of a delta deposited in a pre-late Wisconsinan proglacial lake similar to the late Wisconsinan-age Lake Succasunna. Another delta remnant occurs at Victory Gardens, where a gravel pit formerly exposed cobble gravel overlying sand (Meredith Johnson, written communication, 1935). Salisbury (1902) considered this deposit to be of the same age as the Terminal Moraine. but exposures in remnants of the former pit show crys talline clasts weathered similarly to the crystalline erratics derived from pre-late Wisconsinan till observed in the colluvium described above. The top of this delta is outlet for the late Wisconsinan-age Lake Dover, indicating that it was deposited in a higher lake occupying the north-draining valley of Mill Brook. Pre-late Wisconsinan sediment also occurs in the subsurface beneath late Wisconsinan sediment at and south of the Terminal Moraine. Records of wells in the

Spillway of glacial lake Route of meltwater Recessional ice margin Limit of late Wisconsin

> Maximum extent of glacial lake

Terminal Moraine

Pebble lithologies

Post-glacial alluvium, swamp and marsh sediment, and talus overlie older deposits in places. They are generally thin and of small extent.

GEOLOGIC SETTING

Late Wisconsinan Ice Flow

ment has been observed either at the surface or in the

subsurface north of the Terminal Moraine within the

Ice-flow directions indicated by striations, streamlined landforms, erratic boulders, pebble lithologies, and scouring and plucking of bedrock outcrops and hills indicate that during the late Wisconsinan ice advanced in a direction slightly east of south across the Dover quadrangle, oblique to the regional northeast-southwest structural and topographic strike.

Ice margin orientations during deglaciation, inferred from the trends of ice-contact heads of outwash units, ice-marginal till ridges, valley-bottom striations, and the positions of glacial-lake spillways and meltwater routes, were roughly east-west in the area northwest of Berkshire Valley and northwest-southeast in and southeast of Berkshire Valley (fig. 2). These relationships suggest that the uniform southerly flow during advance was succeeded by flow from two directions during deglaciation. In the northwest part of the quadrangle flow was southerly to southeasterly, out of the Great Valley lowland and across the Highlands. In the central and southeast portions of the quadrangle, flow was southwesterly, parallel to the topographic strike of the Highlands. The change in flow pattern most likely was due to thinning of ice during deglaciation and the resulting enhancement of topographic control of ice flow, similar to that described by Cotter and others (1986) for areas further west in New Jersey.

The distribution of till, erosional form of bedrock ridges and hills, and pebble lithology in till, all indicate that most till deposition and bedrock erosion occurred before thinning of the ice. Throughout the quadrangle, till is generally thicker and more continuous on the northwest-facing slopes of ridges. Where the bedrock surface is exposed on these slopes, it is generally smoothed. Southeast-facing slopes are generally steeper, till is thin and discontinuous, and bedrock crops out on these slopes in joint-controlled cliffs. These landforms suggest abrasion of bedrock and lodging of till on northwest-facing slopes and plucking of bedrock on southeast-facing slopes during flow of ice to the south and southeast. Pebble lithologies in till were determined at 30 sites

throughout the quadrangle (table 2 and fig. 2). Precambrian lithologies dominate, ranging from 32 to 97 percent of the total and averaging approximately 75 percent. Paleozoic content ranges from 3 to 68 percent. The Paleozoic lithologies include purple to red Silurian quartzite and conglomerate; gray to brown sandstone, siltstone, and shale of Devonian age; and minor dolomite and red shale. There is a sharp increase in Paleozoic content from an average of less than 10 percent northwest of the Green Pond Outlier to an average of 30 percent southeast of the outlier. Especially prominent is the increase in the percentage of quartzite and conglomerate pebbles from the Shawangunk Formation, which outcrops along Green Pond Mountain. This rock type is nearly absent in till west of Green Pond Mountain, but constitutes as much as 60 percent of the pebbles in till immediately to the southeast. This distribution and composition indicate that Paleozoic lithologies come chiefly from the Green Pond Outlier and to a lesser extent, from the Great Valley, and indicates ero-

sion of bedrock and deposition of till during southeasterly ice flow. Pebble lithologies in outwash and lacustrine gravels were determined at 21 sites (table 2 and fig. 2), and generally indicate local bedrock as the principal source of sediment. In Berkshire Valley, which is underlain by Devonian shale, siltstone, and dolomite, lacustrine and outwash gravels consist of from 20 to 80 percent, and average approximately 50 percent, shale, siltstone, and dolomite pebbles. Although this narrow valley is bounded on the west by Precambrian rocks and on the east by quartzite and conglomerate of the Shawangunk Formation, the Precambrian content of the gravel only locally exceeds 50 percent and the Shawangunk content nowhere exceeds 7 percent. These observations suggest that most sediment was delivered to the ice front by subglacial drainage carrying rock eroded from the valley bottom, rather than by meltwater bringing in sediment

Maximum Ice Advance and the Terminal Moraine

from neighboring uplands or from the glacier itself.

As late Wisconsinan ice advanced, the pre-glacial Rockaway valley was dammed near Denville (fig. 1) by a lobe of ice occupying the Newark Basin to the east. Glacial Lake Denville filled the blocked valley and drained southward across a bedrock gap at an elevation of approximately 525 feet near Tabor in the Morristown quadrangle (fig. 1), four miles southeast of Rockaway Borough (Harper, unpub.). This lake extended up the Rockaway and Beaver Brook valleys in the eastern part of the Dover quadrangle. Ice advancing through the lake laid down sublacustrine sand and gravel, which may consist of sublacustrine fan deposits, collapsed deltaic deposits, and ice-contact diamict (Qld1); and lakebottom and deltaic fine sand and silt (Qldlb1, section

