DEPARTMENT OF CONSERVATION
Maine Geological Survey
Robert G. Marvinney, State Geologist

OPEN-FILE NO. 99-2

Title: *Surficial Geology of the Center Lovell 7.5-minute Quadrangle, Oxford County, Maine*

Author: *Woodrow B. Thompson*

Date: *1999*

Financial Support: Funding for the preparation of this report was provided in part by the U.S. Geological Survey STATEMAP Program, Cooperative Agreement No. 98HQAG2052.

Associated Maps: Surficial geology of the Center Lovell quadrangle, Open-File 99-1
Surficial materials of the Center Lovell quadrangle, Open-File 98-239

Contents: 12 p. report

Maine Geological Survey
Open-File 99-2

Surficial Geology of the Center Lovell 7.5-minute Quadrangle, Oxford County, Maine

Woodrow B. Thompson
Maine Geological Survey
State House Station 22
Augusta, Maine 04333-0022

INTRODUCTION

This report describes the surficial geology and Quaternary history of the Center Lovell 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 Center Lovell 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, 1999a) 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 provided much useful data on the stratigraphy of the Saco River valley, including numerous test boring and seismic logs (Prescott, 1979; Johnson and others, 1987; Williams and others, 1987; and Tepper and others, 1990).

Geographic setting

The Center Lovell quadrangle is located in the White Mountain foothills of southwestern Maine. The western boundary is very close to the New Hampshire state line, which is less than a mile to the west in the Chatham quadrangle. The map area extends in latitude from 44°07'30" to 44°15'00" N, and in longitude from 70°52'30" to 71°00'00" W. It encompasses parts of the towns of Fryeburg, Lovell, Stow, and Stoneham, including a small part of the White Mountain National Forest. The villages of Lovell and North Lovell are the principal population centers in the quadrangle.

A short segment of the Old Course of the Saco River passes through the southernmost part of the Center Lovell quadrangle. This river channel became relatively inactive in the early 1800's, when a combination of floods and canal excavations diverted the river to its new and shorter course closer to Fryeburg village (Anderson, 1982; Thompson, 1999b,c). The Cold River drains the western part of the quadrangle and empties into the Saco River. Kezar Lake is the largest and most important water body in the map area, providing recreation for many local and seasonal residents. Several smaller ponds also occur in the quadrangle.

The topography of the Center Lovell quadrangle is hilly and generally rises toward the north. Elevations range from about 370 ft (113 m) above sea level (where the Saco River crosses its southern border) to 1650 ft (503 m) on the summit of Adams Mountain near the north edge of the map area. Several hills in the eastern part of the quadrangle have been glacially streamlined in a south-southeasterly direction.

Bedrock geology

Quaternary sediments cover the bedrock over much of the southern half of the Center Lovell quadrangle, but outcrops are very common in the higher hills to the north. Most of the map area is underlain by granite of Carboniferous age, which is part of an extensive granite body called the Sebago pluton. Metasedimentary rocks of Silurian to Devonian age occur in the northwestern part of the quadrangle (Osberg and others, 1985). Veins of granite pegmatite are found throughout the area. On Lord Hill, Deer Hill, Colton Hill, and Adams Mountain, pegmatites have been mined commercially for feldspar, amethyst, and rare minerals.

PREVIOUS WORK

Stone (1899) conducted a reconnaissance of the Saco Valley region during his statewide USGS study of Maine's glacial gravel deposits, but he did not report on the uplands that comprise most of the Center Lovell quadrangle. Prescott (1979) compiled well and test hole data, and carried out preliminary surficial and gravel aquifer mapping (Prescott, 1980; Prescott and Dickerman, 1981). Thompson compiled a more detailed aquifer map that included the Center Lovell quadrangle as part of the Significant Sand and Gravel Aquifer Project sponsored by the MGS, USGS, and Maine Department of Environmental Protection (Williams and others, 1987). The U. S. Department of Agriculture's soil survey of Oxford County (Wilkinson, 1995) provided useful materials information for several sites that the present author did not visit in the field.

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 "lp" for sediments deposited in Lake Pigwacket. Surficial map units in the Center Lovell 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 test borings show that it commonly underlies younger deposits in the valleys. Some of the till in Maine probably was derived from glacial erosion of older surficial sediments (either glacial or non-glacial), while the remainder was freshly eroded from nearby bedrock sources during the latest glaciation.

Pit exposures in the Lovell region have revealed up to 20 ft (6 m) of till, and the thickness locally may be as much as 50-100 ft (15-30 m). 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 Center Lovell quadrangle, 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 Center Lovell 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 the Lovell area, 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 here. 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. Exposures of upper till can be seen in many shallow pits, road cuts, and temporary excavations. It is not weathered (except in the near-surface zone of modern soil formation) and usually light olive-gray in color. Lodgement and ablation facies of the upper till have been recognized in the Center Lovell quadrangle.

The "lower till" consists 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 a borrow pit near the south end of Farrington Pond (site no. 87-50 on materials map). 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).

Occurrences of till overlying sand and gravel. Till is usually the oldest glacial sediment in the study area and is presumed to directly overlie bedrock. However, two unusual exposures of late Wisconsinan till overlying waterlaid glacial fan deposits were found in the town of Lovell (Thompson, 1986, 1994). A large and spectacular section was located in a pit (backfilled in 1997) that formerly existed on the east side of Bryant Hill; the other was exposed in the pit at the south end of Hatch Hill. Both of these pits were situated on the south or southeast (downglacier) side of a bedrock hill.

