



Areas of higher ground are typically underlain by gneiss (green color), which is more resistant to weathering and erosion. Hillshade base map from NJDEF



Figure 5. Morphology of the Moores Pond segment of the late Wisconsinan terminal moraine (shown as wtm in northwestern corner of map area). Morainal landform elements collectively define areas of ridge-andtrough, and knob-and-kettle topography. Figure from Witte (2001b).



accumulation of debris and differential melting causes the terminal area of the glacier to become very thin. This results in stagnation and the formation of a marginal zone of dead ice. Because the leading edge of active ice shifts backwards the transport of debris to the glacier's former active ice margin has ceased. anel D - Gradually the supraglacial debris is let down on the land by the continued melting of dead ice and resedimentation by mass wastage. Except for colluvial ramparts and push ridges, morainal morphology is argely a product of topographic inversion where high areas of glacial ice covered by a veneer of debris now form the low areas (kettles and hollows) and low areas filled with a thick accumulation of debris now form the igh areas (some morainal ridges, knolls and hillocks). Minor oscillations of the glacier's margin and several closely-spaced stillstands may redistribute sediment, override stagnant ice, and leave additional stagnant

ice forming a complex assemblage of morainal landforms. Figure modified from Flint (1971, Fig. 5-14).





may also be glaciotectonized substrate formed when the pre-Illinoian glacier overrode deeply weathered

lartinsburg more than 850,000 years ago. Location shown on map and inset. Photo by R. Witte.



subangular to subrounded stones. Many stones are striated and elongated clasts have a pronounced downvalley fabric. Scale at photo's center is four feet with 1 foot divisions. Photo by R. Witte.







Pequest rivers, and Pohatcong Creek are large streams within the map area that flow in a southwestward direction toward the Delaware River, which is the master stream in this area. The highest point n the map area is approximately 1,150 feet (361 m) above sea level on the summit of County House Iountain, and the lowest point lies where the Musconetcong River flows out of the quadrangle, approximately 375 feet (119 m) above sea level. Surficial geologic materials in the quadrangle include: 1) weathered bedrock, 2) till and meltwater sediment deposited during three glaciations, and 3) nonglacial steam sediment, hillslope sediment, and organic deposits. These deposits are depicted on the map based on their physical characteristics and readily distinguishable boundaries. They are the parent material on which soils form, and they exhibit a wide range of physical characteristics. Cumulative thickness is as much as 250 feet (76 m) for glacial sediment, 80 feet (24 m) for hillslope deposits, and as much as 300 feet (91 m) for weathered rock. Alluvial sediment, and swamp and bog deposits are less than 30 feet (9 m) thick. Drake and others (1996) described the bedrock formations, and the soils were described by Fletcher (1979). PREVIOUS INVESTIGATIONS The surficial geology of the Washington quadrangle and surrounding area was first discussed by Cook (1877, 1878, 1880) in a series of Annual Reports to the State Geologist. He included detailed observations on the terminal moraine, recessional moraines, distribution and kinds of drift, and evidence of glacial lakes. Deposits of "older" weathered drift were discussed by Cook (1880) who noted the distribution of quartzose boulders and scattered patches of thin gravely drift in Pohatcong and Musconectcong valleys in western New Jersey. Most of this material was thought to be "modified glacial drift", possibly deposited by meltwater and reworked later by weathering and fluvial erosion. On further inspection (Salisbury, 1893), this "modified glacial drift" was determined to be of glacial origin and called extra-morainic drift because of its distribution south of the terminal moraine. Salisbury (1902) detailed the glacial geology of New Jersey region by region. The terminal moraine and all surficial deposits north of it were interpreted to be products of a single glaciation of Wisconsinan age. Salisbury also noted "in the northwestern part of the state, several halting places of ice can be distinguished by the study of successive aggradation plains in the valleys." South of the terminal moraine Salisbury (1902, Plate XXVIII) showed two deposits of extra-morainic glacial drift. The first, forming a narrow belt just outside the terminal moraine, consisted of glacial drift of late glacial age mixed with material that was older than the terminal moraine. Salisbury indicated that the drift was deposited during a temporary advance of ice beyond the terminal moraine, or was carried out by meltwater. The second body of extra-morainic drift is largely glacial and much older than the terminal moraine based on its deep weathering and patchy distribution. It lies as much as twenty miles (32 km) beyond the terminal moraine. Salisbury (1902) assigned a Kansan age to the older drift because its deeply weathered appearance suggested it was the product of a much older glaciation than the Wisconsinan. Chamberlin and Salisbury (1906) correlated the oldest drift with the sub-Aftonian glacial stage of lowa, using the term "Jerseyan" as an equivalent stage for the older glacial deposits in insylvania and New Jersey. Bayley and others (1914) divided the extra-morainic drift into "early glacial drift" that was largely till deposited during the Jerseyan stage and "extra-morainic drift" that consisted of a mix of Wisconsinan and early drift. MacClintock (1940) concluded that there were also three ages of glacial drift in New Jersey, the youngest of Wisconsinan age and two pre-Wisconsinan drifts of Illinoian and Kansan age. He largely based his conclusions on the degree of weathering of medium to coarse-grained gneiss and pegmatite clasts. Ridge (1983) and Cotter and others (1986) indicated the youngest glacial deposits in New Jersey are late Wisconsinan age, and are correlative with the Olean drift in Pennsylvania, and Ridge and others (1990) showed that older and weathered drift in the Delaware Valley north of Marble Mountain is late Illinoian age and not early Wisconsinan. The only early Wisconsinan deposits were

ogy of the study area.

INTRODUCTION

and that the two older drifts are of Illinoian, and pre-Illinoian age. Stanford (1997) suggested that the oldest glacial deposits in New Jersey may be pre-Illinoian K age (2.14 – 2.01 Ma; Ma = million years ago), based on similarity of weathering characteristics, topograph c position, and erosional preservation to that of the Pensauken Formation, a Pliocene age braided stream deposit. At least some part of the oldest glacial deposits have an age greater than 780 ka (ka = thousand years ago) as indicated by reversed paleomagnetic directions in laminated glaciofluvial deposits at Kennedys, about 10 miles southwest of Washington, and in laminated glacial-lake deposits t Bernardsville, about 20 miles east of Washington (Stanford and others, 2021). Additional evidence for antiquity of these deposits includes the identification of pre-Pleistocene pollen in the lower part of a 60-foot core from Budd Lake. New Jersey by Harmon (1968). Sediment sampled below 45 fee (14 m) may be laminated clays of pre-Illinoian proglacial lake deposits. It is overlain by Illinoian and late Wisconsinan proglacial lake sediment. Harmon (1968) dismissed the finding of the older pollen because the exotic taxa appeared to be redeposited, prohibiting their use as a trusted indication of Pliocene age Ridge (1983) and Witte (1988, 1997, 2001a) detailed the late Wisconsinan deglaciation for northwestern New Jersey and a small part of northeastern Pennsylvania. Accordingly, deglaciation was characterized by the systematic northeastward retreat of the Kittatinny Valley and Minisink Valley ice obes (fig. 2). This interpretation was based on the distribution of ice-marginal meltwater deposits (morhosequences) and moraines, and correlative relationships between elevations of delta topset-foreset contacts, former glacial-lake-water plains, and lake spillways. The identification of ice retreatal posions by mapping morphosequences was first introduced in New England by Jahns (1941) and later refined by Koteff (1974) and Koteff and Pessl (1981). PHYSIOGRAPHY AND BEDROCK GEOLOGY The Washington quadrangle lies entirely in the Delaware River drainage basin. Both the Musconetcong River and Pohatcong Creek flow southwestward through broad valleys underlain by Lower Paleo zoic age dolomite, slate, and siltstone. The course of these streams, where cut in rock, chiefly lies near the base of the bounding uplands following the trend of the less resistant carbonate rock. The Pequest iver flows southwestward over a thick cover of glacial deposits to the village of Pequest. From here, it turns westward and flows into the Delaware Valley. The physiography of the quadrangle is largely the result of differential weathering on chiefly southrest-trending fold and thrust belts of dolomite, slate and greywacke, and gneiss and granite (fig. 3). he uplands rise as much as 700 feet above the floors of the valleys and are mostly underlain by gneiss and granite. Topography here is rugged and the land is deeply dissected. Ridge lines chiefly follow foliation in the bedrock. although discordant trends are common. In places, deep gaps such as Sykes Ga