With continued advance to its maximum position, ice overrode these deposits. A slightly higher proglacial lake, glacial Lake Dover, was formed when the northtrending stretch of the Rockaway valley near Rockaway Borough was blocked by the advancing ice. Lake Dover drained eastward into Lake Denville through an outlet across bedrock at an elevation of approximately 580 feet near the south end of Snake Hill (Harper, unpub.). Where meltwater entered Lake Dover, sand and gravel (Qldo) were deposited in deltas; farther out in the lake fine sand and silt (Qldolb) settled on the lake bottom. At the same time to the west of Dover, ice at its furthest extent dammed the valleys of Spring and Jackson Brooks to create glacial Lake Wharton. This lake, which may have had several short-lived levels within a range of about 20 feet in elevation, drained to the east into Lake Dover through an ice-walled channel around the north end of the 960-foot hill just south of Wharton. Deltas of sand capped by gravel (Qlw) were deposited in this lake. Concurrently, to the west of Wharton, advancing ice blocked the north-draining pre-glacial valley near Kenvil. This blockage formed glacial Lake Succasunna, which extended southward approximately 8 miles and drained to the south into the Raritan basin via the route of the present Lamington River (fig. 1) (Cook, 1880; Salisbury, 1902). The spillway for Lake Succasunna was across bedrock at an elevation of approximately 680 feet near Milltown (fig. 1) in the Chester quadrangle. While ice stood at the Terminal Moraine, this lake was filled with (1) basal sublacustrine sand and gravel (QIs, confined to the subsurface beneath the Terminal Moraine), overlain by and grading southward to (2) lake-bottom and deltaic fine sand and silt (QIsIb). The lake-bottom sand and silt is capped by (3) fluvial and deltaic sand and gravel (Qso) (section AA'). This sequence is partially exposed at the large gravel pit north of Kenvil. Here, as much as 20 feet of silty sand matrix-supported till of the Terminal Moraine (Qlwtm) overlies at least 20 feet of fluvial cobble to boulder gravel and sand topset beds (Qso), which in turn overlies an undetermined thickness of sand and pebbly sand foreset beds (QIsIb).

sinan ice is marked by a sharp boundary between till to the north and older colluvium and fractured and rubbly bedrock outcrops to the south. Colluvium north of the late Wisconsinan limit is neither as widespread nor as thick as that south of the limit. Bedrock outcrops are less numerous beyond the late Wisconsinan limit and,

Figure 2: Map showing striations, pebble lithologies, Terminal Moraine, maximum extent of glacial

lakes, and locations mentioned in text for Dover quadrangle and vicinity

filled pre-glacial valley north of Kenvil and in the filled pre-glacial Rockaway valley between Dover and Rockaway Borough (table 1) describe a probable till that may be as much as 50 feet thick (unit Qplwt) beneath thick sections of late Wisconsinan till and stratified sediment (sections AA' and DD'). Silt, sand, and gravel (unit Qplwg) occur above and below the lower till. Their age and origin are uncertain. No pre-late Wisconsinan sedi-

The Terminal Moraine took shape during the deposition of stratified deposits in glacial lakes Denville, Dover, Wharton, and Succasunna, and continued to form as ice began to melt back from its maximum extent. In the Dover quadrangle the moraine is a continuous east-west trending belt of thick, kettled till extending as much as 2.5 miles northward from the southern limit of late Wisconsinan ice. In several areas (west and south of Rockaway Borough, north of Dover, and west of Wharton), late Wisconsinan till extends as much as one-half mile south of the edge of ridge-andkettle topography of the moraine. These locations are situated on bedrock hills or in south-sloping valleys where thin ice and steep slopes prevented the isolation of stagnant ice and accumulation of thick till necessary

to generate the characteristic moraine landforms. Good exposures in the moraine are sparse, but where observed the sediment is a massive, cobbly to bouldery, sandy to silty sand matrix-supported diamict, similar to till outside the moraine. Stratified sediment has not been observed at the surface in the moraine outside the Rockaway valley. The till is as much as 150 feet thick on uplands and 100 feet thick in filled valleys (section CC'), where it generally overlaps, and is interbedded with, stratified sediment deposited in the lakes described above (sections BB', DD'). The topography of the moraine consists chiefly of closed depressions separated by short, narrow-crested.

steep-sided ridges and by broader, more gently sloping ridges. The ridges generally lack any preferred orientation, although in several places (northeast of Stephens Brook, south of Mount Hope Pond, northeast of interchange 35 on Interstate Route 80, and east of Duck Pond), long, roughly east-west trending ridges, some with steep south-facing slopes and gentle north-facing slopes, suggest deposition along an active ice margin. Several flat-topped, roughly circular plateau-like mounds bounded by steep scarps also occur in the

Deglaciation from the Terminal Moraine began before 18,000 years ago, based on radiocarbon dates of basal post-glacial sediments at Francis Lake in Warren County (Cotter and others, 1986) and at Budd Lake in Morris County (Harmon, 1968) (fig. 1). Radiocarbon dates on concretions from glacial Lake Passaic sediment south of Morristown (Reimer, 1984) also suggest deglaciation at about this time. As ice withdrew from its southernmost position, the ice dams holding in glacial Lakes Wharton and Dover (fig. 2) melted and the lakes drained eastward along the Rockaway valley into Lake Denville. At the same time the gap in the Rockaway valley just west of Wharton was uncovered and meltwater formerly entering glacial Lake Succasunna was diverted eastward to the Rockaway drainage basin. Outwash carried by this meltwater (Qr) prograded across the bottom sediment of drained Lake Dover. The deposition of outwash sand and gravel on the former lake bottom completed a three-part stratigraphic succession of (1) pre-late Wisconsinan stratified sediment (Qplwg), overlain by (2) lake-bottom and deltaic fine sand and silt (Qldolb), in turn overlain by (3) the outwash (sections BB', DD').