The Bryant Hill pit showed up to 25 ft (8 m) of till overlying 65 ft (20 m) of south-dipping gravel and sand beds (glacial fan deposit). In the northern part of the pit, these two units were truncated by thrust faults and an overlying diamicton (deformation till) resulting from ice shove toward the southwest and shearing of the fan sediments. The deformation probably was a late-glacial event resulting from a forward pulse of the ice sheet that interrupted its recession. Nearby striations on bedrock outcrops along Route 5 trend 184° and 195°, and are associated with a late S-SSW ice-flow that has been recorded over a large area of southwestern Maine (Thompson, in prep.).

The Bryant Hill section raised several problems concerning the age and origin of the stratigraphic units. The fan gravel is very compact (glacially overridden) and contains lenses of till and other evidence of near-ice deposition (Thompson, 1986). This unit was exposed over a north-south distance of several hundred feet. It seems too extensive to have formed in a subglacial cavity, so is presumed to be either a subaerial outwash fan or a subaqueous lacustrine fan.

The Bryant Hill pit showed bedding in the upper part of the fan that intertongues with the overlying late Wisconsinan till, so the fan apparently was deposited during the advance of the last ice sheet (rather than the recession of a previous ice sheet). The thrust-faulting of the upper part of the section suggests that the ice remained active in late-glacial time. During ice retreat, several meltwater channels were cut into the south side of the hill.

The Hatch Hill pit is located in a glacially streamlined hill. The pit face has shown 6-25 ft (2-8 m) of till overlying a sandy subaqueous fan deposit. The till contains large striated boulders, abundant silt and sand layers, and brecciated clasts of laminated silt-sand. Foreset bedding is well developed in the fan and dips south-southeast. Clastic dikes penetrating stress fractures in the fan have been offset by ice shove to the south or southwest. The relationships seen at this locality suggest that the till was deposited by ice advancing into a lake and overriding the earlier fan.

The Bryant Hill and Hatch Hill deposits are similar in having formed by glacial overriding of sand and gravel deposits on the lee sides of bedrock hills. The same relationship (till over gravel) has been observed at the town gravel pit in Norway, Maine. The common characteristics of these localities indicate a high probability that buried sand and gravel resources exist in many other similar geologic settings in western Maine. Preliminary experiments with ground penetrating radar at Bryant Hill and the Norway pit have shown that this instrument can detect stratification in the sand and gravel if the overlying till is not too thick.

Ribbed Moraine (unit Prm)

Ribbed moraine is a geomorphically distinct unit consisting of ridges and hummocks of glacial till. In the Center Lovell quadrangle it forms an elongate deposit extending south from Horseshoe Pond. There are no exposures in this unit, but similar deposits elsewhere in Maine show sand and gravel interbedded with till. The till ridges are usually short and stubby, and they tend to be oriented more-or-less transverse to the direction of glacial flow.

The manner in which ribbed moraine was formed is uncertain. It might be an ice-marginal deposit, in which case the unit includes end-moraines, or it may have been deposited subglacially. Davis and Holland (1997a,b) described similar deposits in the nearby Kezar Falls quadrangle and concluded that they probably were emplaced beneath the ice. The deposits south of Horseshoe Pond collectively form a long ridge parallel to the south-southeast flow of ice during the late Wisconsinan glacial maximum. This suggests that deposition of the ribbed moraine was contemporaneous with the flow of thick active ice across the area.

Hummocky moraine (unit Phm)

There are several areas of hummocky moraine in the Center Lovell quadrangle. These deposits are distinguished in the field by their knobby topography, and in some places there are many large boulders. The scarcity of bedrock outcrops, together with the topographic relief, suggests that the thickness of this unit may be tens of feet. Exposures of hummocky moraine in the quadrangle are limited to a few shallow road cuts. They indicate that unit Phm is mostly diamicton (till), but judging from similar deposits in other quadrangles, it is likely that sand and gravel are also present in variable proportions.

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.

Deltaic(?) deposits (unit Pld)

This unit comprises two small deposits. One is located on a hillside west of Kezar Lake; the other is north of Shave Hill in the southeastern part of the quadrangle. Unit Pld consists of generally well-sorted and stratified sand and minor silt with a thin surface layer of pebble gravel or pebbly sand. The deposits probably are thin, since boulders surrounding them or protruding from pit floors suggest the presence of till at a shallow depth.

The Pld sands may be delta foreset beds, but the pit exposures were not large or fresh enough to determine this with certainty. If they are lacustrine, the Pld sediments may have been deposited in small ice-marginal meltwater ponds. Alternatively, the deposit near Shave Hill may have washed into the Kezar Valley stage of glacial Lake Pigwacket, since there are deposits of this lake stage (unit Plpk) at the same elevation (470 ft) a short distance to the east.

Glacial Lake Stow deposits (unit Pls)

Near the western border of the quadrangle, there are several deposits of sand and gravel (Pls) in the Cold River basin that reach elevations of 500-540 ft (152-165 m). Fresh pit exposures are uncommon in this unit, and they are not diagnostic of its overall depositional environment. However, the widespread occurrence of sand deposits, as well as local accumulations of lacustrine silt, suggest that unit Pls was formed in a glacial lake. This proposed water body is here named "glacial Lake Stow."