cover of loose rock and soil was removed by the erosive action of the last ice sheet. South of the limit, rock outcrops are less common and the topography is not as rugged because in many places the unweathered rock surface is covered by thick weathered bedrock. he large valleys are chiefly underlain by shale, siltstone, dolomite, and minor limestone, and they form broad, southwest-tending lowlands. Musconetcong Valley is deeply incised by its modern river and tributaries, lying as much as 200 feet (61 m) below the main valley floor. The higher areas are underlain by slate and siltstone, the land here marked by gentle to moderately rolling hills and swales. In places, the rock surface is deeply weathered and capped by a thin mantle of pre-Illinoian glacial drift Pohatcong Valley (named Jackson Valley on the quadrangle), in contrast to Musconetcong Valley, is underlain by thick deposits of Illinoian till. Pohatcong Creek is incised as much as 80 feet (24 m) in the older glacial sediment, and its modern river flows along a very narrow course. South of the Illinoian glacial limit, which is marked by an end moraine at the town of Washington, the creek is cut down in rock and the overall physiography of the valley becomes similar to Musconetcong Valley. Pequest Valley is underlain by glacial drift of late Wisconsinan age that includes meltwater sediment laid down in glacial lakes Oxford and Pequest, and till. In places, the Pequest River has cut down as much as 80 feet (24 m) into the overburden. The main part of the valley is mostly underlain by dolomite, that in places has been deeply scoured by glacial erosion. Westward from the village of Pequest, where the river enters the New Jersey Highlands, the valley becomes considerably more narrow, its course constrained by hick glacial deposits (moraine and outwash). PREGLACIAL DRAINAGE The primary drainage routes in the guadrangle and surrounding area were probably established wel before the Pleistocene. The transverse gaps in the Highlands are possibly relicts of an earlier superimposed drainage system that may have flowed in a southeasterly direction (Johnson, 1931). The gaps may also represent places of extensive jointing and faulting or where weak lithology has created an area susceptible to erosion.

up-valley along the strike of less resistant rock. In response to the overall lowering of sea level during e Pleistocene, the drainage has further evolved by incision, which along the larger tributaries of the Delaware River has resulted in the formation of a much lower, narrower, river valley. Extensive headward erosion by first and second-order streams has also resulted in the dissection of the older valley floor, and the surrounding uplands. The location of Illinoian glaciofluvial deposits in the Delaware Valley (Witte and Stanford, 1995) suggests that the Delaware River was almost lowered to its present levels by the time of the Illinoian glaciation. Post-Illinoian incision has been minor, estimated at less than 20 QUATERNARY GEOLOGY New Jersey's terrestrial glacial record shows that the Laurentide ice sheet reached New Jersey at least three times (Stone and others, 2002) over the last two million years. These glaciations (fig. 1) are from youngest to oldest the late Wisconsinan (Marine Isotope Stage (MIS) 2), late Illinoian (MIS 6), and pre-Illinoian G (MIS 22) or older and possibly more than one glaciation. Braun (2004) cited evidence of four glaciations in Pennsylvania: late Wisconsinan, late Illinoian or pre-Illinoian B (MIS 12), pre-Illinoian D (MIS 16), and pre-Illinoian G (MIS 22). Similar to New Jersey's oldest glacial deposits, those in Pennsylvania may represent more than one glaciation. There is some disagreement concerning the age of the older glaciations and number of pre-Illinoian glaciations, but there is a remarkable congruency between the glacial limits mapped on either side of the Delaware River. The youngest glacial deposits laid down during the late Wisconsinan substage provide the clearest record of glaciation. The glacial record, indicated by the Illinoian and especially the pre-Illinoian deposits, is less clear due to an extensive and complex periglacial and weathering history. Multiple glacial cycles have greatly modified New Jersey. Valleys were deeply scoured, and bedrock ridges, hills, and slopes were worn down by glacial erosion. In places, glacial ice and drift dammed valleys, rerouted streams, and established new drainage ways. Most of the eroded debris entrained by the ice sheets was deposited as till and meltwater sediment. Numerous ice-marginal lakes formed n valleys dammed by moraine, ice-contact deltaic deposits and ice. These lakes and their associated deposits, and recessional moraines, provide a detailed record of deglaciation. The many unweathered and lightly weathered bedrock outcrops north of the terminal moraine show that most of the pre-existing weathered bedrock and surficial material had been removed by glacial erosion. This area lies in stark contrast to that south of the late Wisconsinan limit where outcrops are fewer. The late Wisconsinan limit also divides the largely glacial landscape in the north from the largely colluvial landscape in the south. Although the effects of glaciation in modifying the landscape are pronounced, these modifications in the older glacial landscapes have been largely masked or removed by periglacial weathering. Based on the sawtooth record of the marine isotope record, Braun (1989) indicated that there may have been as many as ten glaciations of a magnitude sufficient to glaciate or introduce a periglacial climate to

the lower parts of hillslopes and onto the floors of narrow valleys and heads of drainage basins. It is chiefly a monolithic diamicton derived from weathered bedrock (chiefly by fragmental disintegration of outcrop and regolith by frost shattering) and transported downslope largely by creep. Over time, t accumulated at the base of slopes, forming an apron of thick material, and it also collected on the floors of narrow valleys and in first-order drainage basins. In places, it is greater than fifty feet thick and it covers large parts of the landscape. In contrast, during the warm interglacials, the relative rate of chemical weathering increased and an extensive cover of deeper-rooted vegetation helped reduce the rate of mass wasting. During these periods, thick soils formed and thick saprolite and decomposition residuum formed on deeply weathered bedrock. Braun (1999) suggested that sub-till dissolution of carbonate bedrock in the Great Valley has been sufficient to overprint the primary glacial topography on the oldest till Constructional knob and kettle glacial topography subsequently altered by periglac processes and bedrock dissolution produced a composite topography that Braun (1999) referred to as "pseudo-moraine The oldest glaciation, named the Jerseyan in Chamberlin and Salisbury (1906) and now represented by the pre-Illinoian Port Murray Formation (Stone and others, 2002) covered the guadrangle. The Port Murray drift appears to be chiefly till. It is highly and deeply weathered, and it lies on weathered bedrock. Constructional topography is not preserved, and the drift lies a minimum of 60 feet (18 m) above modern valley floors in areas that are protected from hillslope and fluvial erosion. The second ice sheet reached the study area during the Illinoian stage (150 ka) and it covered about 75 percent of the quadrangle (fig. 2). This glaciation is represented by the Lamington and Flanders formations (Stone and others, 2002). These deposits are moderately weathered, and the underlying bedrock is not as weathered as it is beneath the Port Murray deposits. The deposits lie in modern valleys and constructional topography is preserved, although it's subdued, and the drift in many places has not been colluviated off hillslopes. The difference in the distribution of Illinoian and pre-Illinoian glacial drift suggests that uplift and/or a drop in sea level after the pre-Illinoian glaciation had lowered base level. The Delaware River and its tributaries adjusted by downcutting as much as 100 feet (30 m). The position of Illinoian glaciofluvial deposits in the Delaware River valley (Stanford and others, 2016) suggests that most of the erosion may have taken place well before the onset of the Illinoian glaciation. The narrow, rock-walled valleys of parts of the modern Delaware River, Musconetcong River, and Pohatcong Creek support this hy-The youngest ice sheet reached the guadrangle during the late Wisconsinan substage of the Wisconsinan stage; approximately 22 to 19 ka (Cotter and others, 1986; dates younger than 25 ka are in radiocarbon years). Its southernmost advance (fig. 2) is generally marked by the terminal moraine (Salisbury, 1902). The deposits of this glaciation are represented by the Rockaway, Kittatinny Mountain, and