Lake Denville, which was fully displaced in the former basin during deglaciation. A delta and associated sublacustrine fan deposits (Qld2), and lake-bottom and deltaic fine sand and silt (Qldlb2) were deposited in Lake Denville as ice receded past the location of Rockaway Borough. Later, when a gap near Boonton (fig. 1) was uncovered by retreating ice in the Newark Basin. Lake Denville drained and this delta was eroded by meltwater descending the Rockaway. Continued retreat of ice north from the Terminal Moraine opened up several more proglacial lakes. The valley of Green Pond Brook was dammed across its south end by the Terminal Moraine, and glacial Lake Picatinny, held in by the moraine, extended up this

gap in a bedrock ridge, occupied at present by New Jersey Route 15, at an elevation of approximately 700 feet. Glacial Lake Picatinny was filled with a three-part vertical sequence of sublacustrine sand and gravel (Qlpi1), overlain by lake-bottom and deltaic fine sand and silt (Qlpilb), and capped by fluvial and deltaic sand and gravel (Qpo). After ice had retreated up the valley of Green Pond Brook, a ridge of till at the south end of modern Picatinny Lake served as a dam for a smaller and slightly higher glacial lake where the present Picatinny Lake is located Small deltas of sand and gravel (Qlpi2) were deposited

valley as ice retreated (Harper, unpub.). This lake drained

south and east into the Rockaway drainage through a

As the ice margin melted northward across the upland area east of Picatinny Lake, it blocked the northsloping valley south of Lake Ames. A small proglacial lake filled this valley, at first draining southward into the White Meadow Brook drainage, then later to the east into the Hibernia Brook valley through an ice-walled channel around the north end of the hill south of Lake Ames. Accordant levels of small knolls and terraces of poorly-sorted deltaic gravel and ice-contact diamict (both included in unit Qla) mark these short-lived lake In Berkshire Valley three fluvial-deltaic sequences

(Qbv1, Qbv2, Qbv3) and a portion of a fourth (Qbv4) were deposited at successive, stable ice margin positions as ice retreated north from the Terminal Moraine. Successive proglacial lakes, dammed on the south by the Terminal Moraine or by the heads of previous sequences, formed as ice retreated north from the stable positions. Sublacustrine and collapsed deltaic sand and gravel (Qlbv1, Qlbv2, Qlbv3, and Qlbv4) and overlying lake-bottom and deltaic fine sand and silt (Qlbvlb) were deposited in these lakes as the ice front receded northward from one stable position to the next (section AA'). The fluvial-deltaic sequences grading from the stable positions eroded through the previous deposits as spillways eroded and collapsed and the lakes lowered or

The first fluvial-deltaic unit (Qbv1) coarsens to a

head of outwash approximately 1 mile north of Interstate Route 80. This head of outwash is well preserved on the east side of the valley. The unit may grade to a base level across the Terminal Moraine at an approximate elevation of 700 feet, near the crossing of Interstate Route 80 and Berkshire Valley Road. The second fluvial-deltaic unit (Qbv2) is extensively collapsed and coarsens to a prominent head of outwash approximately 2.5 miles north of Interstate Route 80. The base level for this unit, as for Obv1, may have been across the Terminal Moraine, possibly at a lower elevation along the present alignment of the Rockaway River. The prominent, collapsed delta (part of Qlbv2) at the head of unit Qbv2 forms an embankment at an elevation in excess of 770 feet. Prior to collapse and erosion this delta extended across the valley and held in a lake at an elevation as much as 40 feet higher than the previous outlet across the Terminal Moraine. Collapsed delta

gravels deposited in this higher lake rise to an elevation of approximately 770 feet 1.5 miles to the north of Qbv2. At an exposure near Longwood Lake, the base of fluvial beds of unit Qbv3 lying on earlier foreset beds is at approximately 750 feet, demonstrating erosional lowering The third fluvial-deltaic unit (Qbv3) heads near Voodstock and may have been supplied, in part, by a sediment influx when meltwater formerly draining southward down Beaver Brook and Weldon Brook into the Musconetcong River was rerouted into Berkshire

Valley. This diversion probably occurred when ice with-

drew north of the Rockaway-Musconetcong divide on

Bowling Green Mountain, approximately 1 mile north of

where present, display abundant residual rubble and extensive disintegration along joint and foliation planes. These exposures contrast with the slightly weathered, polished, and plucked outcrops within the limit. In addition, erratics are much less abundant at the surface south of the late Wisconsinan limit and, in places, are

deposited in a lake dammed by the head of deposit Qbv3. Before erosion or collapse, sediment of unit Qbv3, and possibly ice, blocked the valley to an elevation in excess of 780 feet, as indicated by the elevation of the uneroded Qbv3 terrace just east of Woodstock. During deglaciation of the area west and north of Berkshire Valley, the receding ice front trended northeast-southwest. Ice thus blocked several westwarddraining valleys, ponding small proglacial lakes that drained eastward into the Rockaway basin. Units Qe, Qtc1, Qtc2, Qbb1, Qbb2, Qsh1, Qsh2, and Qsh3 in the headwaters of Lake Hopatcong were deposited in these impoundments. Meltwater from the spillways for Qtc1, Qtc2, Qsh1, and Qsh2 eroded channels in units Qbv2 and Qlbv2 in Berkshire Valley, indicating that ice in Berkshire Valley had retreated north of deposit Qlbv2 when these spillways were operating. Further retreat of the ice to the northwest opened drainage southwestward into the Musconetcong basin, and outwash units Qbb3 and Qwe were deposited along Beaver and Weldon Brooks by southward-draining meltwater. Concurrently, glacial Lake Hopatcong extended northward into the Dover quadrangle as ice retreated. Glacial Lake Hopatcong drained southward down the Musconetcong valley across the Terminal Moraine near Landing (about 4 miles southeast of Espanong) at an elevation of approximately 915 feet. Sediment deposited in this lake (Qho) includes sublacustrine and deltaic sand and gravel, and lake-bottom fine sand and silt. Meltwater continued to feed sediment into glacial Lake Hopatcong by way of Weldon and Beaver Brooks until ice withdrew beyond the north end of Bowling Green

