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Surficial geology of the Pleasant Mountain quadrangle, Open-File 99-5
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Surficial Geology of the Pleasant Mountain 7.5-minute Quadrangle, Oxford and Cumberland Counties, Maine

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INTRODUCTION

This report describes the surficial geology and Quaternary history of the Pleasant Mountain 7.5-minute quadrangle in southwestern Maine. Surficial earth materials include unconsolidated sediments (sand, gravel, etc.) of glacial and nonglacial origin. Most of these deposits formed during and after the latest episode of glaciation in Maine, within the last 25,000 years. Surficial sediments cover the bedrock over most of the quadrangle and are subject to many uses and environmental considerations. These include sand and gravel extraction, development and protection of ground-water supplies, siting of waste disposal facilities, and agriculture.

The field work for this study was carried out in stages, first to gather data for the Maine Geological Survey's (MGS) sand-and-gravel aquifer mapping program (Williams and others, 1987) and later to complete the surficial geologic mapping of the Pleasant Mountain quadrangle. Field work to update earlier observations, and preparation of the present report, were done in 1998-99 for the STATEMAP cooperative between the MGS and the U. S. Geological Survey (USGS).

Two maps are associated with this report. The *geologic map* (Thompson, 1999g) shows the distribution of sedimentary units and indicates their age, composition, and known or inferred origin. It also includes information on the geologic history of the quadrangle, such as features indicating the flow direction of glacial ice. This map, along with mapping done by the author in adjacent quadrangles, provides the basis for the discussion of glacial and postglacial history presented here. The *materials map* (Thompson, 1998) shows specific data used to help construct the geologic map. These data include observations from gravel pits, shovel and auger holes, construction sites, and natural exposures along stream banks. Sand and gravel aquifer studies by the MGS and USGS provide useful data on the stratigraphy of the quadrangle, including depth-to-bedrock from seismic logs (Williams and others, 1987).

Geographic setting

The Pleasant Mountain quadrangle is located in the White Mountain foothills of southwestern Maine. The map area extends in latitude from 44°00'00" to 44°07'30" N, and in longitude from 70°45'00" to 70°52'30" W. It includes part of the town of Bridgton in Cumberland County, and parts of Denmark, Fryeburg, and Sweden in Oxford County. The topography of the quadrangle is hilly, with elevations ranging from 362 ft (110 m) above sea level (Pleasant Pond in the southwest corner of map) to 2006 ft (611 m) on the highest summit of Pleasant Mountain.

The most prominent geographic feature in the map area is Pleasant Mountain, which consists of several peaks aligned along a north-south ridge. This mountain is underlain by a Mesozoic syenite complex (Sanders, 1971; Osberg and others, 1985). The syenite has intruded granite of the Sebago pluton, which is the dominant rock type throughout the remainder of the quadrangle. Many low hills and ridges occur elsewhere in the area. Some of them are elongated in a southeasterly direction as a result of glacial shaping.

A valley extends all along the western side of the quadrangle, including the Elkins Brook valley and its topographic extensions to the north and south. This valley forms the eastern margin of the Saco River lowland (see adjacent Fryeburg quadrangle). It played an important role in the glacial lake history of the region and is also significant because it contains nearly all of the sand and gravel resources in the study area. This topographic feature will be referred to henceforth as the Elkins Brook valley.

Several ponds occur in the quadrangle, the largest being Moose Pond. There are no major rivers in the map area. The brooks and ponds in the central and western parts of the quadrangle ultimately drain into the Saco River, while the easternmost part of the area drains into the Sebago Lake basin. Bedrock outcrops occur mainly at higher elevations, while the lowlands are thickly blanketed by glacial sediments. There are particularly extensive ledge exposures on Pleasant Mountain.

PREVIOUS WORK

Stone (1899) conducted a reconnaissance of this region during his statewide USGS study of Maine's glacial gravel deposits. Leavitt and Perkins (1935) likewise examined the area for their *Survey of Road Materials and Glacial Geology of Maine*. Prescott (1979, 1980) compiled well and test hole data, and carried out preliminary surficial and gravel aquifer mapping. Thompson compiled a more detailed aquifer map that included the Pleasant Mountain quadrangle, as part of the Significant Sand and Gravel Aquifer Project sponsored by the MGS, USGS, and Maine Department of Environmental Protection (Tepper and others, 1987; Williams and others, 1987).