Two other lines of evidence support the former existence of a lake in the Cold River valley. Just west of the Center Lovell quadrangle, where Route 113 crosses the state line, a delta was built into the valley from the Bradley Brook basin in the hills to the west (Thompson, 1986). A pit in this delta showed 1-3 ft (1 m) of gravelly topset beds overlying 20 ft (6 m) of sandy foreset beds dipping to the east. The topset/foreset contact in the Bradley Brook delta indicates a lake level of approximately 500 ft (152 m). Directly east of the delta, a test boring on the flood plain of the Cold River encountered 61 ft (19 m) of lacustrine sand, silt, and clay beneath alluvial gravel (Williams and others, 1987; see materials map). Some of this lake-bottom sediment may be contemporaneous with the younger Lake Pigwacket deposits discussed below (if the latter lake extended this far up the Cold River valley), but at least part of it probably was deposited along with the nearby delta in glacial Lake Stow.

Some kind of dam was required to have the Pls deposits graded to elevations of at least 500 ft. There is no surviving barrier at such a high elevation in the lower Cold River Valley, so the dam is presumed to have been a temporary obstruction consisting of glacial ice and/or sediments, which has been removed by subsequent melting or erosion. This blockage may have been located in the part of the Cold River valley just east of Stow village.

Lake Pigwacket Deposits

During and following the deglaciation of southwestern Maine, a succession of temporary lakes formed in the Saco River valley. 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. 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 existence of a lake in the Fryeburg area was proposed long ago by George H. Stone in his volume titled *The Glacial Gravels of Maine and Their Associated Deposits*. Stone noted that "In this [lake] was deposited a broad fluvial delta extending from Conway, New Hampshire, east to Lovell and Brownfield" (Stone, 1899, p. 256). He referred to the lake deposits as "alluvium" and "valley drift," but did not give a clear opinion regarding their age and origin. Leavitt and Perkins (1935) noted the presence of varved (annually layered) lacustrine clays beneath the Fryeburg-Conway sand plain. They referred to the former water body in the Saco Valley as a "great fresh water lake covering this part of western Maine and eastern New Hampshire" (p. 94). It was described as a glacial lake that drained down the valley, with sand deposits covering the clay as the lake filled with sediment (p. 210).

In 1938, a brief summary of the postglacial evolution of the Saco Valley by Richard Lougee (then professor of geology at Colby College) was included in a town history of Fryeburg (Barrows, 1938, p. 134-135). According to Lougee, a glacial lake first occupied the valley at the close of the Ice Age, with deltas in Stow and North Chatham marking the water level. This lake supposedly emptied due to postglacial tilt of the land, following which "The newly-formed post-Glacial Saco River, possibly still fed by meltwater from ice in the headwaters of the valley, spread immense deposits of fine sand into the lowland, burying the clay beds and any pre-Glacial channels in the bed rock, and building up a widespread sandy flood-plain."

The deltas mentioned by Lougee are much higher than the lake deposits around Fryeburg village, and probably were deposited in an earlier ice-dammed lake in the Stow area (Chatham and Center Lovell quadrangles). These high-level lake deposits are described above under glacial Lake Stow.

On the Maine side of the state border, from Fryeburg to Hiram, the upper surfaces of many lacustrine deposits in the Saco Valley cluster around 400-420 ft (122-128 m) in elevation. The similarity in elevations suggests the possibility that a single lake existed throughout this section of the valley. However, it is questionable whether such a continuous water body ever existed at one time. The morphology, textures, and spacing of the lake deposits, together with radiocarbon ages from the Fryeburg quadrangle, indicate that sedimentation was episodic over an interval ranging from late-glacial into early postglacial time. The system of adjoining and interrelated water bodies that formerly existed in the Saco River valley between Hiram and Bartlett, N.H., has been named "Lake Pigwacket" (Thompson, 1999b,c).

Kezar Valley Stage Deposits (unit Plpk). Unit Plpk extends from Lovell village north along the Kezar River valley and its tributaries, including Prays Brook and Alder Brook in the Center Lovell quadrangle. The southern extremity of this unit is located in the northeast corner of the Fryeburg quadrangle, where it forms a sand plain at elevations of 400-420 ft (122-128 m). As the unit is followed upvalley into the Center Lovell and North Waterford quadrangles, its upper surface rises to 500 ft (152 m) near Center Lovell village and reaches a maximum of about 525 ft (160 m) just below the Kezar Falls gorge in the North Waterford quadrangle.

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. 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 deltaic 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 downvalley decrease in elevation and reduction of ice-contact topography suggest that the southern part of the delta has been modified. The low sand plain at about 420-435 ft in the southeast corner of the Center Lovell quadrangle probably resulted from downcutting of the delta by the Kezar River in late-glacial time.

The water body in which unit Plpk was deposited is called the Kezar Valley stage of Lake Pigwacket (Thompson, 1999b,c). The lake sediments in the Kezar River valley reach 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 hold the lake at an elevation of about 500 ft (152 m) during the Kezar Valley stage. At this time, the lake may have either spilled southwestward across ice/sediment barriers in the Saco Valley, or southward across older Lake Pigwacket deposits in the Pleasant Mountain quadrangle. The latter alternative would require a long, narrow lake corridor to open up along the east side of the Saco River basin, while the basin itself remained choked with ice.

Undifferentiated Lake Pigwacket Deposits (unit Plp). There are several sand deposits in the quadrangle that were probably emplaced by streams flowing into Lake Pigwacket, but whose relation to the history of the lake is unclear. These deposits (unit Plp) occur in two areas: near The Narrows on Kezar Lake and Stow village in the lower Cold River valley. They reach elevations of only 400-420 ft (122-128 m), which is similar to deposits of the Fryeburg stage of Lake Pigwacket to the south (Thompson, 1999b,c).