Woodstock in the Franklin quadrangle. The base level

for Qbv3 may have been an unstable spillway across the

Franklin quadrangle and forms a terrace eroded slightly

into Qbv3. Qbv4 overlies lake sediments that were

A fourth fluvial-deltaic unit (Qbv4) heads in the

Mountain in the Franklin quadrangle. Although the locations and elevations of stratified deposits indicate a generally continuous ice margin retreating in a stepwise manner during deglaciation, stagnant ice may have been isolated in at least one sizable area east of Lake Shawnee in the Beaver Brook valley. Here, hummocky, bouldery diamict suggesting deposition from stagnant ice occupies a bowl-shaped east-west trending stretch of the valley bounded on the north and west by a high ridge. No linear ice-margin features occur in this area, and the topographic setting is such that a stagnant ice mass could have become isolated from the main glacier during downwasting and recession of the active ice to the north and west. After ice receded northward out of the Dover quadrangle, meltwater continued to drain down the Rockaway valley until melting uncovered the Pequannock valley (fig. 1). At this time meltwater was diverted eastward down the Pequannock and glacial deposition in the Dover quadrangle ceased.

POST-GLACIAL HISTORY

After deglaciation, deposition of silt and clay, then peat, began in ponds, marshes, and swamps (Qs). On uplands, these wetlands commonly occupy shallow basins eroded in bedrock. In the valleys of the Rockaway River and Green Pond Brook they occupy floodplains and large ice-block depressions; along the Terminal Moraine they occupy kettle holes. Following cessation of meltwater deposition, postglacial alluvium (Qal, Qst) began to accumulate along the Rockaway River and the lower reaches of its tributaries. These deposits are markedly thinner, finergrained, and of smaller extent than the meltwater On steep, southeast-facing slopes, principally on the quartzite and conglomerate of Green Pond and Copperas Mountains, but to a lesser extent on Precambrian bedrock, glacial plucking produced or enhanced steep cliffs. Coarse, angular talus (Qta) began to accumulate at the base of the cliffs shortly after deglaciation; in many places the talus is unvegetated and continues to accumulate.

Barnett, S. B., 1976, Geology of the Paleozoic rocks of the Green Pond Outlier: N. J. Geological Survey Geologic Report Series 11, 9 p. Bayley, W. S., Salisbury, R. D., Kummel, H. B., 1914, Geologic atlas of the United States, Raritan folio: U. S. Geological Survey Folio 191, 32 p. Canace, Robert, Hutchinson, W. R., Saunders, W. R., Andres, K. G., 1983, Results of the 1980-81 drought emergency ground water investigation in Morris and

Passaic Counties, New Jersey: N. J. Geological

Survey Open File Report 83-3, 132 p. Cook, G. H., 1880, Surface geology—report of progress: N. J. Geological Survey Annual Report for 1880, Cotter, J. F. P., Ridge, J. C., Evenson, E. B., Sevon, W. D., Sirkin, Les, Stuckenrath, Robert, 1986, The Wisconsinan history of the Great Valley, Pennsylvania and New Jersey, and the age of the "Terminal Moraine."

in Cadwell, D. H. (ed.), The Wisconsinan stage of the first geological district, eastern New York: N. Y. State Museum Bulletin 455, p. 22-49. Harmon, K. P., 1968, Late Pleistocene forest succession in northern New Jersey, New Brunswick, N. J., Rutgers University, unpublished Ph.D. thesis, 164 p. Harper, D. P., unpub., Late Wisconsinan glacier margin positions and ice front drainage [map]: N. J. Geological Survey (1982), scale 1:250,000.

Harte, P. T., Sargent, B. P., Vowinkel, E. F., 1986, Description and results of test-drilling program at Picatinny Arsenal, New Jersey 1982-84: U. S. Geological Survey Open File Report 86-316, 54 p. Leverett, Frank, 1934, Glacial deposits outside the Wisconsinan terminal moraine in Pennsylvania: Pa. Geological Survey Bulletin 67, 123 p. MacClintock, Paul, 1940, Weathering of the Jerseyan till:

Geological Society of America Bulletin, v. 51, Reimer, G. E., 1984, The sedimentology and stratigraphy of the southern basin of glacial Lake Passaic, N. J., New Brunswick, N. J., Rutgers Univ., unpublished M. S. thesis, 205 p.

Ridge, J. C., 1983, The surficial geology of the Great

for 1891, p. 35-108.

Valley section of the Ridge and Valley Province in eastern Northampton County, Pennsylvania and Warren County, New Jersey, Bethlehem, Pa., Lehigh Univ., unpublished M. S. thesis, 234 p. Salisbury, R. D., 1892, A preliminary paper on drift or Pleistocene formations of New Jersey: N. J. Geological Survey Annual Report of the State Geologist

Salisbury, R. D., 1902, The glacial geology of New Jersey: N. J. Geological Survey Final Report, v. 5, Sevon, W. D., Crowl, G. H., and Berg, T. M., 1975, The late Wisconsinan drift border in northeastern Pennsylvania: Pa. Geological Survey Guidebook for 40th Annual Field Conference of Pennsylvania Geolo-