DESCRIPTION OF GEOLOGIC MAP UNITS

The surficial deposits represented on the geologic map have been classified on the basis of their age and origin. Map units are designated by letter symbols, such as "Pt." The first letter indicates the age of the unit:

"P" - Pleistocene (Ice Age)
"H" - Holocene (postglacial, i.e. formed during the last 10,000 years)
"Q" - Quaternary (encompasses both the Pleistocene and Holocene epochs)

The Quaternary age is assigned to units which overlap the Pleistocene-Holocene boundary, or whose ages are uncertain. The other letters in the map symbol indicate the origin and/or assigned name of the unit, e.g. "t" for glacial till and "lpb" for sediments deposited on the bottom of Lake Pigwacket. Surficial map units in the Pleasant Mountain quadrangle are described below, starting with the older deposits that formed in contact with glacial ice.

Till (unit Pt)

Till is a glacially deposited sediment consisting of a more-or-less random mixture of sand, silt, and gravel-size rock debris. In southern Maine it typically includes numerous boulders. Till blankets much of the upland portions of the quadrangle, where it is the principal surficial material; and it is likely to underlie younger deposits in valleys. Some of the till in Maine probably was derived from glacial erosion of older surficial sediments (either glacial or nonglacial), while the remainder was freshly eroded from nearby bedrock sources during the latest glaciation.

Pit exposures in the study area have revealed up to 12 ft (4 m) of till, and subsurface data shows that the thickness locally is 50-100 ft (15-30 m) or more. Till is thin on the tops of many hills, where bedrock is likely to be exposed. A ruled line pattern on the geologic map indicates areas where bedrock outcrops are common and/or the till thickness is inferred to be less than 10 ft (3 m).

Till is, by definition, a poorly sorted sediment (diamicton) in which there is a very wide range of rock and mineral particle sizes. However, the texture and structure of individual till deposits vary depending on their source and how they were formed. In the Pleasant Mountain area, till may include a small percentage of clay, but it has a dominantly sandy or silty-sandy matrix as a consequence of having been eroded from coarse-grained bedrock. Till has little or no obvious stratification in some places. Elsewhere it is crudely stratified, with discontinuous lenses and laminae of silt, sand, and gravel resulting from sorting by meltwater during deposition.

Stones are abundant in this unit, and boulders scattered across the ground surface often indicate the presence of till. Till stones in the Pleasant Mountain quadrangle chiefly consist of coarse-grained igneous and metamorphic rocks, especially granitic rocks derived mainly from local bedrock sources. Most till stones are more-or-less angular, and some have smooth, flat, striated surfaces due to subglacial abrasion. These faceted surfaces are best developed on dense, fine-grained rocks such as basalt (basalt occurs as dikes cutting other rock types in southwestern Maine).

Varieties of till formed beneath a glacial ice sheet include lodgement and basal melt-out tills. Lodgement till was deposited under great pressure beneath the ice sheet. It may be very compact and difficult to excavate ("hardpan"), with a platy structure (fissility) evident in the upper, weathered zone. Basal melt-out till is difficult to identify with certainty, but typically shows a crude stratification inherited from debris bands in the lower part of the glacier. Ablation till formed during the melting of the ice and tends to be loose-textured and stony, with numerous lenses of washed sediment. More than one of these till varieties may occur at a single locality. For example, a thin veneer of stony ablation till commonly overlies lodgement till.

Field evidence in western Maine, coupled with studies elsewhere in New England (e.g. Koteff and Pessl, 1985; Thompson and Borns, 1985; Weddle and others, 1989), suggests that till deposits of two glaciations are present in this region. The "upper till" is clearly the product of the most recent, late Wisconsinan glaciation, which covered southern Maine between about 25,000 and 13,000 years ago. This is the common surface till seen throughout the quadrangle. Exposures of the upper till can be seen in shallow pits, road cuts, and temporary excavations. It is not weathered (except in the near-surface zone of modern soil formation) and is usually light olive-gray in color. Lodgement and ablation facies of the upper till have been observed in the Pleasant Mountain quadrangle.

The "lower till" consists chiefly of compact, silty-sandy lodgement deposits. In southwestern Maine, as in other parts of New England, it is likely to be found in smooth, glacially streamlined hills where a considerable thickness of till has accumulated. These thick deposits often occur as ramps on the gentle northwest-facing slopes of hills, while bedrock is exposed on the steeper, glacially plucked southeast slopes.