The Plp deposits on Kezar Lake terminate abruptly to the north, so it is inferred that they washed out of glacial ice that still occupied the central and northern parts of the lake basin. At this time, the ice margin probably stood at the position labeled "Plp" on the geologic map. In the Cold River valley, unit Plp occupies an intermediate position between a higher terrace in glacial Lake Stow deposits (Pls) and the modern flood plain to the east. This Plp deposit may have been more extensive formerly, prior to erosion by the Cold River.

Lake-Bottom Deposits (unit Plpb). The fine-grained sediments deposited on the floor of Lake Pigwacket consist of silt, clay, and sand that washed into the lake. Surface exposures of this map unit in the Center Lovell quadrangle occur mainly in the Prays Brook valley in the southeast part of the map area. Auger holes in this valley revealed laminated silt, locally overlain by a thin cover of sand. The silt probably has annual layers (varves), which have been seen in several exposures of unit Plpb in the Fryeburg quadrangle (Thompson, 1999b,c).

The thickest lake-bottom sediments are beneath the Saco River flood plain, where they are largely concealed under younger alluvial, wetland, and eolian deposits. Detailed studies of the Saco Valley aquifer in the Fryeburg-Conway-Bartlett area have provided much information on the distribution and character of the buried lake sediments (Johnson and others, 1987; Tepper and others, 1990). Test borings at the bridge crossing on the Old Course of the Saco River in Fryeburg Harbor show that lake-bottom sand and silt extends to depths approaching 100 feet (30 m) beneath the flood-plain surface (see materials map).

Fossil plant remains were encountered in the lake-bottom sediments in several borings done for Saco Valley aquifer studies in the Fryeburg area (Johnson and others, 1987; Prescott, 1979; Thompson, 1999b,c). Split-spoon samples containing organic materials were recovered during the installation of monitoring wells and supplied to the author by Dorothy Tepper (USGS). Hu (1989) identified a variety of plant pollen and macrofossils in three samples from wells north of Fryeburg village. He concluded that they came from a forest environment indicative of a relatively warm, nonglacial climate. The radiocarbon ages of the plant fossils ranged from 11,680 to 11,255 years (Thompson, 1999b,c). This information shows that the Fryeburg stage of Lake Pigwacket persisted into early postglacial time. The dated material probably corresponds to the Allerod climatic interval, marked by moderately warm conditions (Stuiver and others, 1995).

Sucker Brook Deposits (unit Pgos)

Borrow Pits and auger holes have revealed a variety of waterlaid glacial sediments (Pgos) north of Foxboro Road in the Sucker Brook valley. Glaciolacustrine silt and clay were found both overlying and underlying outwash sand and gravel. It appears that during deglaciation the valley was temporarily blocked by ice, causing ponding of fine-grained laminated sediments. At other times there was free drainage of meltwater flowing down the valley and depositing coarser materials. The pit exposures in this map unit are shallow (less than 10 ft deep), and the sand and gravel deposits are similarly thin in most places.

Howard Brook Deposits (unit Pgoh)

Borrow pits in the Howard Brook valley (see materials map) have shown 6-8 ft (1.8-2.4 m) of outwash sand and gravel (Pgoh) deposited by glacial meltwater streams. Glaciolacustrine silt and very fine sand were found beneath the floor of the southern pit, indicating an episode of meltwater ponding similar to that which occurred in the Sucker Brook valley to the east. The extent and cause of ponding in these two valleys are unknown.

Coffin Brook Deposits (unit Plc)

Up to 8 ft (2.4 m) of sand and silt (Plc) were observed in several auger holes and a pond excavation along the Coffin Brook valley. These deposits are located in the northeast corner of the quadrangle and adjacent portion of the North Waterford quadrangle. Their fine texture and limited extent indicates they probably were deposited in a small glacial lake. Meltwater ponding in the Coffin Brook valley may have occurred because of blockage by glacial ice remnants in the Kezar Lake basin, at the lower end of the valley.

Great Brook Deposits (unit Pgog)

Great Brook crosses the northern border of the quadrangle and empties into Kezar Lake. This stream drains a sizable area in the mountainous terrain of the adjacent Speckled Mountain quadrangle, but only a short segment of Great Brook is included in the present study area. An outwash terrace (Pgog) was mapped along the east side of the brook. Just north of the quadrangle, a borrow pit in this terrace showed materials ranging from sand to cobble gravel, and minor silt was seen nearby. The outwash deposits were traced up into the Speckled Mountain quadrangle, where bedrock outcrops protruding from this unit show that it is locally very thin.

Evergreen Valley Fan (unit Pgfe)

"Evergreen Valley" is the name of a broad portion of the Cold Brook basin, located midway across the northern border of the quadrangle. It is the site of a residential development and former ski area. The open, gently sloping area crossed by the main access road is underlain by a fan deposit (Pgfe). This fan was built by streams issuing from the valleys of Cold Brook and an unnamed brook draining part of the Speckled Mountain region to the north. It may comprise both glacial and postglacial sediments, but the large size of the fan suggests that much of it was deposited by glacial meltwater. No fresh exposures have been seen in this deposit, and its thickness and composition are unknown. Other fans in the mountains of western Maine are very coarse-grained, so it is assumed that gravel is the principal component of the Evergreen Valley fan.

Rattlesnake Brook Fan (unit Pgfr)

Rattlesnake Brook is a tributary of Shell Pond near the northwest corner of the quadrangle. This stream drains part of the Speckled Mountain area to the north. It has built a large gravelly fan (Pgfr) where it comes out of the hills and empties into the valley of Shell Pond and Shell Pond Brook. At the head of the fan (in the Speckled Mountain quad), Rattlesnake Brook passes through a small, narrow bedrock gorge about 15-20 ft (5-6 m) deep.