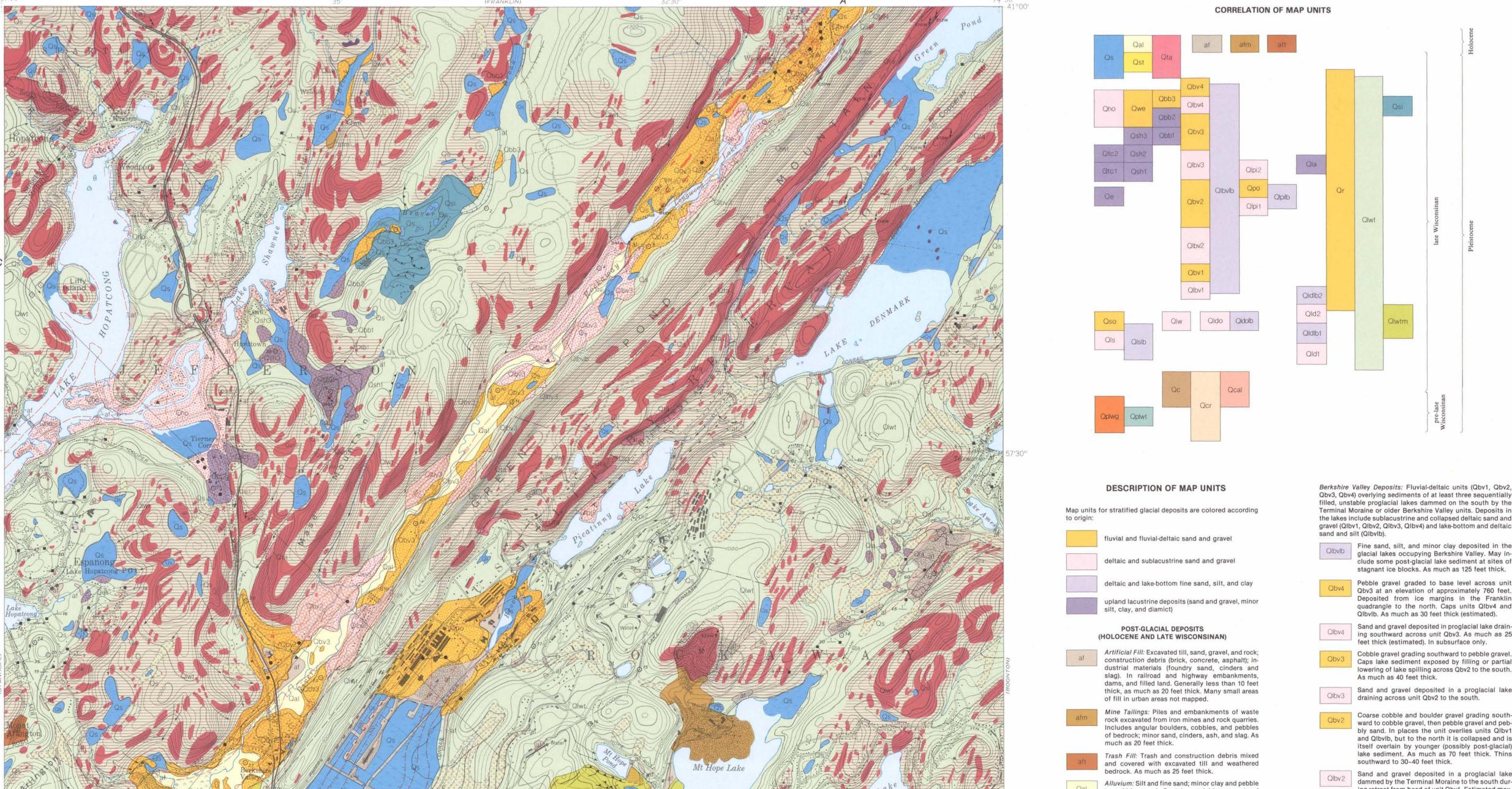
Sims, P. K., 1958, Geology and magnetite deposits of Dover district, Morris County, New Jersey: U., S. Geological Survey Professional Paper 287, 162 p. Stanford, S. D., Canace, Robert, unpub., Bedrock topography of the lower and middle Rockaway Valley, Morris County, New Jersey [map]: N. J. Geological Survey (1985), scale 1:12,000.

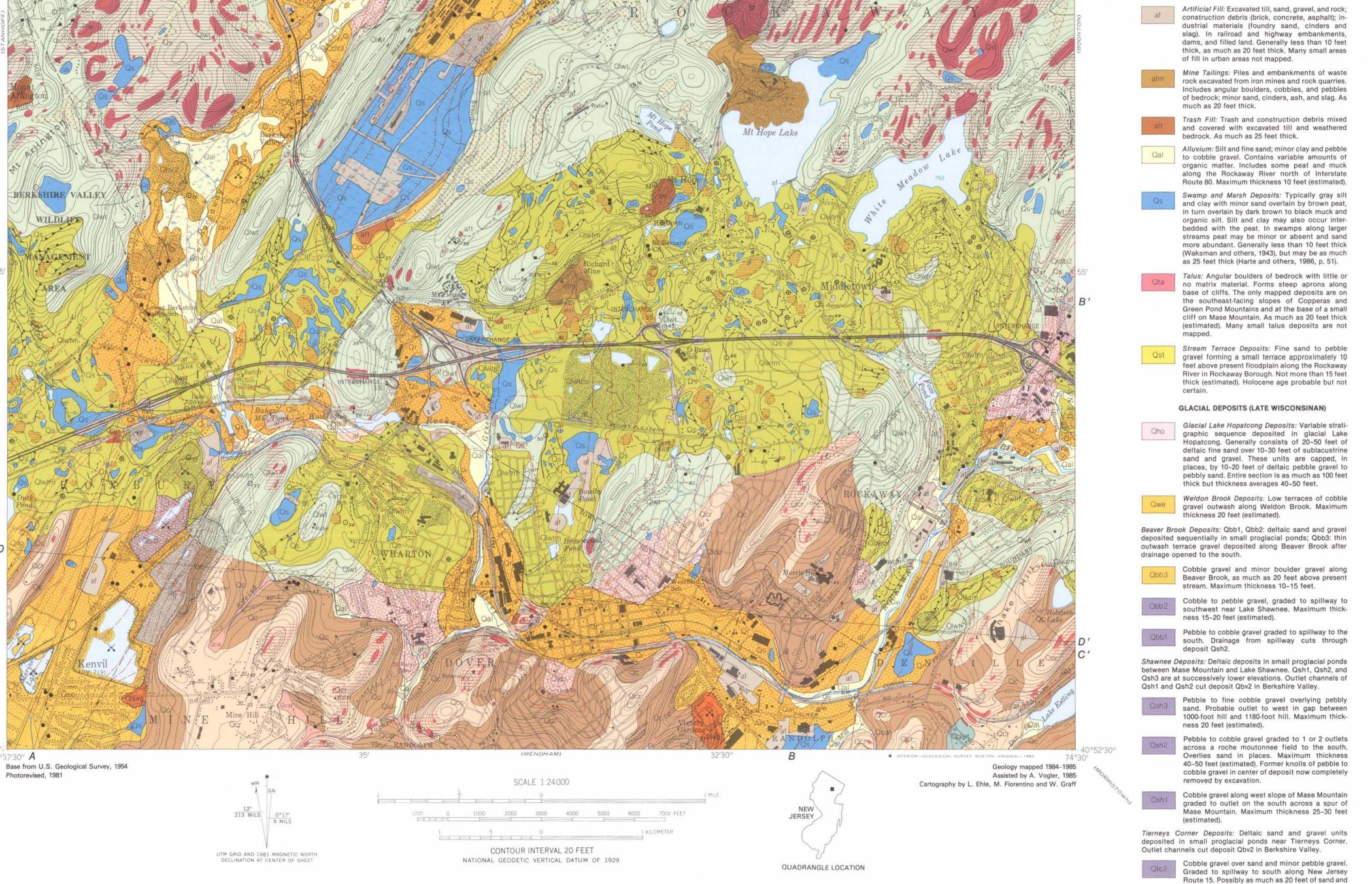
Waksman, S. A., Schulhoff, H., Hickman, C. A., Cordon, T. C., and Stevens, S. C., 1943, The peats of New Jersey and their utilization: N. J. Department of Conservation and Development Geologic Series, Bulletin 55, Part B, 278 p.