The lower till is distinguished by its thick weathering profile, which may extend to a depth of 10 ft (3 m) or more. Within this weathered zone, the till is oxidized and has an olive-gray to dark olive-gray or dark grayish-brown color. Dark-brown iron/manganese oxide staining coats the surfaces of stones and joints. Probable equivalents of this till in southern New England are believed to be have been deposited during an earlier glaciation in Illinoian time, prior to 130,000 years ago (Weddle and others, 1989).

Material believed to be lower till was seen in only two exposures in the Pleasant Mountain quadrangle: a roadside ditch on the west side of Carter Hill in Fryeburg (site no. 83-17 on materials map), and an excavation on the northwest slope of Black Mountain (site 88-11). The rarity of lower till exposures may be attributed to two factors: burial beneath upper till, and lack of borrow pits in this very hard-to-excavate sediment. The two tills have been observed in superposition in a few places in adjacent quadrangles. The contact between them is sharp and erosional; and fragments of the lower till occur in the basal part of the upper till (see, for example, Thompson, 1986).

Hummocky moraine (unit Phm)

The valley southeast of Pleasant Mountain contains extensive deposits of hummocky moraine. These deposits are distinguished in the field by their knobby topography and abundance of large boulders. The scarcity of bedrock outcrops, together with the topographic relief, suggests that the thickness of this unit may be tens of feet. The few available exposures indicate that the hummocks and ridges of unit Phm vary in composition from diamicton to sand and gravel, but diamicton seems to be the most abundant constituent. The materials may change very abruptly, both horizontally and vertically.

Hummocky moraine is usually concentrated in lowlands, but occurs on the sides of valleys at higher elevations than adjacent waterlaid glacial deposits consisting of sand and gravel. As proposed by Holland (1986), the location, composition, and topography of unit Phm suggest that it formed during the melting of stagnant debris-rich ice in a late stage of deglaciation. However, the hummocky deposits north and west of Highland Lake form ridges that extend southeast from bedrock hills, and thus appear to be related in some way to the former southeastward ice flow over these hills.

Esker deposits (unit Pge)

The Pleasant Mountain quadrangle contains a very well-developed esker system (Pge). It trends north-south along the axis of the Elkins Brook valley in the western part of the map area and continues into adjacent quadrangles. The esker is a nearly continuous ridge of sand and gravel. It is 20-60 ft (6-18 m) high and typically 200-400 ft (61-122 m) across. This ridge was deposited by meltwater streams flowing south in a tunnel at the bottom of the last glacial ice sheet. It is part of a long esker system that can be traced from the the East Stoneham quadrangle discontinuously southward for many miles to a large glaciomarine delta in the Dayton area (York County). The delta contains sediments that washed into the sea at the mouth of the ice tunnel. Whether meltwater flowed simultaneously through this entire tunnel network is debatable, but it is likely that the esker segments formed progressively from south to north as the tunnel became clogged with sediment during deglaciation.

Pit exposures in the esker usually show more sand than gravel, and most of the gravel is in the pebble-cobble size range. In most places, the gravel fraction of the esker is probably concentrated deep in the core of the ridge, having formed in a subglacial ice tunnel that carried a high-velocity meltwater stream. The surrounding sand deposits are often lacustrine in character, and probably formed as the mouth of the ice tunnel melted back in contact with the waters of Lake Pigwacket (see below).

Willett Brook deposits (unit Plwb)

Sand and gravel deposits of uncertain origin (Plwb) occur in the Willett Brook valley in the southeast corner of the quadrangle. This valley drains north to the town of Bridgton, and is called “Willett Brook” in the North Sebago quadrangle and “Willis Brook” in the Bridgton quadrangle. It probably was dammed by the receding ice margin during deglaciation, forming a lake in which sediment was trapped. Thus, although the Willett Brook deposits are poorly exposed in the Pleasant Mountain quadrangle, they are inferred to be mainly of lacustrine origin. Sediment would have been delivered to the lake through an ice tunnel whose location is now marked by an esker extending part way up Willett Brook in the Bridgton quadrangle. The Plwb deposits can be traced south into the North Sebago quadrangle, at elevations of about 520-540 ft (159-165 m), to where the meltwater drainage emptied into glacial Lake Hancock (Lepage, 1997a,b).

Moose Pond deposits (unit Pgim)

Several small deposits of ice-contact sand and gravel (Pgim) are scattered along the sides of Moose Pond southeast of Pleasant Mountain. These deposits appear to be related to final melting of decaying glacial ice that left the hummocky moraine deposits on the lower slopes of the mountain. Meltwater drained southward through what is now Denmark village (Hiram quadrangle) and ultimately to the Saco River. Remnant ice in the present site of Moose Pond prevented the Pgim outwash from extending across the valley as a continuous surface.