Netcong tills (Stone and others, in 2002). They are lightly weathered, generally lie on nonweathered rock, and lie in the modern drainage. During deglaciation the outer part of the ice sheet thinned and its flow became more constrained by the northeast-to-southeast orientation of Kittatinny Valley. The obation of the Kittatinny Valley and Minisink Valley ice lobes also became more pronounced (fig. 2). During glacial retreat, meltwater sediment was chiefly laid down in glacial lakes (fig. 2) that occupied parts of the Pequest River valley, and to a lesser extent in small upland basins and valleys (Ridge 1983) Witte, 1997). These former lake basins were dammed either by stratified drift, moraine, and stagnant ice, or by the margin of the ice lobe. The area within the Washington guadrangle was uncovered by ic approximately 20 ka to 19 ka based on the oldest radiocarbon date from Francis Lake (fig. 2) (Cotter, 1983). Meltwater continued to flow down Pequest Valley until the glacier margin retreated out of the Pequest River drainage basin and into the Paulins Kill drainage basin sometime about 18 ka (Witte, Following the late Wisconsinan glaciation, cold and wet conditions, and sparse vegetative cover enhanced erosion of hillslope material by solifluction, soil creep, and slope wash. The mechanical disintegration of rock outcrops by freeze and thaw provided additional sediment, some of which forms aprons of talus at the base of large cliffs in the New Jersey Highlands. A few small boulder fields were formed

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karst-fill materials. Weathering extends deeply in the subsurface along fractures, joints, and bedding planes. In many places the weathered bedrock alternates in the subsurface with nonweathered bedrock alternates in the sub rock. Bedrock outcrops are widely scattered, most are marked by a pile of irregularly shaped boulders along the crest of a ridge or on a hillslope. The rock surface is very irregular and deeply etched or VALLEY-FILL STRATIGRAPHY The geologic framework of the late Wisconsinan stratified valley-fill deposits shows that meltwater deposits were laid down in two depositional settings. The first includes deposits laid down in lake basins that were not filled completely with glaciolacustrine sediment (fig. 8). Typically, these basins were large and at least 100 feet deep (31 m). Deltas and lacustrine-fan deposits are generally separated by extensive areas of lake-bottom sediment, and a large part of the basin is covered by the lake-bottom plain Lakes Oxford, Buttzville, and the part of Pequest that lies north of Great Meadows, that are located in the Washington, Blairstown, and Belvidere (Witte and Ridge, 2021) quadrangles, illustrate this setting. The second setting includes deposits in lake basins that are nearly or completely filled with glaciolacustrine sediment. Typically, these basins are small and/or narrow, and topset beds may have been extensively aggraded as deposition in the basin became largely dominated by glaciofluvial sedimentation Deltas and lacustrine-fan deposits commonly coalesce, and delta plains commonly form the floor of an entire lake basin. Lacustrine-fan deposits may also lie beneath younger deltaic and lake-bottom deposits. Typically, these fans lie on till or bedrock at the bottom of the former lake basin and well records show that they do not form continuous sheets across the basin floor. The part of Lake Pequest that lies southward from Great Meadows, located in the northeast corner of the quadrangle, illustrates STYLE AND TIMING OF DEGLACIATION Pre-Illinoian Due to the scant distribution and poor preservation of the pre-Illinoian deposits, and lack of record nizable recessional deposits, the history of the pre-Illinoian deglaciation is unclear. If deglaciation proceeded as it did in the late Wisconsinan, then ice-recessional positions may have been marked by the heads-of-outwash of glaciofluvial deposits laid down in the Musconetcong and Pohatcong valleys. and ice-contact deltas laid down in glacial lakes in the Pequest Valley. Except for a few high-standing emnants in the lower parts of the Musconetcong and Pohatcong valleys (Witte and Stanford, 1995) all pre-Illinoian stratified deposits have been removed by erosion. Similar to the older glacial drift, the Illinoian deposits also preserve a poor record of deglaciation. Based on the distribution of Illinoian drift in the quadrangle and surrounding area (Witte and Stanford, 1995 the Illinoian glacial border lies a few miles south of and generally mimics the course of the late Wisconsinan glacial border. The southern edge of the Illinoian drift sheet is poorly defined, although a remnant of a terminal moraine crosses the Pohatcong Valley at the town of Washington. Thick till just up-valley rom the moraine (table 1) helps support the location of a terminal position here. An end moraine in Pequest Valley is the only recessional deposit of Illinoian age identified in the quadrangle. This feature was originally thought to have been of late Wisconsinan age by Bayley and others (1914) and Ridge 1983) based on their finding a few lightly weathered dolostone boulders on its surface. However, close inspection has shown that the dolostone clasts were only found near dolostone outcrops on the western side of the ridge. The dolostone clasts may have also been derived from ice-rafted debris laid down in Lake Oxford in late Wisconsinan time. Additionally, a 14 foot (4 m) deep trench dug at the crest of the moraine showed moderately weathered till devoid of carbonate clasts. Based on the lack of carbonate material, the advanced degree of weathering of crystalline clasts, and pervasive ferro-manganese staining, this material compares favorably with other till in the area that has been mapped as Illinoiar An exploratory boring located near the crest of the moraine (well 23, table 1) shows that the drift there s 52 feet (16 m) thick and provides additional evidence that this cross-valley ridge is a moraine rather than thin till perched on carbonate bedrock. The similarity in the course of the Illinoian and late Wisconsinan drift borders suggests that the Illinoian deglaciation may have proceeded similarly as the late Wisconsinan with glacial lakes forming in parts of the Pequest Valley. Illinoian stratified deposits are rare. They include stratified sand and gravel in the Pohatcong Creek valley southeast of the guadrangle that appears to be remnants of an extensive Illinoian valley train and outwash-fan laid down at the time of the Illinoian glacial maximum. In the adjoining Belvidere uadrangle (Witte and Ridge, 2021), small deposits of weathered gravel and sand on Scotts Mountain record deposition in ice-dammed proglacial lakes that formed in basins that drained toward the glacier (Witte and Ridge, 2021). All other recessional deposits have been eroded or lie buried beneath the Late Wisconsinan The late Wisconsinan recessional history of the Laurentide ice sheet is well documented for northwes ern New Jersey and parts of eastern Pennsylvania Epstein (1969) Ridge (1983) Cotter and others (1986), and Witte (1988 and 1997) showed that the margin of the Kittatinny and Minisink Valley lobes retreated systematically with minimal stagnation. By mapping morphosequences (Jahns, 1941; Koteff and Pessl, 1981) many ice-recessional positions have been delineated in Kittatinny Valley (Ridge, 1983; Witte, 1988 and 1997). In addition, moraines and the interpretation of glacial lake histories, based on correlative relationships between elevations of delta topset-foreset contacts, former glacial-lake-water plains, and lake spillways, provided a firm basis for reconstruction of the ice-recessional history of the Kittatinny Valley ice lobe. However, the age of the terminal moraine, timing of the late Wisconsinan maximum, and precise chronology of deglaciation is very uncertain. This is due to scant radiocarbor dates because of a lack of organic material that can be used to date deglaciation, inadequacies of dating bog-bottom organic material and concretions, and use of sedimentation rates to extrapolate bottom radiocarbon dates. In addition, few lake-bottom exposures show varves that can be used The few radiocarbon dates available bracket the age of the terminal moraine and retreat of ice from New Jersey Radiocarbon dating of pre-advance organic material cored from Budd Lake in the Tranguility guadrangle by Harmon (1968) vielded a date of 22.89 ka +/- 720 yr (I-2845) and a concretion sampled from sediments of Lake Passaic by Reimer (1984) that yielded a date of 20.18 ka +/- 500 yr (QC-1304) suggests that the age of the terminal moraine is about 22 ka to 20 ka. Basal organic material cored from a bog on the side of Jenny Jump Mountain approximately 3 miles (4.8 km) north of the erminal moraine by D. H. Cadwell (written comm., 1996) indicates a minimum age of deglaciation at 19.34 ka +/- 695 yr (GX-4279). Similarly, basal-organic material from Francis Lake in Kittatinny Valley (Cotter, 1983), which lies approximately 8 miles (12.9 km) north of the terminal moraine, indicates a minimum age of deglaciation at 18.57 ka +/- 250 yr (SI-5273). The edge of the late Wisconsinan ice sheet in the study area, called the Kittatinny Valley lobe, consisted of several smaller sublobes named here the Delaware Valley. Mountain Lake, Moores Pond, and equest (fig. 9). These were initially identified by Ridge (1983) with the exception of Moores Pond, which was grouped with the Mountain Lake sublobe. The limit of the late Wisconsinan glacial border is well defined in the quadrangle, as it is most elsewhere in New Jersey. It is generally marked by the outer edge of the terminal moraine. However, in some places the border extends as much as 1,000 feet