Young, D. A., 1971, Precambrian rocks of the Lake

America Bulletin, v. 82, p. 143-158.

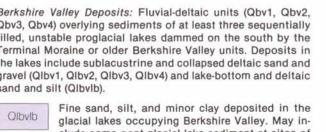
Hopatcong area, New Jersey: Geological Society of











gravel at the base of the deposit. Complete thick

ness as much as 60 feet. Partially removed by ex-

Jersey Route 15. Graded to probable ice-walled outlet around west side of 1060-foot hill on the

ble to fine cobble gravel on northwest side of

080-foot hill east of Espanong. Graded to possi-

ble outlet along Minisink Road to the south. Less

Cobble gravel filling small valley east of Nev

south. Estimated thickness 15-20 feet.

Espanong Deposits: Small deltaic deposits of peb-

than 20 feet thick (estimated).

cavation and grading.

surface in Dover quadrangle.

more than 30 feet thick.

feet thick (estimated).

Deposited from ice margins in the Franklin quadrangle to the north. Caps units Qlbv4 and ing southward across unit Qbv3. As much as 25 wering of lake spilling across Qbv2 to the south. Sand and gravel deposited in a proglacial lake

Coarse cobble and boulder gravel grading southward to cobble gravel, then pebble gravel and peb bly sand. In places the unit overlies units Qlbv and Qlbvlb, but to the north it is collapsed and is itself overlain by younger (possibly post-glacial lake sediment. As much as 70 feet thick. Thins Sand and gravel deposited in a proglacial lake dammed by the Terminal Moraine to the south durng retreat from head of unit Qbv1. Estimated max mum thickness in most areas is 40 feet, but unit thickens to as much as 140 feet in the large delta at the north end.

across the Terminal Moraine either along Berkshire Valley Road near Stephens Brook or along the present Rockaway River. As much as 50 feet thick. Unit is contiguous with, but slightly younge than, unit Qr. Sand and gravel deposited in a proglacial lake draining across the Terminal Moraine either along Berkshire Valley Road near Stephens Brook of along the present Rockaway River. At most places

as much as 100 feet thick (estimated). Thickens to an estimated 150 feet at head of outwash unit Qbv1. In subsurface only. Glacial Lake Picatinny Deposits: Vertical sequence o sublacustrine sand and gravel (Qlpi1), lake-bottom and delta fine sand and silt (Qlpilb), and overlying fluvial and deltaic sand and gravel (Qpo) deposited in a proglacial lake in the valley of Green Pond Brook in Picatinny Arsenal, and deltas (Qlpi2 deposited in a slightly higher proglacial lake to the north in the

basin of present-day Picatinny Lake. Cobble gravel overlying probable sand and pebble gravel along both sides of Picatinny Lake. Maximum thickness 30 feet (estimated). Cobble gravel, fining south to pebbly sand. As much as 40 feet thick.

Fine sand, silt and minor clay. As much as 150 feet Olpilb thick. In subsurface only. Sand and gravel. Ranges in thickness from 0 to 60 Qlpi1 feet. In subsurface only. Glacial Lake Ames Deposits: Poorly sorted pebble to cobble gravel. Includes collapsed deltaic

deposits and ice-contact diamict. As much as 20 Glacial Lake Denville Deposits: Sediment deposited in glacial Lake Denville. At the Terminal Moraine, sublacustrine sand and gravel (Qld1) and lake-bottom and deltaic fine sand and sil AldIb1) deposited during advance of ice are overlain by till of the moraine (Qlwtm, described below). North of the Termina Moraine units Qld2 (sublacustrine and deltaic sand and gravel) and Qldlb2 (lake-bottom and deltaic fine sand and silt) were deposited during retreat of ice from the Terminal Moraine.