Kame deposit (unit Pgk)

A small mound of ice-contact gravel (Pgk) was mapped on the hillside east of Kezar Pond. The origin of this deposit is unknown, but it has been classified as a kame on the basis of topography. It is higher than nearby Lake Pigwacket deposits, and may be a fluvial gravel that washed into a hole in melting glacial ice.

Outwash Deposits (unit Pgo)

One deposit of proglacial outwash (Pgo) has been mapped in the Pleasant Mountain quadrangle. It consists of a sandy terrace on the west side of the unnamed stream connecting Stearns Pond and Highland Lake. This deposit probably was formed by a meltwater stream flowing southward from ice in the Stearns Pond basin. It has since been dissected by the modern drainage.

Lake Pigwacket Deposits

During and following the deglaciation of southwestern Maine, a succession of temporary lakes formed in the Saco River basin. Sediments deposited in these lakes, or in glacial streams tributary to them, have been recognized over a long stretch of the valley, extending at least from the Hiram area upstream to Bartlett, New Hampshire. For example, the town of Fryeburg is situated on a sand plain deposited in a lake as it filled with sediment; and test borings have shown that thick accumulations of lake-bottom sand, silt, and clay underlie the Saco River valley. The system of interrelated water bodies that formerly existed in the Saco Valley was named "Lake Pigwacket" by Thompson (1999c,d).

Sand and gravel deposited into Lake Pigwacket occur extensively in the Elkins Brook valley along the west side of the quadrangle. These deposits are believed to have formed in early ice-dammed stages of the lake, when it was a narrow water body confined between Pleasant Mountain to the east and remnant ice in the Saco River valley to the west. If this ice barrier had not existed, the lake could not have stood as high as the stages described below. It would have immediately fallen to the level of the final Fryeburg stage (Thompson, 1999c,d).

Pleasant Mountain Stage Deposits (units Plpp and Plppf). Unit Plpp consists of sandy deposits in the Elkins Brook valley west of Pleasant Mountain. These deposits flank the long esker system that passes down the middle of the valley. The unit is not well exposed. Information on its composition is derived from shallow surface exposures and shovel/auger holes, inactive borrow pits, and a few well and seismic records. Unit Plpp typically has uneven ice-contact topography, though a few deposits are flat-topped where graded to former water levels. The materials are mostly sand with lesser amounts of silt and gravel in some places.

This map unit is interpreted as a complex of glaciolacustrine deposits including deltas, subaqueous fans, and lake-bottom deposits. Five ice-margin positions have been inferred from the Plpp deposits, as shown on the geologic map. These positions are based on the ice-contact slopes found on the north sides of fans and deltas. They indicate the successive retreat of the glacier margin from the Elkins Brook valley.

Unit Plpp is assigned to a late-glacial stage of Lake Pigwacket, defined here as the Pleasant Mountain stage. It was deposited in an area of ponded meltwater between the hills to the east and a remnant mass of glacial ice inferred to have existed in the Saco River lowland to the west. Delta(?) elevations west of Pleasant Mountain suggest a lake level of about 450 ft (137 m).

Unit Plppf is a subaqueous fan which was mapped separately on the basis of its distinctive morphology. It is located along the esker system, just northeast of Kezar Pond. This fan was built into Lake Pigwacket at the mouth of the ice tunnel in which the esker formed.

The location of the dam for the Pleasant Mountain stage of Lake Pigwacket is uncertain. Plpp deposits at elevations of about 440 ft (134 m) can be traced southward nearly to the Saco River in the Hiram quadrangle. Ice-contact topography in this area suggests a temporary dam for the lake, consisting of remnant ice masses choking the Saco Valley and its tributaries in the northwest part of the Hiram quadrangle. Eventual failure of the dam lowered base level in the Saco Valley, allowing deposition of younger Lake Pigwacket sediments at elevations close to 400 ft (122 m).

Kezar Valley Stage Deposits (unit Plpk). In the northwest corner of the Pleasant Mountain quadrangle, there is a small area of sandy glaciolacustrine sediments (Plpk) deposited into a younger stage of Lake Pigwacket as the glacier margin retreated north from the quadrangle. The following description is provided to give the regional framework of these deposits, but it applies mostly to adjacent portions of the Fryeburg, Center Lovell, and North Waterford quadrangles, where unit Plpk is more extensive (Thompson, 1999a-f).