deltas lie down-valley from the moraine and mark the southern limit of the ice sheet. The distribution of late Wisconsinan till and ice-contact meltwater deposits out beyond the terminal moraine are consistent with the stratigraphy observed in the Delaware River valley near Foul Rift (Witte and Stanford, 1995; Witte and Ridge, 2021), which shows that the Delaware Valley sublobe extended southward from the position of the terminal moraine approximately 3,000 feet (914 m). The sublobe retreated northward of the position marked by the terminal moraine, and finally readvanced and deposited an end moraine. Therefore, the terminal moraine in some places is a recessional deposit. Regionally, the terminal moraine is a chronostratigraphic unit that marks or very nearly marks the late Nisconsinan glacial border. Locally it may mark as much as two thousand years of deposition at the margin of a very slowly retreating ice lobe. Based on the geometry of the Moores Pond segment, the outer margin of the moraine may be much older than its inner margin. The width of the morainal belt near Moores Pond compared with the much narrower moraine down-valley suggests that in places the terminal moraine was laid down during a period of very slow glacial retreat. Typically, the innermost parts of the morainal segments have fewer ridges, fewer elongated depres-Glacial Lakes Promorainal ice-contact deltas in the Pequest Valley south of Townsbury indicate the former existence of a glacial lake in the Oxford basin. The lake and its deposits were described earlier by Ridge (1983 Apparently, during the initial advance of the Kittatinny Valley lobe, ice from the Delaware Valley and Mountain Lake sublobes blocked drainage in Pequest Valley (fig. 9). This ice dam resulted in the formation of Lake Oxford stage L which in the Belvidere guadrangle (Witte and Ridge 2021) rose to a level controlled by a low drainage divide, located near the site of the Oxford Stone Quarry at an elevation of 580 feet (177 m). Discharge from the lake spilled out into the Pophandusing Brook valley. Based on the glacial stratigraphy observed near Foul Rift (Witte, 2001b), the margin of the Townsbury sublobe may have also retreated north of the position now marked by the terminal moraine Due to steep relief, the position of the Mountain Lake and Moores Pond sublobes may not have varied that nuch during this phase of ice margin oscillation. Because there have been no other stage I deposits recognized in the Pequest Valley it is assumed that retreat from the terminal position was continuous After a small re-advance the terminal moraine was deposited at the margin of the Pequest sublobe.

> Concurrently, a moraine was laid down at the margins of the other sublobes. At some time prior to or synchronous with the formation of the terminal moraine was the lowering of Lake Oxford to stage II (fig. 9), marked by deltaic deposits that are as high as 520 feet (158 m). These deposits are correlative (time equivalent) with the Townsbury segment of the terminal moraine. This lake may have spilled out through a threshold located near St. Nicholas Church (520 feet) as suggested by Ridge (1983), or it may have followed a course along the edge of the Mountain Lake and Delaware Valley sublobes. There is no direct evidence for this other than the fact that this is the only path that the lake water could have taken. Erosion of the Bridgeville segment of the terminal moraine on the south side of the Pequest River may indicate erosion by the lake's outlet waters. Retreat from the terminal moraine resulted in the formation of Lake Pequest in the Pequest Valley and ake Buttzville in the Mountain Lake basin. These lakes and their deposits were previously described by Salisbury (1902) and Ridge (1983). Both lakes formed in valleys that drained away from the glacier margin and that were dammed by the terminal moraine, and they discharged over local spillways cut through the moraine. In Pequest Valley, ice-retreatal positions are marked by two ice-contact deltas laid down in Lake Pequest and in the Mountain Lake area two retreatal positions are marked by lacus-

> also become lower due to erosion. Ridge (1983) suggested that drainage may have been catastrophic

deposits and erosion of Lake Oxford, stage II deposits south of the moraine in Pequest Valley. A mas-

sive failure of the moraine dam in the Buttzville area may be an alternative explanation for the sudden

based on erosion of the Townsbury moraine's outer margin, and the geometry of meltwater-terrace

Based on the composition and morphology of the terminal moraine it is a polygenetic deposit that was formed by the melting out of and release of sediment from the glacier terminus, and the pushing of debris and debris-rich ice at an active glacier margin (fig. 7). Its morphology and its composition were further trine-fan deposits laid down in Lake Buttzville. Coincident with or following retreat from the terminal moraine was the lowering of Lake Oxford and ero-The moraine in the Pohatcong Creek valley near Washington represents the Illinoian terminal moraine sion of the moraine and deltaic deposits along the course of the modern-day Pequest River. The timing and a small moraine in the Pequest River valley marks an Illinoian recessional position. Both moraines of this event is not clear. The elevation of ice-contact deltas laid down in Lake Pequest near the village form cross-valley ridges, are chiefly made of moderately weathered till, and have subdued knob and of Great Meadows suggests that Lake Oxford may have remained at or nearly at the St. Nicholas urch level during the initial retreat from the terminal moraine. Deltas in Lake Pequest become lower in the northern part of the lake basin (Ridge, 1983; Witte, 1988) indicating that the lake's spillway had

Deposits of glacial meltwater streams Sediment carried by glacial meltwater streams was chiefly laid down in the Pequest Valley and in the Beaver Brook Valley in the northwest corner of the quadrangle at and beyond the glacier margin in

morainal areas are formed by several enclosed to partially enclosed depressions and bowls. They

represent the opposite form of the compound morainal knoll and they formed where residual ice

In places the moraine is cut by small, narrow, straight to sinuous channels. These features may be as

streams where they carry off discharge from small springs. Some channels probably formed during the

earlier phases of moraine formation when meltwater streams emanating from the active glacier margin

flowed through the moraine's outer border. Later, during stagnation, meltwater chiefly from melting stag-

sions and are marked by knob and kettle rather than ridge and trough topography. Overall, segments

parallel ridges than those abutting thin patchy drift. This strongly suggests that unconsolidated ma-

terial near the glacier's terminus may have supplied most of the sediment that makes up the moraine,

End moraines consist of non-compact, bouldery, silty-sandy to sandy till with minor beds and lenses

of compact till and water-laid sand, silt, and gravel (fig. 6). Additionally, stratified drift is not a major

constituent, even in places where the moraine crosses river vallevs or former glacial lake basins.