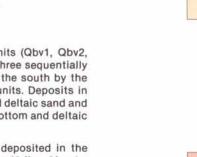
Fine sand, silt, minor clay. As much as 60 feet Qldlb2 thick in the Dover quadrangle. Cobble gravel, grading to pebble gravel on the Old2 south. As much as 50 feet thick. Interfingers with Qldlb1 to the south.

Fine sand, silt, minor clay. As much as 50 feet Oldlb1 thick. Not exposed at surface in Dover quad-Sand and gravel. As much as 100 feet thick (estimated). Interfingers with Qldlb1. Not exposed at Rockaway River Outwash: Chiefly cobble grave

Includes some boulder gravel north of Dover, and minor pebbly sand and pebble gravel in the vicinity of Mill Brook and Victory Gardens. Deposited by meltwater descending the Rockaway valley and entering from tributaries to the north. North of Dover and in Rockaway Borough the deposit is incised into till of the Terminal Moraine; between Dover and Rockaway the outwash prograded across the drained bed of Lake Dover and caps unit Oldolb (described below). As much as 50 feet thick to the north of Wharton, but generally no

Glacial Lake Succasunna Deposits: Sediment deposited glacial Lake Succasunna. Sublacustrine sand and gravel (QIs grades southward to lake-bottom fine sand and silt (QIsIb) his in turn is overlain by fluvial-deltaic sand and gravel (Qso Cobble gravel grading southward to pebble gravel and pebbly sand. As much as 50 feet thick. Fine sand, silt, minor clay. Interfingers to the north with unit Qls. As much as 150 feet thick.

Chiefly sand, some pebble to cobble gravel. In subsurface only, beneath till of the Terminal Moraine (unit Qlwtm, see below). As much as 100 Glacial Lake Wharton Deposits: Delta of pebble to Clw cobble gravel, generally overlying sand, deposited in a proglacial lake filling the north ends of the valleys of Spring and Jackson Brooks. Estimated maximum thickness is 50 feet.



Colluvium and Alluvium: Silt, sand, and cobble to boulder gravel and diamict partially filling valley bottoms. As much as 20 feet thick (estimated). Partly of late Wisconsinan age. Till: Weathered pebbles, cobbles, and boulders of Precambrian rock and some unweathered sandstone, quartzite, and quartzite conglomerate pebbles, cobbles, and boulders in an orange-brown to yellow-brown clayey silt. Occurs as a thin veneer over weathered bedrock west of Lake Estling. In the subsurface, till occurs in patches beneath colluvium and late Wisconsinan deposits in glacial

from records of wells and test borings. May be as much as 50 feet thick in the subsurface, 10 feet lacustrine sand and gravel with minor amounts of silt and clay. Occurs at the surface in Kenvil and Victory Gardens, and in the subsurface beneath late Wisconsinan sediment in glacial lakes Dover and Succasunna. Age uncertain; the subsurface units may include both glacial and interglacial deposits. Maximum thickness approximately 120

tered bedrock outcrops; surficial deposits generally less than 10 feet thick. Solid pattern indicates extensive bedrock outcrop; surficial deposits generally absent. Dot indicates isolated bedrock outcrop in area where surficial deposits are generally greater than 10 feet thick. Boulder gravel and coarse cobble gravel fining southward to cobble gravel. Graded to base leve Surface accumulations of boulders, generally on terraces and valley bottoms. May be till surfaces washed by subglacial, proglacial, and ice-margina meltwater. Does not include talus (unit Qta). Spillway for glacial lake, lettering indicates

associated deposit Meltwater channel: Narrow, linear, boulder-filled drainageways, bounded in places by cutbanks, in which present streams are underfit or non-Striation: observation at dot

 Erratic boulder of Cambrian or Ordovician car-Axis of streamlined hill Contact: dashed where approximately located, dotted where excavated

Glacial Lake Dover Deposits: Lake-bottom and deltaic fine

sand and silt (Qldolb) and deltaic sand and gravel (Qldo)

Chiefly cobble gravel overlying sand and pebble

entered the lake. Interbedded, in places, with

Qldolb. Estimated maximum thickness 50 feet.

Qldo gravel. Forms deltas where meltwater channels

Fine sand, silt, minor clay. As much as 100 feet

Till: Unstratified and unsorted boulders, cobbles

and pebbles in a yellowish-brown (10YR5/4-5/6)

silty fine sand to fine to medium sand matrix. The

matrix is coarse sand at some locations and on

the west slope of Green Pond Mountain near

shale from the underlying High Falls Formation

Observed depths of oxidation range from about

to 20 feet. Outside the Terminal Moraine the till

averages approximately 20 feet thick and can be

as much as 50 feet thick in areas of continuous

till. It is generally thicker and more continuous on

the northwest-facing slopes of principal ridges

and hills. In places the till is underlain by

The map unit includes colluvium (mixed till and, in

places, angular pebbles, cobbles, and boulders of

bedrock debris in a matrix of orange-brown to

yellow-brown silty fine sand to coarse sand). Col-

luvium forms discontinuous aprons and fans

along bases of steep slopes, especially in Berl

shire Valley. It may be as much as 10 feet thick.

Till of the Terminal Moraine: Yellowish-brown to

grayish-brown till as above forming ridge- and ket-

as 150 feet thick on uplands and 100 feet thick in

filled valleys, where it generally overlies and is in-

terbedded with stratified sediment deposited in

tagnant Ice Deposits: Sandy, bouldery diamict

rming hummocky topography along Beaver

Brook east of Lake Shawnee. As much as 30 feet

Colluvium: Unstratified and unsorted boulders,

cobbles, and pebbles of angular bedrock debris

silty sand matrix. Partly of late Wisconsinan age.

Colluvium and Weathered Bedrock: Discontinuous

colluvium, as above, generally less than 10 feet

thick, overlying weathered bedrock. The weathered

bedrock ranges from sandy (minor clavey sand)

saprolite to a rubble of angular cobbles and

boulders of fractured rock with little or no matrix

is guite variable. In places the colluvium may be

replaced by a diamict produced by in-place mixing

of pre-late Wisconsinan till and underlying

weathered bedrock, with little or no downslope

lakes Dover and Succasunna, where it is inferred

MAP SYMBOLS

Bedrock Outcrop: Ruled pattern indicates scat-

movement. Partly of late Wisconsinan age.