The age of the Rattlesnake Brook fan is uncertain. Some of it may be a paraglacial deposit, formed by the brook eroding freshly exposed, unvegetated sediments from hillsides immediately after deglaciation. However, the bedrock gorge at the head of the fan suggests intense erosion by a torrential glacial stream carrying a heavy sediment load. For this reason, it is likely that much of the fan sediment is glacial outwash.

Styles Mountain fan (unit Qfs)

A very small alluvial fan (Qfs) was mapped on the east side of Styles Mountain, near the north edge of the quadrangle. Sand and pebbly sand were seen in a shallow roadside exposure in this unit. The fan was deposited by a brook that is not shown on the topographic map. Given the small size of the unit, and the apparent lack of evidence of glacial meltwater drainage higher on the hillside, the brook itself may have deposited the fan during postglacial time. Since its age is very uncertain, the map unit has a generalized "Quaternary" label.

Wetland deposits (unit Hw)

Unit Hw consists of fine-grained and organic-rich sediments deposited in low, flat, poorly drained areas. In the Center Lovell quadrangle this unit occurs in numerous small valleys and upland basins. 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. In the Saco Valley south of Kezar Lake and Charles Pond, much of the alluvial unit (Ha) is poorly drained and may have vegetation typical of wetlands, as suggested by the marshgrass pattern printed on the topographic map.

There is little information on the thickness of wetland deposits in the quadrangle. A report by Cameron and others (1984) describing peat deposits in southwestern Maine found that they usually average less than 20 ft (6 m) thick.

Stream Alluvium (unit Ha)

Unit Ha consists of alluvial sand, gravel, silt, and organic material deposited by modern streams. In the Center Lovell and adjacent Fryeburg quadrangles these deposits occur in great abundance along the Saco River and its tributaries, including the rich agricultural land on the broad valley floor. The river has meandered back and forth across this flood plain, repeatedly changing course and leaving many abandoned channels that form striking arcuate patterns in aerial views of the Saco Valley. Gravelly alluvium in this area is usually not coarser than pebble-size, and is limited to high-energy environments such as present or former stream channels. The slack-water deposits on the Saco flood plain are finer grained, typically silt and sand (Lewis, 1985).

Numerous wells have been drilled through the alluvium in the Saco River valley (Johnson and others, 1987; Tepper and others, 1990). The boundary between the alluvium and underlying Lake Pigwacket sediments is not obvious from the textural descriptions in most well logs. Textural boundaries recorded in logs from the Fryeburg quadrangle suggest that the river alluvium can be up to 20 ft (6 m) thick and perhaps even thicker (Thompson, 1999b,c). Just north of Fryeburg Fairgrounds, the topographic map shows elevations of 400+ ft on a point bar along the river bank and 386 ft in the bottom of a nearby abandoned channel on the flood plain, so at least 14 ft (4 m) of alluvium is present in the bar.

A noteworthy alluvial feature called a "lake-outlet delta" occurs at the south end of Lower Bay in Kezar Lake. This is a delta formed where a lake drains into an adjacent river at nearly the same elevation. When the river floods, the rising water backs up *into* the lake and deposits deltaic sediment at the point which is normally the lake's outlet (Chormann, 1983; Caldwell and others, 1989). Another example can be seen in the Fryeburg quadrangle, on the southwest side of Kezar Pond.

GLACIAL AND POSTGLACIAL GEOLOGIC HISTORY

The following reconstruction of the Quaternary history of the Center Lovell 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 study area during the Pleistocene Ice Age. Till deposits in western Maine 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 this part of the state (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. Examples in the Center Lovell quadrangle include Christian Hill and Hatch Hill in the southeast part of the map area.

Late Wisconsinan glaciation produced a large portion of the stony till deposits that blanket the upland areas of the quadrangle. Glacial plucking on the lee sides of bedrock hills eroded steep south-facing slopes and cliffs, such as those seen on Deer Hill and Adams 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 see in the Center Lovell quadrangle because they are either concealed beneath surficial sediments, or have been destroyed by weathering where the coarse granite ledges are exposed at the ground surface. Only four striation localities were encountered during this study. On a hill west of Kezar Lake, striated bedrock exposed in the floor of a till pit indicated an average ice-flow direction of 174^{o}. A ledge south of Styles Mountain showed striation trends ranging from 143^{o} to 169^{o}. The south-southeast flow probably occurred during the maximum phase of late Wisconsinan glaciation, when the glacially streamlined hills were sculpted with the same orientation.

Striations on ledges along Route 5 trend 184^{o} and 195^{o}, indicating south to south-southwest ice flow. The same trend is evident from striations in the Fryeburg quadrangle (Thompson, 1999b,c) and elsewhere. This southward 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; Thompson, in prep.).

The minimum age of glacial retreat from the Center Lovell quadrangle can be estimated from 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 quad), so the study area probably was 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, 1999b,c).

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 absent in the Center Lovell quadrangle, making it difficult to reconstruct the pattern of deglaciation. However, the distribution of meltwater channels and heads of outwash for sand and gravel deposits provide clues to the history of ice recession in the area.