Unit Plpk extends from Lovell village northeast along the Kezar River valley and its tributaries. The southern extremity of this unit is located in the northeast corner of the Fryeburg quadrangle. There it forms a sand plain at elevations of 400-420 ft (122-128 m) (Thompson, 1999c,d). As the unit is followed up the valley into the Center Lovell and North Waterford quadrangles, the upper surface quickly rises to 500 ft (152 m) and reaches a maximum of about 525 ft (160 m) just below the Kezar Falls gorge.

Plpk deposits in the North Waterford quadrangle are pockmarked by depressions (kettles) resulting from melting of glacial ice blocks. Surface exposures typically show fine sand, but gravel is present toward the north end of the unit. The depth of stream dissection suggests that the unit is locally quite thick, and this is confirmed by borings and seismic data. An observation well (13-7) in the northeast corner of the Fryeburg quadrangle penetrated 81 ft (25 m) of sand, silt, and clay (fining downward) without reaching the bottom of the unit; and a nearby seismic line (FR-15) showed a depth-to-bedrock of 200 ft (61 m) (Williams and others, 1987; Tepper and others, 1987).

The thick sand deposits that form much of unit Plpk are poorly exposed. A few shallow pits and road cuts in the Center Lovell and North Waterford quadrangles show well-sorted, thin-bedded fine sand and silt with current ripples. The texture of these sediments suggests they are lake-bottom and/or delta-front deposits that formed in a low-energy (quiet-water) environment. The ice-contact topography along the Kezar River valley is evidence that the unit was deposited when remnants of glacial ice still existed in the area.

Unit Plpk originally may have been a delta that was built to a lake level of approximately 500 ft (152 m), but the rapid down-valley decrease in elevation and reduction of ice-contact topography suggest that the southern part of the delta has been modified. The low Plpk surface at 400-430 ft in the northwest corner of the Pleasant Mountain quadrangle may have resulted from fluvial or shoreline erosion of Plpk deposits during the later Fryeburg stage of Lake Pigwacket (Thompson, 1999c,d).

The water body in which unit Plpk was deposited is called the Kezar Valley stage of Lake Pigwacket (Thompson, 1999c,d). Like the Plpp unit described above, the lake sediments in the Kezar River valley reach significantly higher elevations than the floor of the neighboring Saco Valley, which is only about 370 ft (113 m) in elevation. A temporary dam of some kind was required to impound the lake at an elevation of about 500 ft (152 m) in the Kezar Valley. The Kezar Valley lake may have either spilled southwestward across ice/sediment barriers in the Saco Valley (Fryeburg quadrangle), or southward across older Plpp deposits in the western part of the Pleasant Mountain quadrangle. In the latter case, the spillway would have been located in the southwestern part of the Pleasant Mountain quadrangle, and the Kezar Valley deposits could be grouped with those of the Pleasant Mountain stage. This alternative would require a long, narrow lake corridor to open up along the path of the esker system on the east side of the Saco River basin, while the basin itself remained choked with ice. Perhaps the high-energy meltwater drainage that formed the esker in this area also caused rapid ice disintegration and opening of the lake.

Lake-Bottom Deposits (unit Plpb). Fine-grained sediments deposited on the floor of Lake Pigwacket are grouped as a single unit, since their ages in relation to the lake stages are uncertain. This unit is not exposed in the Pleasant Mountain quadrangle, but information from the adjacent Fryeburg quadrangle shows that it includes fine sand, silt, and clay (Thompson, 1999c,d). The sandy facies probably were deposited in a prodelta environment, close to where streams entered the lake, while the muddy sediments settled from suspension and dispersed more widely across the lake bottom.

Eolian deposits (unit Qe)

Eolian (windblown) sand deposits occur in the northwest corner of the quadrangle, along the west base of Popple Hill. Unit Qe consists of very fine to very coarse sand. The thickness of the deposits may vary abruptly over short distances. Map contours in the Popple Hill area suggest thicknesses up to 20 ft (6 m) or more. Dunes are present locally, including at least one longitudinal ridge with an east-west trend.

McKeon (1989) measured the orientations of longitudinal dunes in central Maine and found that they consistently indicate a prevailing wind from the west-northwest, the same as today. Dunes in the Fryeburg area show a range of wind directions, but all are generally from the west (Thompson, 1999c,d). The Popple Hill deposits likewise are inferred to have a westerly source. They formed as wind eroded sand from the Lake Pigwacket deposits and piled it against the flank of Popple Hill on the east side of the Saco River lowland.