The lithology of the moraine is decidedly local in origin. This was noted by Salisbury (1902, p. 254)

ture of the formations over which the ice has passed." For example, in the Delaware Valley where

the terminal moraine rests on outwash, it contains many rounded, waterworn stones that mimic the

the guadrangle, crystalline materials make up the bulk of the moraine. Outcrops of morainal materials

value. The most outcrops occur where the moraine has been removed to expose economic deposits

of sand and gravel, such as Foul Rift, New Jersey located in the Belvidere quadrangle (Witte and

till with minor interlayers and lenses of sorted sand, silt, and gravel. Upon close inspection most of

the till is faintly layered with individual layers varying greatly in thickness from less than one foot to as

much as 10 feet (3 m). Layering is typically subhorizontal, its base marked by a concentration of larger

of morainal sediment. its indistinct lavering and grading, and inclusion of water-laid sand, silt, and gravel

beds and lenses suggest that most of this material has had a complex history of deposition.

modified by contemporaneous and postglacial resedimentation due to the melting of buried ice.

stones and crude normal grading has been observed in some of these pseudo beds. The heterogeneity

are rare due to the difficulty of digging the bouldery drift, but more importantly its lack of economic

Ridge 2021) The few exposures observed by the authors show that the moraine consists largely of

who reported "... the lithologic composition of the till varied from point to point, according to the na-

provenance of the outwash. Whereas on Jenny Jump Mountain, located in the northwest corner of

abutting thick, continuous till are larger, more continuous, and have more fully developed moraine

nant ice, drained from hollow to hollow and eventually formed a loosely organized drainage network.

much as 40 feet (12 m) deep, and typically have bouldery floors. Today they are used by ephemeral

initially supported the higher areas along the glacier's margin.

rather than nearby glacially eroded bedrock.

swale topography.

drop in the level of Lake Oxford. Coarse-grained meltwater-terrace deposits in the Bridgeville area in the Belvidere guadrangle (Witte and Ridge 2021) may have been laid down during this event and these deposits further support the flood hypothesis. Retreat of the ice sheet from the Great Meadow area resulted in the expansion of Lake Pequest (fig. 2) in the upper part of Pequest Valley. Several ice-recessional positions are marked by ice-contact deltas and lacustrine-fan deposits laid down in the former glacial lake (Ridge, 1983; Witte, 1988). The decrease in the relative elevations of deltas in the upper part of the lake basin also shows that the lake's outlet over the moraine at Townsbury continued b become lower throughout the later part of the lake's history. It is not known whether Lake Pequest existed in postglacial time. The position of stream-terrace deposits along the Pequest River and Bear Creek, and the distribution of thick peat that appears to occupy former stream channels cut in the floor of the former lake basin seems to suggest that the lake may have drained in the late Pleistocene or early Holocene time. However, the timing of this event is not clear. POSTGLACIAL HISTORY Following deglaciation, cold and wet conditions, and sparse vegetative cover enhanced erosion of hillslope material by solifluction, soil creep, and slope wash. Some of this material lies in small colluvial fills in first-order drainage basins. Mechanical disintegration of rock outcrops by freeze-thaw provided additional sediment, some of which now lies in aprons at the base of cliffs on Jenny Jump Mountain. A few small boulder fields were formed where boulders, transported downslope by creep, accumulated at the base of hillslopes and in first-order drainage basins. These fields, and other concentrations of boulders that were formed by glacial transport and meltwater erosion, were further modified by freeze and thaw, their stones reoriented to form crudely shaped stone circles. Gradually as climatic conditions warmed, vegetation spread, and was succeeded by types that further limited erosion. Between 14.25 ka and 11 25 ka (Cotter 1983) lacustrine sedimentation, which had been dominated by clastic material became enriched in organic material. This transition represents a warming of the climate such that subaquatic vegetation could be sustained and also marks a change in terrestrial vegetation from herb (tundra) to spruce and hemlock parkland, and eventually to spruce and hemlock forests. Oak and mixed hardwood forests started to populate the landscape around 9.7 ka (Cotter, 1983). The onset of stream-terrace deposition presumably started when meltwater was cut off from the stream valleys, and stream discharge diminished substantially. This promoted an interval of lateral erosion across the valley floor as the larger streams began to meander. Sometime later, a period of incision ensued and the streams cut down to their present levels. Based on the alluvial stratigraphy in Minisink Valley (Witte, 1997) it appears that the onset of delayed isostatic rebound, which has been estimated at 14 ka (Koteff and Larsen 1989) and the onset of warmer climate which led to the growth of deeper-rooted and more extensive vegetation that reduced sediment load in the drainage basin, may have initiated incision.

ECONOMIC RESOURCES The most valuable geologic resource in the quadrangle is sand and gravel. It is used extensively in construction as aggregate, sub-base material, select fill, surface coverings, and decorative stone. A large part of the local groundwater supply also lies in stratified deposits. Most of the sand and gravel are mined from deltaic deposits laid down in Lake Pequest. These deposits typically contain sand and gravel in their upper and proximal parts, whereas their lower and more distal parts contain more silt and clay. Peat and humus, which are primarily used as a soil conditioner, are found in the many bogs and swamps that lie north of the late Wisconsinan limit. Most of the peat is of reed and sedge type with organic content varying between 60 and 96 percent (Waksman, 1942). In places underlain by carbonate rock, marl (calcium-rich mud) may be found in small lakes and ponds. It was used as a soil conditioner and an ingredient to make cement.

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Clay, derived from glacial lake-bottom deposits, deeply weathered older till, and weathered bedrock,

facture bricks and ceramics.

was also of limited economic importance. It was used as a soil conditioner and raw material to manu-

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DESCRIPTION OF MAP UNITS Map units denote unconsolidated materials more than 5 feet (1.5 m) thick. Color designations, based on Munsell Color Company (1975), were determined from naturally moist samples. HOLOCENE AND LATE WISCONSINAN Postglacial deposits

ARTIFICIAL FILL - Man-made rock waste, gravel, sand, silt, and manufactured materials. As much as 25 feet (8 m) thick. Not shown beneath roads, and railroads where it is less than 10 feet (3 m) thick. Primarily used to raise the land surface, construct earthen dams, and form a solid base for roads and railways. ALLUVIUM - Stratified, moderately- to poorly-sorted sand, gravel, silt, and minor clay and organic material. Locally bouldery. As much as 25 feet (8 m) thick. Includes planar- to cross-bedded gravel and sand in channel deposits, and cross-bedded and rippled sand. massive and parallel-laminated fine sand, and silt in flood-plain deposits. In places, overlain by and interlayered with thin organic material and colluvium. STREAM-TERRACE DEPOSITS - Stratified, well- to moderately-sorted, massive to laminated, and minor cross-bedded fine sand, and silt in terraces above and flanking present or former stream courses. As much as 15 feet (4 m) thick. Overlies planar to cross-bedded cobble-pebble gravel and pebbly sand; as much as 20 feet (6 m) thick.