Initial glacial retreat from the Center Lovell quadrangle uncovered the Kezar River valley in Lovell, and the Kezar Valley stage of Lake Pigwacket (unit Plpk) developed in this area. Meltwater channels and a belt of hummocky moraine (Phm) near Center Lovell village suggest that the glacier margin stood at the position shown on the geologic map during some part of the time when Plpk sediments were being deposited in the southeast part of the quadrangle. It is inferred that remnants of glacial ice still occupied the Saco River basin during the deposition of unit Plpk, because no lake deposits occur at comparably high elevations over most of the Fryeburg quadrangle. Also, a large remnant ice mass would have been required to help impound Lake Pigwacket at the level of the Kezar Valley stage, which reaches elevations up to 500 ft (152 m) in the adjacent North Waterford quadrangle.

Continued northward ice recession was accompanied by deposition of sand and gravel in glacial Lake Stow, which temporarily occupied the Cold River valley. One ice-margin position can be inferred in this area, based on high-level Pls deposits flanking both sides of the valley (see geologic map). At the same time that ice withdrew from the Cold River basin, small outwash deposits accumulated in the Howard Brook and Sucker Brook valleys to the east (units Pgoh and Pgos). The youngest glacial meltwater deposits in the quadrangle are the outwash and lacustrine units scattered across the northern part of the study area (units Pgfr, Pgfe, Pgog, and Plc). Most of these deposits formed when the ice margin lay to the north in the Speckled Mountain quadrangle.

When the floor of the Saco Valley finally became ice-free, this low-lying area was flooded by the Fryeburg stage of Lake Pigwacket. The principal sediment source probably was the thick glacial-lake sediments that previously were deposited into Lake Pigwacket at North Conway, NH. The influx of this reworked sediment into the Fryeburg area may have been delayed until the postglacial Saco River cut through till barriers near Conway and Center Conway. Sediments also washed into the lake from tributary valleys such as the Cold River in Stow. Unit Plp in the Kezar Lake and Cold River valleys may have been deposited at this time

Lake-bottom deposits (unit Plpb) accumulated in Lake Pigwacket over a broad area between Fryeburg and Lovell, reaching elevations of 410-440 ft (125-134 m) near Lovell village. However, the thickest lake-bottom deposits underlie the Saco flood plain south of the Center Lovell quadrangle, between Fryeburg and North Fryeburg, where dated plant remains in unit Plpb record sedimentation prior to 11,000 radiocarbon years ago.

In postglacial time the Saco River gradually assumed its present form as the remnants of Lake Pigwacket mostly filled with sediment and the river subsequently began to erode these deposits. The Saco River has meandered across the old lake bottom, depositing fine-grained alluvium (unit Ha) on its flood plain. Wetlands (unit Hw) have formed in small upland basins, along sluggish parts of streams, and in a few places adjacent to Kezar Lake.

Rapid uplift and southeastward tilt of the earth's crust occurred soon after deglaciation (Kelley and others, 1992) and may have played a significant role in the evolution of the Saco Valley. The gradient of crustal tilt is known to be approximately 4.75 ft/mi in central New England (Koteff and Larsen, 1989). This tilt steepened the gradient of the south-flowing parts of the Saco River, including the North Conway section, and reduced the gradient of the north-flowing section in Fryeburg. Tilting would have accelerated the erosion of glacial-lake sediments in the North Conway area, and promoted the development of the sluggish meander belt in the Old Course of the Saco north of Fryeburg village.

ECONOMIC GEOLOGY

Sand and gravel supplies are limited to a few small areas of the quadrangle. Sand is very abundant in the Lake Pigwacket deposits (units Plpk and Plp), though much of it is fine grained and perhaps of little economic value. Several pits have been worked for sand or gravel in the glacial Lake Stow deposits (unit Pls) in the Cold River valley, and in the Howard Brook and Sucker Brook valleys (Pgoh and Pgos deposits). In some cases till is not too difficult to excavate, and has a silty-sandy matrix that compacts well in applications where fill is needed.

Surprisingly large quantities of gravel were excavated from beneath glacial till in the pit that used to exist on the east side of Bryant Hill, between Lovell and North Lovell. Till is generally older than associated gravel deposits, and often is known or assumed to rest directly on bedrock. However, several rock-cored hills in western Maine have been found to have gravel beneath the till on their southeast sides. This knowledge may lead to the discovery of other gravel resources in the Oxford Hills region.

Glacial-lake clay from the bottom sediments of Lake Pigwacket (unit Plpb) was formerly used for making bricks. One site reportedly was excavated for this purpose next to Prays Brook, south of where it crosses Route 5 in Lovell (just south of the Center Lovell quadrangle). Concentrations of brick houses in Lovell and other villages may provide clues to the existence of nearby abandoned clay pits.

REFERENCES CITED

Anderson, H. L. V., 1982, Canals and inland waterways of Maine: Portland, Maine Historical Society, Research Series No. 2.

Barrows, J. S., 1938, Fryeburg, Maine -- An historical sketch: Pequawket Press, Fryeburg, 309 p.

Caldwell, D. W., FitzGerald, D. M., and Fenster, M. S., 1989, Origin and sedimentation of Maine lakes with emphasis on lake-outlet deltas, *in* Tucker, R. D., and Marvinney, R. G. (editors), Studies in Maine geology -- Volume 5: Quaternary geology: Maine Geological Survey, p. 97-108.

Cameron, C. C., Mullen, M. K., Lepage, C. A., and Anderson, W. A., 1984, Peat resources of Maine - Volume 4: southern and western Maine: Maine Geological Survey, Bulletin 31, 123 p.

Chormann, J., 1983, Origin of Maine's reverse deltas: M. A. thesis, Boston University, 72 p.