Wetland deposits (unit Hw)

Unit Hw consists of fine-grained and organic-rich sediments deposited in low, flat, poorly drained areas. In the Pleasant Mountain quadrangle this unit occurs around ponds, in kettle holes, and in small upland basins surrounded by glacial till. The boundaries of unit Hw were mapped primarily from aerial photographs. These boundaries are approximately located and should not be used rigorously for land-use zoning.

Stream alluvium (unit Ha)

Unit Ha consists of alluvial silt, sand, gravel, and organic material deposited by modern streams. In the Pleasant Mountain quadrangle these deposits have been mapped only on a narrow flood plain along the stream connecting Stearns Pond and Highland lake in the northeast part of the map area. Small areas of alluvium probably exist along a few other brooks in the quadrangle, especially next to Elkins Brook south of Kezar Pond and beneath the wetland mapped along part of this brook.

GLACIAL AND POSTGLACIAL GEOLOGIC HISTORY

The following reconstruction of the Quaternary history of the Pleasant Mountain quadrangle and surrounding area is based on the interpretations of surficial earth materials described in this report, together with related topographic features. It is uncertain how many episodes of glaciation have affected the area during the Pleistocene Ice Age. Till deposits clearly record the most recent (late Wisconsinan) glaciation, and probably one earlier event. The deeply weathered lower till found elsewhere in central and southern New England has also been recognized in southern Maine (Thompson and Borns, 1985; Weddle and others, 1989). Although it is not well-dated, the lower till was deposited during the penultimate glaciation, of probable Illinoian age.

Data summarized by Stone and Borns (1986) indicate that the late Wisconsinan Laurentide Ice Sheet expanded out of Canada and spread into Maine approximately 25,000 radiocarbon years ago. As the glacier continued to flow across the state for thousands of years, it reshaped the surface of the land by eroding, transporting, and depositing tremendous quantities of sediment and rock debris. The combined effects of erosion and deposition have given some hills a streamlined shape, with their long axes parallel to the south-southeastward flow of the ice. The geologic map shows several examples in the eastern half of the quadrangle.

Late Wisconsinan glaciation produced a large portion of the stony till deposits that blanket the upland areas. Glacial plucking on the lee sides of bedrock hills eroded steep southeast-facing slopes and cliffs on many hills in Maine, such as Pleasant Mountain. Rocks torn from these hills were scattered in the direction of glacial transport.

On a smaller scale, abrasion by rock debris dragged at the base of the glacier polished and striated the bedrock surface. The striations are not easy to find in the study area because they are either concealed beneath surficial sediments, or have been destroyed by weathering where ledges are exposed at the ground surface. Striations recorded at three sites on the Pleasant Mountain fire tower trail have a southeast trend (see geologic map). They are parallel to streamlined hills in the map area, and thus may indicate flow during the late Wisconsinan glacial maximum.

Striations at a site on Lewis Hill record ice-flow directions of 170^{o} and 221^{o}. This south to southwestward flow was a regional event that is believed to have resulted from reorganization of ice flow in southwestern Maine as the glacier thinned over the Mahoosuc Range to the north (Thompson and Koteff, 1995).

The minimum age of glacial retreat from the Pleasant Mountain quadrangle can be determined through radiocarbon dating of organic material in sediments that were deposited on lake bottoms soon after deglaciation. Thompson and others (1996) obtained an age of 13,200 years from nearby Cushman Pond in Lovell (North Waterford quadrangle), so the map area probably was likewise deglaciated by this time. However, isolated masses of stagnant ice may have lingered in valleys. The Saco Valley was certainly ice-free by 12,000 radiocarbon years ago, judging from dated plant remains in Fryeburg (Thompson, 1999c,d).

In coastal Maine it is possible to trace the retreat of the glacier margin in detail because there are hundreds of end-moraine ridges, submarine fans, and deltas that were deposited at the edge of the ice during its recession in a marine environment. End moraines are essentially absent in the Pleasant Mountain quadrangle, but the ice-contact sand and gravel deposits left by meltwater streams flowing into Lake Pigwacket provide clues to the history of ice retreat. The locations, elevations, and morphology of these deposits are the basis for the sequence of events proposed below.