SWAMP AND BOG DEPOSITS - Peat of reed, sedge, and woody origin, and muck underlain

with alluvium and thin colluvium. In areas underlain by carbonate rock, marl as much as 20

by laminated organic-rich silt and clay. As much as 25 feet (8 m) thick. Locally interbedded

feet (6 m) thick, typically underlies the peat and muck.

Meltwater deposits GLACIAL-LAKE DELTAS - Stratified, sand, gravel, and silt deposited by meltwater streams proglacial lakes at and beyond the glacier margin. Includes well sorted sand and boulr-cobble to pebble gravel in glaciofluvial topset beds that are as much as 25 feet (8 m) hick. Overlie and grade into foreset beds that dip 20° to 35° basinward and consist of well- to moderately-sorted, rhythmically-bedded cobble-pebble and pebble gravel and sand. These beds grade downward and outward into ripple cross-laminated and parallel-laminated, sand, silt and pebble gravel that dip less than 20°. Lower foreset beds grade into gently inclined prodelta bottomset beds of rhythmically-bedded, ripple cross-laminated to graded fine sand and silt with minor clay drapes. Thickness may be as much as 100 feet (30 m). Qwdv similar to Qwde, but fluvial topset beds may be as much as 65 feet (20 m) thick and deposit may have once filled the valley from wall to wall. GLACIAL LACUSTRINE-FAN DEPOSITS - Stratified sand, gravel, and silt deposited by neltwater streams in proglacial lakes at and beyond the glacier margin. As much as 60 feet 18 m) thick. Includes well- to moderately-sorted sand and gravel in massive- to rhythmical-

ly-bedded foreset beds that dip as much as 25° basinward and grade into ripple cross-laminated to parallel-laminated foreset beds of sand, fine gravel and silt. Foreset beds grade outward into or overlap gently inclined bottomset beds that consist of rhythmically-bedded. ripple cross-laminated and parallel-laminated fine sand and silt with minor drapes of silty clay. GLACIAL LAKE-BOTTOM DEPOSITS - Parallel-laminated, irregularly to rhythmically-bed ded silt, fine sand, and clay; and minor cross-laminated silt, fine sand, and minor clay deposited on the floor of glacial lake basins chiefly by density flows and settling of fines. As much as 100 feet (30 m) thick.

MELTWATER-TERRACE DEPOSITS - Stratified, well- to moderately-sorted sand, cobble-pebble to pebble gravel, and minor silt deposited by meltwater streams as terraces incised in terminal moraine and valley-delta deposits. As much as 20 feet (6 m) thick. Sedinent and bedforms similar to delta topset beds. Includes bouldery lag deposits formed on till. KAME - Stratified, well- to poorly-sorted sand, boulder- to pebble-gravel, silt, and interbedded flowtill in small collapsed hills and ridges overlying till. Presumed to be ice-hole and crevasse fillings. As much as 50 feet (15 m) thick. Attitude of bedding is highly variable, and beds are commonly collapsed.

VETCONG TILL - Compact, unstratified, poorly sorted yellowish-brown (10YR 5/4), light sh-brown (2.5Y 6/4), pale brown (10YR 6/3) to brown (10YR 5/3) noncalcareous sand nd silty sand that typically contains 10 to 20 percent gravel; as much as 80 feet (24 m) thick. ocally overlain by thin discontinuous non-compact to slightly compact poorly sorted indistinctly layered yellow-brown (10YR 5/6-8), light yellowish-brown (10YR 6/4) sandy silt that contains as much as 30 percent gravel, and minor thin beds of well- to moderately sorted sand, gravel, and silt; as much as 10 feet (3 m) thick. Clasts consist of unweathered to lightly weathered gneiss and granite with minor marble, quartzite, sandstone, and carbonate rock. Matrix is a varied mixture of gneiss and granite fragments, guartz, feldspar, mica, heavy minerals, and silt; minor constituents may include fragments of sandstone, siltstone, quartzite, carbonate rock, and clay. Near the limit of the late Wisconsinan glaciation weathered naterials derived from preglacial surficial deposits and weathered rock are mixed with the lesser weathered sediment. Qwtnr denotes areas of thin till, typically less than 10 feet thick, cattered bedrock outcrops, and minor thin colluvium.

KITTATINNY VALLEY TILL - Compact, unstratified, poorly sorted light olive-brown (2.5Y 4) to grayish-brown (2.5Y 5/2), gray (5Y 5/1) to olive-gray (5Y 5/2) calcareous sandy silt and silty sand that typically contains 5 to 15 percent gravel; as much as 70 feet (21 m) thick. Locally overlain by thin, discontinuous, non-compact to slightly compact, poorly sorted, indistinctly layered yellow-brown (10YR 5/6-8), light yellowish-brown (10YR 6/4) sandy silt that contains as much as 30 percent gravel, and minor thin beds of well- to moderately sorted sand, gravel, and silt; as much as 10 feet (3 m) thick. Clasts chiefly are unweathered to lightly weathered slate, silstone, sandstone, dolostone with minor limestone, chert, quartzite, and quartz-pebble condomerate. Matrix is a varied mixture of nonweathered to lightly weathered quartz, rock fragments, and silt; minor constituents include feldspar and clay. On the northwest flank of Jenny Jump Mountain and the New Jersey Highlands, additional minor ponstituents include clasts of gneiss, and granite, and mica and heavy minerals in matrix. Qwtkr denotes areas of till; typically less than 10 feet thick, a few bedrock outcrops, and minor thin colluvium.

FERMINAL MORAINE – Unsorted, poorly compact sandy-gravelly till with minor layers of very poorly stratified sand, gravel, and silt deposited in hummocky, bouldery, segmented idges at the margin of the Kittatinny Valley lobe near or at its terminal position. As much as 150 feet (46 m) thick. Locally named the Mountain Lake, Moores Pond, and Townsbury moraines. IOLOCENE AND WISCONSINA

ALLUVIAL-FAN DEPOSITS - Stratified, moderately-to poorly sorted, brown to vellowish-brown, gray sand, gravel, and silt in fan-shaped deposits; as much as 35 feet (11 m) thick. Includes massive to planar-bedded sand and gravel and minor cross-bedded channel-fill sand. Bedding dips as much as 30° toward the trunk valley. Locally interlayered with instratified, poorly sorted, sandy-silty to sandy gravel. ALLUVIUM AND COLLUVIUM, UNDIFFERENTIATED - Stratified, poorly to moderately sorted, brown to yellowish-brown, gray sand, silt and minor gravel; as much as 20 feet (6 m)

thick. Interlayered with or overlying, massive to crudely layered, poorly sorted sand, silt, and minor gravel. MIDDLE PLEISTOCENE TO HOLOCENE GNEISSIC AND GRANITIC COLLUVIUM - Massive to crudely layered, slightly compact,

poorly sorted vellowish-brown (10YR /4-8) to dark vellowish-brown (10YR 4/4), brown (10YR 5/3), strong brown (7.5YR 5/6) silty sand and sandy silt, containing as much as 60 percent ightly to moderately weathered angular to subangular cobbles, pebbles, and boulders of gneiss and foliated granite; as much as 50 feet (15 m) thick. Matrix consists of a varied mixture of quartz sand, weathered feldspar, mica, amphibole, heavy minerals, silt, and clay. CARBONATE ROCK COLLUVIUM - Massive to crudely lavered, slightly compact, poor-

ly sorted dark yellowish-brown (10YR 4/4) to yellowish-brown (10YR 5/4), reddish-yellow 5YR 6/8) to strong-brown (7.5YR 5/6-8) clayey silt containing as much as 5 percent angular to subangular fragments and pebbles of leached carbonate rock, chert, and minor quartzite; as much as 20 feet (6 m) thick. Matrix consists of a varied mixture of clay, quartz sand, rock fragments, and silt. JNDIFFERENTIATED COLLUVIUM - Poorly sorted, brown to yellowish-brown, gray sand, It, and minor gravel derived from a mixture of weathered bedrock and till; as much as 10