Davis, P. T., and Holland, W. R., 1997a, Surficial geology of the Kezar Falls quadrangle, Maine: Maine Geological Survey, Open-File Map 97-52.

Davis, P. T., and Holland, W. R., 1997b, Surficial geology of the Kezar Falls 7.5-minute quadrangle, Oxford and York Counties, Maine: Maine Geological Survey, Open-File Report 97-67, 14 p.

Holland, W. R., 1986, Features associated with the deglaciation of the upper Saco and Ossipee River basins, northern York and southern Oxford Counties, Maine, *in* Newberg, D. W. (editor), Guidebook for field trips in southwestern Maine: New England Intercollegiate Geological Conference, 78th annual meeting, Bates College, Lewiston, Maine, Trip B-1, p. 98- 123.

Hu, F., 1989, A report on the botanical analyses of four sediment samples from test borings in the Saco Valley: unpublished report to the Maine Geological Survey, University of Maine, Department of Botany and Plant Pathology, Orono, Maine.

Johnson, C. D., Tepper, D. H., and Morrissey, D. J., 1987, Geohydrologic and surface-water data for the Saco River valley glacial aquifer from Bartlett, New Hampshire to Fryeburg, Maine: October 1983 through January 1986: U. S. Geological Survey, Open-File Report 87-44, 80 p.

Kelley, J. T., Dickson, S. M., Belknap, D. F., and Stuckenrath, R., Jr., 1992, Sea-level change and late Quaternary sediment accumulation on the southern Maine inner continental shelf, *in* Quaternary coasts of the United States: Marine and lacustrine systems: Society of Economic Paleontologists and Mineralogists, Special Publication No. 48, p. 23-34.

Koteff, C., and Pessl, F., Jr., 1985, Till stratigraphy in New Hampshire: Correlations with adjacent New England and Quebec, *in* Borns, H. W., Jr., LaSalle, P., and Thompson, W. B. (editors), Late Pleistocene history of northeastern New England and adjacent Quebec: Geological Society of America, Special Paper 197, p. 1-12.

Koteff, C., and Larsen, F. D., 1989, Postglacial uplift in western New England: Geologic evidence for delayed rebound, *in* Gregersen, S., and Basham, P. W. (editors), Earthquakes at North-Atlantic passive margins: Neotectonics and postglacial rebound: Kluwer Academic Publishers, p. 105-123.

Leavitt, H. W., and Perkins, E. H., 1935, A survey of road materials and glacial geology of Maine -- Volume II: Glacial geology of Maine: Maine Technology Experiment Station, Orono, Maine, Bulletin 30, 232 p.

Lewis, M. R., 1985, Stratigraphy and geomorphology of the Saco River valley north of Fryeburg, Maine: senior thesis, Bates College, Lewiston, Maine, 83 p.

Osberg, P. H., Hussey, A. M., II, and Boone, G. M. (editors), 1985, Bedrock geologic map of Maine: Maine Geological Survey, 1:500,000-scale map.

Prescott, G. C., Jr., 1979, Royal, upper Presumpscot, and upper Saco River basins (Maine) area: U. S. Geological Survey, Maine Hydrologic-Data Report No. 10, Ground-Water Series, 53 p.

Prescott, G. C., Jr., 1980, Ground-water availability and surficial geology of the Royal, upper Presumpscot, and upper Saco River basins, Maine: U. S. Geological Survey, Water-Resources Investigations 79-1287, 3 maps.

Prescott, G. C., Jr., and Dickerman, D. C., 1981, Sand and gravel aquifers map 14; Oxford County, Maine (compiled by A. L. Tolman and E. M. Lanctot): Maine Geological Survey, Open-File Report 81-50, 6 p. and map.

Stone, B. D., and Borns, H. W., Jr., 1986, Pleistocene glacial and interglacial stratigraphy of New England, Long Island, and adjacent Georges Bank and the Gulf of Maine, *in* Sibrava, V., Bowen, D. Q., and Richmond, G. M. (editors), Quaternary glaciations in the Northern Hemisphere - IGCP Project 24: Pergamon Press, Oxford, England, p. 39-53.

Stone, G. H., 1899, The glacial gravels of Maine and their associated deposits: U.S. Geological Survey, Monograph 34, 499 p.

Stuiver, M., Grootes, P. M., and Braziunas, T. F., 1995, The GISP2 d^{18}O climate record of the past 16,500 years and the role of the sun, ocean, and volcanoes: Quaternary Research, v. 44, p. 341-354.

Tepper, D. H., Lanctot, M., and Thompson, W. B., 1987, Hydrogeologic data for significant sand and gravel aquifers - Map 14: Maine Geological Survey, Open-File No. 87-1d.

Tepper, D. H., Morrissey, D. J., Johnson, C. D., and Maloney, T. J., 1990, Hydrogeology, water quality, and effects of increased municipal pumpage of the Saco River valley glacial aquifer: Bartlett, New Hampshire to Fryeburg, Maine: U. S. Geological Survey, Water-Resources Investigations Report 88-4179, 113 p.

Thompson, W. B., 1986, Glacial geology of the White Mountain foothills, southwestern Maine, *in* Newberg, D. W. (editor), Guidebook for field trips in southwestern Maine: New England Intercollegiate Geological Conference, 78th annual meeting, Bates College, Lewiston, Maine, Trip C-1, p. 275-288.

Thompson, W. B., 1994, Glacial fan deposits overridden by the late Wisconsinan ice sheet, southwestern Maine (abs.): Geological Society of America, Abstracts with programs, v. 26, no. 3, p. 76.