Early in the deglacial sequence, a southward-flowing lobe of ice still covered most of the study area, and the glacier margin stood near the south edge of the Pleasant Mountain quadrangle. Meltwater streams washed sediment out of the ice and into early stages of Lake Pigwacket, which then occupied the Brownfield-Hiram section of the Saco Valley. The glacier probably melted faster in a narrow corridor along the west side of the quadrangle, along the Elkins Brook valley and the east side of Kezar Pond. There was an early subglacial drainage in this area, now marked by an esker ridge deposited in a tunnel within the ice. Meltwater discharging from the tunnel may have accelerated local melting and retreat of the ice margin. This drainage system became an open water body -- the Pleasant Mountain stage of Lake Pigwacket -- which expanded northward along the east side of the Saco Valley.

A series of ice-contact deltas and subaqueous fans (unit Plpp) indicates successive positions of the ice margin associated with the Pleasant Mountain stage of Lake Pigwacket. The lake had a surface elevation of about 440-450 ft (134-137 m) near the south edge of the quadrangle and drained southward into the Saco River valley. (The elevations of former glacial lake levels are now generally higher to the north due to uplift and tilt of the earth's crust in response to deglaciation.) The dam for this stage of the lake is not apparent, but presumably was a temporary obstruction caused by glacial sediments or remnant ice blocking the Saco Valley in the western part of the Hiram quadrangle.

Continued ice retreat uncovered the Kezar River valley in Lovell and Sweden (north of the Pleasant Mountain quadrangle), and the Kezar Valley stage of Lake Pigwacket developed in this area. Sediments discharging from the local esker tunnel were deposited in the lake, eventually filling it and building a deltaic sand plain (unit Plpk) to elevations of 500-520 ft (152-158 m). This stage of the lake may been continuous with the Pleasant Mountain stage to the south. Some of the Kezar Valley deposits were laid down on top of stagnant ice masses, which later melted and formed kettles.

It is inferred that remnants of glacial ice still occupied the Saco River basin around Fryeburg during the deposition of units Plpp and Plpk, because no lake deposits occur at comparably high elevations over most of the Fryeburg quadrangle. When the main part of the Saco Valley finally became ice-free, this low-lying area was flooded by the Fryeburg stage of Lake Pigwacket. Sediments washed into the lake from the upper Saco Valley in New Hampshire and from smaller tributary valleys north and west of Fryeburg (Thompson, 1999c,d).

Concurrently with ice retreat from the western part of the quadrangle, the glacier margin receded north to northeastward from the valleys east of Pleasant Mountain. The Moose Pond (Pgim) and Willett Brook (Plwb) deposits formed during the early stages of deglaciation as meltwater streams emptied into these two valleys. Meltwater channels provide further evidence of ice retreat in the eastern part of the quadrangle, but there is very little sand and gravel in this area. Large quantities of bouldery till were released from the ice, but apparently there was no esker system or other focused meltwater drainage to generate stratified drift deposits in the eastern half of the quadrangle. The youngest meltwater deposit is a tiny outwash terrace remnant between Stearns Pond and Highland Lake.

Deposits of eolian sand (Qe) formed on the east side of the Saco Valley in late-glacial to postglacial time. Wetlands (Hw) and flood plains (Ha) began to develop soon after deglaciation and continue to accumulate sediments to the present day.

ECONOMIC GEOLOGY

Large volumes of sand and gravel occur in the esker system and adjacent glacial lake deposits in the western part of the Pleasant Mountain quadrangle. However, there is much more sand than gravel in this area. Borrow pits have been opened along the esker, but most were inactive at the time of this study. Future prospects for gravel mining are most favorable along remaining segments of the esker that have not been previously exploited.

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APPENDIX A
GLOSSARY OF TERMS USED ON MAINE GEOLOGICAL SURVEY SURFICIAL GEOLOGIC MAPS

compiled by
John Gosse and Woodrow Thompson

Note: Terms shown in italics are defined elsewhere in the glossary.

Ablation till: *till* formed by release of sedimentary debris from melting glacial ice, accompanied by variable amounts of slumping and meltwater action. May be loose and stony, and contains lenses of washed sand and gravel.

Basal melt-out till: *till* resulting from melting of debris-rich ice in the bottom part of a glacier. Generally shows crude stratification due to included sand and gravel lenses.

Clast: pebble-, cobble-, or boulder-size fragment of rock or other material in a finer-grained *matrix*. Often refers to stones in glacial till or gravel.

Clast-supported: refers to sediment that consists mostly or entirely of *clasts*, generally with more than 40% clasts. Usually the clasts are in contact with each other. For example, a well-sorted cobble gravel.