PRE-WISCONSINAN **DLDER COLLUVIUM** - Massive to crudely layered, slightly compact, poorly sorted red 5YR 4/8), strong-brown (7.5YR 5/6) clavey silt to sandy silt; as much as 25 feet (8 m) thick. ontains as much as 20 percent angular to subangular clasts of weathered gneiss and grante and minor subangular to rounded weathered carbonate rock, sandstone, and quartzite. Matrix is typically a mixture of quartz, clay, silt, rock fragments, minor mica, and heavy minerals. In subsurface only, typically underlies Wisconsinan colluvium, particularly unit Qcg.

et (3 m) thick

FLANDERS TILL - Massive, compact, poorly sorted strong-brown (7.5YR 5.6), pale-brown (10YR 6/3), yellow (10YR 7/6) to yellowish-brown (10YR 5/4-6) clayey silt and sandy silt that vpically contains 5 to 15 percent gravel. As much as 60 feet (18 m) thick. Locally reddish in till rich in weathered carbonate rock. Clasts consist of gneiss, foliated granite, quartzite, quartz-pebble conglomerate, slate, sandstone, chert, and carbonate rock. Crystalline clasts have thick to thin weathering rinds (0.5 in.); carbonate clasts are generally decomposed to lepths exceeding 10 feet (3 m). Other clasts have thin weathering rinds (0.1 in.), and pitted surfaces. Matrix is a varied mixture of quartz, rock fragments, silt, clay, weathered feldspar. minor mica, and heavy minerals. Subvertical joints moderately developed to depths of at least 10 feet (3 m). Iron and iron-manganese stain the surface of clasts, sand grains, and joints to depths of at least 10 feet (3 m). In places, some clasts are rubified (reddish) due to a thin coating of iron oxide.

MORAINAL DEPOSITS - Sandy silty to silty sandy compact till, stony noncompact sandy till, and minor well- to moderately-sorted sand and gravel in broad cross-valley ridge; as much as 65 feet (20 m) thick.

PRE-ILLINOIAN

PORT MURRAY TILL - Deeply weathered, compact, massive to crudely layered reddish-yellow (7.5YR 6/6-8) to strong-brown (7.5YR 5/6-8)to yellowish-brown (10YR 5/6-8), or reddish-brown (5YR 4/3) to weak-red (2.5YR 4/3) sandy silt and clayey silt that typically contains to 5 percent gravel: as much as 30 feet (9 m) thick. Gravel consists of pebbles and cobbles of quartzite, gneiss, sandstone, shale, chert, carbonate rock, an a few boulders of quartzite and gneiss. Gneiss clasts have thick weathering rinds or are completely decomposed; carbonate clasts are fully decomposed. Quartzite, sandstone, and chert pebbles and cobbles nave pitted surfaces and thin weathering rinds. Matrix contains clay, quartz weathered rock fragments, minor weathered mica, and few heavy minerals. Subvertical joints are poorly to moderately developed to depths exceeding 10 feet (3 m). Clasts and joints are commonly coated with red iron and black iron-manganese oxide.

TERTIARY (?) TO QUATERNAR WEATHERED BEDROCK DERIVED FROM GNEISS, FOLIATED GRANITE, AND MINOR SYENITE - Massive to lavered, noncompact to compact brown (10YR 5/3), vellowish-brown 0YR 5/6-8), strong-brown (7.5YR 5/6), white (5YR 8/1), and red (2.5YR 5/8) silty sand to clayey silt saprolite consisting of clay, quartz, minor mica and heavy minerals; and sandy, blocky rock rubble. As much as 100 feet (30 m) thick. Includes thin stony and blocky colluvium on hillslopes, and bouldery to cobbly mantle of angular to subangular gneiss and granite on very gentle hillslopes; as much as 10 feet (3 m) thick. Weathered zone grades downward through a bouldery zone of joint blocks into underlying unweathered bedrock, and extends deeply along joints, fractures, and bedrock layers. Joint blocks and rock rubble typically have

WEATHERED BEDROCK DERIVED FROM SLATE, SILTSTONE AND SANDSTONE Massive to layered, noncompact to slightly compact reddish-brown (5YR 4/3-2.5YR 4/4) silt clay or sandy silt decomposition residuum of clay, quartz, and rock fragments; and slate-chip gravel containing flat pebbles of slate, tabular pebbles of siltstone, and sandstone; as much as 30 feet (9 m) thick. Locally includes thin shaly colluvium on hillslopes: as much as 10 feet) thick. Weathered zone typically grades downward through a zo

thick weathering rinds.

underlying unweathered bedrock. WEATHERED BEDROCK DERIVED FROM DOLOSTONE AND LIMESTONE - Massive, compact light-red (2.5YR 6/6) to red (2.5YR 5/6), reddish-vellow (7.5YR 7/8) to strong-brown 7.YR 5/6) to yellowish-brown (10YR 5/6), or yellow (10YR 7/6), locally highly variegated, clay and silty-clay solution residuum of clay, quartz, and iron oxide; generally containing less than 5 percent chert, vein quartz and minor quartzite; thickness is highly variable, typically less than 15 feet (5 m), but locally as much as 100 feet (30 m). Locally includes thin colluvium as much as 5 feet (1.5 m) thick on gentle hillslopes. Also may include sand, gravel, silt, and clay washed into sinkholes and solution cavities from overlying colluvial, alluvial, and glacial sediment. Weathered zone typically ends at an abrupt, very irregular contact with unweathered bedrock and also extends deeply along joints and fractures.

Bedrock - Extensive outcroppings, minor regolith, and scattered erratics. **Bedrock** - Regolith; chiefly rock waste on steep hillslopes and ridge crests, minor talus, scattered erratics, and a few small outcrops.

EXPLANATION OF MAP SYMBOLS

..... Contacts - dashed where inferred. Location of well or boring - locations accurate to within 500 feet. Geologic log listed in table 1 (in pamphlet) 9.4 Location of figure 4.

-400- Subsurface contours - topography of the buried bedrock surface. Contour interval is 50 feet. Small meltwater channel.

Glacial lake spillway - elevation listed in feet.

Moraine ridge Large kettle in glacial outwash or moraine - smaller kettles on moraines are not shown. Tic marks point downslope.

VERTICAL EXAGGERATION 10x. Wells projected to line of section

Fluvial scarp - line lies at base of scarp. Tic marks point upslope. Water body.

★ Inactive sand and gravel pit in 2015.

X Active sand and gravel pit in 2015.



1995 MAGNETIC NORTH NEW JERSEY DECLINATION AT CENTER OF MAP

SURFICIAL GEOLOGY OF THE WASHINGTON QUADRANGLE WARREN, HUNTERDON, AND MORRIS COUNTIES, NEW JERSEY



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2021







Surficial Geology of the Washington Quadrangle Warren, Hunterdon, and Morris Counties, New Jersey

New Jersey Geological and Water Survey Open-file Map OFM 144 2021

Pamphlet containing Table 1 to accompany map.

Table 1. Selected records of wells in the Washington quadrangle, Warren, Hunterdon, and Morris Counties, New Jersey. The listed wells were drilled for private and public water supply and exploration. Wells listed with a NJDEP permit number are on file at the New Jersey Department of Environmental Protection. All other records are from exploratory borings that are on file at the New Jersey Geological and Water Survey. The location of wells listed with NJDEP permit numbers are based on property maps and are generally accurate to within 500 feet of the actual well location. Exploratory borings located in the field. Well/boring number is **bolded** when depicted on cross section A-A' (wells 21 and 23).