It may be as much as 50 feet thick, but thickness

and some rounded erratics in an orange-brown

May be as much as 50 feet thick at the base of

glacial lakes Succasunna, Dover, and Denville.

GLACIAL AND NON-GLACIAL DEPOSITS

(PRE-LATE WISCONSINAN)

long, steep slopes.

tle topography of the Terminal Moraine. As much

Longwood Lake consists of angular chips of red

deposited in glacial Lake Dover.

Scarp eroded by meltwater Excavation scarp Active gravel pit

Inactive gravel pit -500 -- Elevation of bedrock surface, contour interval 50 feet (100 feet where data is sparse). Shown only

where depth to rock generally exceeds 20 feet. and test borings selected from files of the N. J of Water Resources, and several dozen seismic traverses (Canace and others, 1983; Stanford and Canace, unpub.). Hachures indicate closed con-Well or test boring used to construct section

 Seismic traverse used to construct section (Canace and others, 1983; Stanford and Canace, Well or test boring on section, dot indicates location of bedrock surface

Seismic traverse on section, dot indicates loca-tion of bedrock surface

Surface texture of stratified deposits cobble gravel and sand pebble gravel and sand

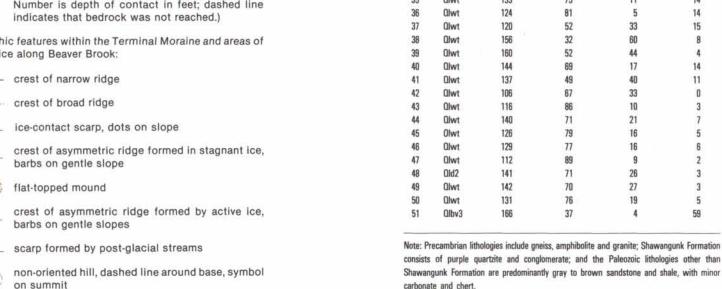
y

△ Site of well, log in table 1 530 Site of pebble lithology count, data in table 2 ■ 1 Selected well in upland area, with abbreviated log $\frac{Wr}{62}$ (t = till, c = colluvium, wr = weathered bedrock).

Number is depth of contact in feet; dashed line indicates that bedrock was not reached.) opographic features within the Terminal Moraine and areas of stagnant ice along Beaver Brook: crest of narrow ridge ---- crest of broad ridge _ · · · ice-contact scarp, dots on slope

crest of asymmetric ridge formed in stagnant ice barbs on gentle slope flat-topped mound crest of asymmetric ridge formed by active ice, barbs on gentle slopes scarp formed by post-glacial streams

on summit



DOVER QUADRANGLE, NEW JERSEY

TABLE 1: Records of Representative Wells: Selected from approximately 400 well logs in the quadrangle

to show the information used to infer subsurface geology.

Number Water Resources

1 25-11,371

Permit Number

GEOLOGIC MAP SERIES 89-2

0-50 fine to coarse sand 0-50 Osc

coarse pebbly sand

gravel and boulders

195-250 medium to very 195-310 Oplwg

overburden with 0-41 Obv1

50-100 fine sand

250-295 silty clay

310-380 dolomite

28-41 sand, gravel

41-102 fine sand

102-108 sand, gravel

108-132 sand

test well

132-135 sand, gravel

abbreviated log

(Canace 0-25 sand, some gravel 0-25 Obv2

and others, 25-80 silt and very fine 25-80 Olbvlb

domestic 0-40 sand and gravel 0-40 Obv3

40-160 gray silt

fine sand

70-218 granite rock

monitoring 0-20 coarse sand, pebbles 0-42 Opo

2 medium to coarse

62-123 silty sand and sandy

123-186 gravel, pebbles,

and boulders

186-245 saprolite (clay

sand, gravel,

40-84 muddy sand and

84-87 sandy clay mixed

87-104 soft rock

104-114 hard rock

25-35 dirty sand

35-60 clean sand and

(on file at test boring 0-163 no log, rock at 163-198 weathered

0-15 coarse sand

70-130 silt, fine sand,

80-124 blue liver clay

94-119 silty clay

136-147 clay and boulders

abbreviated log

fill, cobbles,

132-143 weathered gneiss

abbreviated log

sand, gravel,

boulders

17-48 sandy clay and

48-105 sandy clay

105-140 sand, gravel,

143-153 hard gneiss

sand and gravel

20-94 fine sand and silt 20-119 Oldolb

119-132 coarse sand, some 119-132 Oplwg

cobbles and boulders 132-143 weathered

clayey silt

abbreviated log

sand and gravel

Dover) 15-70 fine to very

Denville) 17-80 fine sand

wellfield 163-198 soft rock

Survey) completed 198-230 hard rock

municipal

industrial

municipal

(Rockaway

Borough)

25-9,669

4 Qlbv3

8 Obv3

10 Obv3

11 Qbv3

13 Qlwt

16 Qlwt

19 Qsh2

20 Osh3

22 Obv2

28 Obv2

(McWilliams 0-2

N.J. Geo- at Dover

with gravel

hardpan and

60-68 fine sand with 60-163 Oldolb

clay and hardpan

and rock fragments

sand, some gravel

silt with some thin

245-268 Hardyston quartzite 245-268 bedrock

160-167 shale

public 0-52 yellow clay and

Water Co.) 60-70 soft granite rock

(Picatinny 20-27 fine sand and silt

42-62 fine sand

(Sparta Mt. 52-60 broken rock

80-102 gravel and sand 80-102 Qlbv2

295-310 fine to coarse sand

100-195 clay