Delta: a body of sand and gravel deposited where a stream enters a lake or ocean and drops its sediment load. Glacially deposited deltas in Maine usually consist of two parts: (1) coarse, horizontal, often gravelly topset beds deposited in stream channels on the flat delta top, and (2) underlying, finer-grained, inclined foreset beds deposited on the advancing delta front.

Deposit: general term for any accumulation of sediment, rocks, or other earth materials.

Diamicton: any poorly-sorted sediment containing a wide range of particle sizes, e.g. glacial *till*.

Drumlin: an elongate oval-shaped hill, often composed of glacial sediments, that has been shaped by the flow of glacial ice, such that its long axis is parallel to the direction of ice flow.

End moraine: a ridge of sediment deposited at the margin of a glacier. Usually consists of till and/or sand and gravel in various proportions.

Englacial: occurring or formed within glacial ice.

Eolian: formed by wind action, such as a sand dune.

Esker: a ridge of sand and gravel deposited at least partly by meltwater flowing in a tunnel within or beneath glacial ice. Many ridges mapped as eskers include variable amounts of sediment deposited in narrow open channels or at the mouths of ice tunnels.

Fluvial: Formed by running water, for example by meltwater streams discharging from a glacier.

Glaciolacustrine: refers to sediments or processes involving a lake which received meltwater from glacial ice.

Glaciomarine: refers to sediments and processes related to environments where marine water and glacial ice were in contact.

Head of outwash: same as *outwash head*.

Holocene: term for the time period from 10,000 years ago to the present. It is often used synonymously with "postglacial" because most of New England has been free of glacial ice since that time.

Ice age: see *Pleistocene*.

Ice-contact: refers to any sedimentary deposit or other feature that formed adjacent to glacial ice. Many such deposits show irregular topography due to melting of the ice against which they were laid down, and resulting collapse.

Kettle: a depression on the ground surface, ranging in outline from circular to very irregular, left by the melting of a mass of glacial ice that had been surrounded by glacial sediments. Many kettles now contain ponds or wetlands.

Kettle hole: same as *kettle*.

Lacustrine: pertaining to a lake.

Late-glacial: refers to the time when the most recent glacial ice sheet was receding from Maine, approximately 15,000-10,000 years ago.

Late Wisconsinan: the most recent part of *Pleistocene* time, during which the latest continental ice sheet covered all or portions of New England (approx. 25,000-10,000 years ago).

Lodgement till: very dense variety of till, deposited beneath flowing glacial ice. May be known locally as "hardpan."

Matrix: the fine-grained material, generally silt and sand, which comprises the bulk of many sediments and may contain *clasts*.

Matrix-supported: refers to any sediment that consists mostly or entirely of a fine-grained component such as silt or sand. Generally contains less than 20-30% clasts, which are not in contact with one another. For example, a fine sand with scattered pebbles.

Moraine: General term for glacially deposited sediment, but often used as short form of *"end moraine."*

Morphosequence: a group of water-laid glacial deposits (often consisting of sand and gravel) that were deposited more-or-less at the same time by meltwater streams issuing from a particular position of a glacier margin. The depositional pattern of each morphosequence was usually controlled by a local base level, such as a lake level, to which the sediments were transported.

Outwash: sediment derived from melting glacial ice and deposited by meltwater streams in front of a glacier.

Outwash head: the end of an *outwash* deposit that was closest to the glacier margin from which it originated. *Ice-contact* outwash heads typically show steep slopes, *kettles* and hummocks, and/or boulders dumped off the ice. These features help define former positions of a retreating glacier margin, especially where *end moraines* are absent.

Pleistocene: term for the time period between 2-3 million years ago and 10,000 years ago, during which there were several glaciations. Also called the "Ice Age."

Proglacial: occurring or formed in front of a glacier.

Quaternary: term for the era between 2-3 million years ago and the present. Includes both the *Pleistocene* and *Holocene*.

Striation: a narrow scratch on bedrock or a stone, produced by the abrasive action of debris-laden glacial ice. Plural form sometimes given as "striae."

Subaqueous fan: a somewhat fan-shaped deposit of sand and gravel that was formed by meltwater streams entering a lake or ocean at the margin of a glacier. Similar to a *delta*, but was not built up to the water surface.

Subglacial: occurring or formed beneath a glacier.

Till: a heterogeneous, usually non-stratified sediment deposited directly from glacial ice. Particle size may range from clay through silt, sand, and gravel to large boulders.

Topset/foreset contact: the more-or-less horizontal boundary between topset and foreset beds in a *delta*. This boundary closely approximates the water level of the lake or ocean into which the delta was built.