Well/Boring Number	NJDEP Permit Number	Discharge Reported by Drillers (gpm)	Depth Below Land Surface (ft)	Driller's Log
1	24-6286	10	0-18 18-61 61-65	clay and gravel very rotten granite granite
2	24-12547	10	0-68 68-69 69-110 110-123	overburden and sand stone quartz and rotten stone granite
3	24-16306	none reported	0-98 98-498	sand granite
4	24-18802	30	0-105	clay, sand, and gravel
5	24-12545	none reported	0-74 74-80 80-92	overburden, sand, clay, and gravel brown limestone limestone with water
6	24-15669	5	0-15 15-180 180-225	overburden sand, clay, and gravel brown and white granite
7	24-21677	30	0-105 105-120	clay and gravel sand and gravel
8	24-15419	none reported	0-45 45-100	clay, sand, gravel, and water granite
9		none reported	0-15 15-34 34-38 38-40	sand, silt, trace of gravel sand, gravel, trace of silt boulders sand, gravel, trace of silt
10	24-18577	70	0-138 138-148	sand, clay, and gravel limestone
11	24-14810	20	0-46 46-70	sand and clay brown sandstone and granite

Well/Boring Number	NJDEP Permit Number	Discharge Reported by Drillers (gpm)	Depth Below Land Surface (ft)	Driller's Log
12	24-13404	35	0-18 18-56 56-99	hardpan brown sandstone granite
13	24-18428	12	0-70 70-105 105-248	sand, clay, and gravel soft sandstone granite
14	24-6529	22	0-67 67-98	clay, sand, and gravel soft granite
15	24-18096	14	0-30 30-50 50-100 100-121 121-126 126-133	sand yellow clay clay and gravel hard clay brown granite water
16	24-20443	10	0-47 47-52 52-125	sand and gravel boulder gravel
17	24-5451	15	0-135 135-142 142-155	sand and gravel clay gravel
18	24-11549	8	0-8 8-140	overburden sand and gravel
19	24-14135	30	0-35 35-91 91-100	hardpan sand, clay, and gravel sand, gravel, and water
20		none reported	0-28 28-50 50-91	clay, sand, and gravel mix of rock and clay hard rock
21		none reported	0-28 28-37 37-40 40-68 68-101 101-104	sand and gravel sand, silt, and gravel boulder clay, rocks, some sand mix of clay, gravel, and rock hard rock
22		none reported	0-52 52-56 56-78 78-104	sand and gravel light brown clay sand and gravel rock
23		none reported	0-25 25-50 50-52 52-61 61-600	sand and gravel clay and gravel cobbles soft, sandy yellow rock carbonate rock
24	24-7192	300	0-147 147-155	silt, gravel, and brown silt large gravel and water
25	24-18319	20	0-120 120-300	clay brown rock

Well/Boring Number	NJDEP Permit Number	Discharge Reported by Drillers (gpm)	Depth Below Land Surface (ft)	Driller's Log
26	24-13958	10	0-20 20-55 55-148	clay sand mix of soft and hard granite
27	24-16743	30	0-50 50-165	clay and sand granite
28	24-14474	50	0-60 60-200	overburden limestone
29	24-4871	30	0-58 58-81	clay and sand granite or limestone
30	24-19525	100	0-60 60-375	overburden limestone
31		none measured	0-10 10-20 20-25 25-50 50-61	sand and silt sand, silt, and gravel sand and silt sand, silt, and gravel yellow silt, clay, trace of sand
32	24-16524	15	0-29 29-125	overburden granite
33	24-15090	100	0-10 10-20 20-28 28-82	sand and clay gravel clay gravel and broken stone
34	24-17634	9	0-5 5-20 20-120	clay sandy clay granite
35	24-8554	25	0-26 26-120	overburden and boulders gray granite
36	24-1562	10	0-40 40-73	clay and boulders limestone
37	24-19193	15	0-55 55-75	clay and silt limestone
38	24-18427	none reported	0-40 40-75 75-165	clay and sand sandstone granite
39	24-5838	none reported	0-5 5-25 25-50 50-70	overburden sand and gravel clay and mud gravel and rotten shale
40	24-2808	16	0-126 126-146	clay, boulders, and hardpan sandstone
41	24-17697	25	0-15 15-75	clay and boulders granite

Well/Boring Number	NJDEP Permit Number	Discharge Reported by Drillers (gpm)	Depth Below Land Surface (ft)	Driller's Log
42	24-17318	50	0-10 10-50 50-70	sandy clay and boulders sandy clay brown shale
43	24-18099	15	0-35 35-91 91-148	sandy hardpan sandy clay brown shale
44	24-15931	6	0-30 30-50 50-325	clay shale slate
45	24-17656	14	0-69 69-198	clay, shale, and sand slate
46	24-11116	2	0-28 28-260 260-273	clay and gravel gray shale water at 260 ft and shale
47	24-13187	6	0-8 8-165	overburden shale
48	24-15998	10	0-200 200-250	clay limestone to shale
49	24-17636	15	0-51 51-145	clay and sand granite
50	24-16554	4	0-54 54-248	yellow hardpan granite
51	24-4158	2	0-20 20-54 54-230	clay clay, traces of sand rotten limestone
52	24-18389	20	0-95 95-170	overburden limestone
53	24-16900	15	0-5 5-15 15-200	soil hardpan shale
54	24-15589	27	0-45 45-198	clay gray shale
55	24-8679	20	0-80 80-105	overburden, gravel, water, and clay limestone
56	24-11588	none reported	0-70 70-350	boulders, clay, and gravel limestone
57	24-8198	0 (dry)	0-200	brown and gray granite
58	24-8261	none reported	0-87 87-345	yellow clay and stones limestone
59	24-1718	4	0-84	yellow clay, boulders, and gravel

Well/Boring Number	NJDEP Permit Number	Discharge Reported by Drillers (gpm)	Depth Below Land Surface (ft)	Driller's Log
60	24-5945	15	0-40 40-240 240-260	yellow clayey micaceous soil clay and sand mylonite
61	24-1462	2	0-25 25-44	clay limestone
62	24-15687	100	0-10 10-12 12-50 50-440	clay with broken boulders boulders boulders, broken rock, and clay limestone
63	24-6820	45	0-32 32-248	overburden limestone
64	24-320	30	0-90 90-100 100-223 223-240 240-263	clay clay and limestone black rock black rock and rotten brown rock granite
65	24-6807	30	0-20 20-115	overburden limestone
66	24-11136	15	0-70 70-260	overburden limestone
67	24-5771	5	0-22 22-262	clay hard limestone
68	24-8275	9	0-28 28-173 173-178 178-198	overburden limestone soft seam (decomposed zone) limestone
69	24-15429	20	0-53 53-60 60-79 79-90	overburden with clay and boulders limestone clay, limestone void limestone with clay and water
70	24-1570	2	0-16 16-160	hardpan limestone
71	24-18518	50	0-10 10-95 95-198	clay broken limestone limestone
72	24-18405	2	0-55 55-200	sand and gravel sandstone

Well/Boring Number	NJDEP Permit Number	Discharge Reported by Drillers (gpm)	Depth Below Land Surface (ft)	Driller's Log
73	24-6139	25	0-4 4-16 16-20 20-32 32-49 49-71	overburden brown granite gray granite water seam soft brown granite hard gray granite
74	24-16796	20	0-30 30-330	overburden granite
75	24-14492	16	0-16 16-71 71-80	sand and large gravel brown clay, sand, and gravel large gravel, sand, and water
76	24-1459	10	0-30 30-64	gravel and boulders sandstone