Thompson, W. B., 1998, Surficial materials of the Center Lovell quadrangle, Maine: Maine Geological Survey, Open-File Map 98-239.

Thompson, W. B., 1999a, Surficial geology of the Center Lovell quadrangle, Maine: Maine Geological Survey, Open-File Map 99-1.

Thompson, W. B., 1999b, Surficial geology of the Fryeburg quadrangle, Maine: Maine Geological Survey, Open-File Map 99-7.

Thompson, W. B., 1999c, Surficial geology of the Fryeburg 7.5-minute quadrangle, Oxford County, Maine: Maine Geological Survey, Open-File Report 99-8, 20 p.

Thompson, W. B., in prep., Deglaciation of western Maine, *in* Weddle, T. K., and Retelle, M. J. (editors), Deglaciation history and relative sea-level changes, northern New England and adjacent Canada: Geological Society of America.

Thompson, W. B., and Borns, H. W., Jr., 1985, Till stratigraphy and late Wisconsinan deglaciation of southern Maine: A review: Geographie physique et Quaternaire, v. 39, no. 2, p. 199-214.

Thompson, W. B., and Koteff, C., 1995, Deglaciation sequence in southwestern Maine: stratigraphic, geomorphic, and radiocarbon evidence (abs.): Geological Society of America, Abstracts with programs, v. 27, no. 1, p. 87.

Thompson, W. B., Fowler, B. K., Flanagan, S. M., and Dorion, C. C., 1996, Recession of the late Wisconsinan ice sheet from the northwestern White Mountains, New Hampshire, *in* Van Baalen, M. R. (editor), Guidebook to field trips in northern New Hampshire and adjacent regions of Maine and Vermont: New England Intercollegiate Geological Conference, 88th annual meeting, Harvard University, Cambridge, Trip B-4, p. 203-234.

Weddle, T. K., Stone, B. D., Thompson, W. B., Retelle, M. J., Caldwell, D. W., and Clinch, J. M., 1989, Illinoian and late Wisconsinan tills in eastern New England: A transect from northeastern Massachusetts to west-central Maine, *in* Berry, A. W., Jr. (editor), Guidebook for field trips in southern and west-central Maine: New England Intercollegiate Geological Conference, 81st annual meeting, University of Maine at Farmington, Farmington, Maine, Trip A-2, p. 25-85.

Wilkinson, D. E. (editor), 1995, Soil survey of Oxford County, Maine: U. S. Department of Agriculture - Soil Conservation Service, 296 p. and maps.

Williams, J. S., Tepper, D. H., Tolman, A. L., and Thompson, W. B., 1987, Hydrogeology and water quality of significant sand and gravel aquifers in parts of Androscoggin, Cumberland, Oxford, and York Counties, Maine: Maine Geological Survey, Open-File Report 87-1a, 121 p. and maps.

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.

APPENDIX B

LOGS OF OBSERVATION WELLS AND OTHER BORINGS IN THE SACO RIVER VALLEY

(from Williams and others, 1987; see materials map for locations)

OW 14-1. Latitude: 44°07'28", Longitude: 70°56'27". Located in Stow, in field off Rt.113 near Maine - New Hampshire state line. Depth to water approximately 9 feet.

Material	Depth (feet)	Thickness (feet)
Granules, pebbles, and cobbles	0-11	11
Sand, medium to very coarse; granules and pebbles	11-16	5
Sand, coarse to very coarse; granules and pebbles	16-21	5
Sand, medium to very coarse; granules and pebbles	21-26	5
Sand, medium, well-sorted	26-36	10
Sand, fine to coarse, poorly sorted; granules and pebbles	36-46	10
Sand, fine to coarse, well-sorted, stratified, iron-stained, interbedded with clay	46-56	10
Clay, blue and green, interbedded with some moderately sorted, fine to medium sand	56-66	10
Clay, interbedded with very fine sand and silt	66-72	6
Refusal (bedrock)	72	—

OW 14-1 is screened from 18 to 23 feet below land surface with 0.010-inch slotted pVC screen.

OW 14-8. Latitude: 44°09'35", Longitude: 70°58'40". Located in Stow, in gravel pit on north side of New Road, near the intersection with Route 113. Depth to water approximately 10 feet.

Material	Depth (feet)	Thickness (feet)
Sand, medium, well-sorted	0-6	6
Sand, medium to coarse	6-16	10
Sand, fine to very coarse	16-18	2
Clay, with thin laminations of well-sorted very fine to medium sand	18-23	5
Sand, fine to medium; granules and pebbles	23-24	1
Sand, fine to very coarse poorly sorted; granules and pebbles	24-26	2
Clay, grey; stratitied with layers of moderately well sorted fine to coarse sand; coarser sand layers are iron-stained	26-32	6
Till	32-37	5
Refusal (bedrock)	37	—

OW 14-8 is screened from 22.5 to 25 feet below land surface with 0.0006-inch slotted pvc screen.

(from Johnson and others, 1987; see materials map for locations)

OW74. 4407410705653.01, Drilled 1985.
Altitude 382.2 ft. Depth to water 12.7 ft.
Log by U.S. Geological Survey.

	Depth (feet)	Thickness (feet)
Topsoil	0 - 2	2
Sand, fine	2 - 7	5
Sand, very fine to fine	7 - 12	5
Sand, medium to very coarse	12 - 22	10
Clay, green/gray	22 - 23	1
Till	23 - 44	21
Refusal (bedrock?)	at 44	

OW75D. 4407420705602.01, Drilled 1985.
Altitude 383.5 ft. Depth to water 16.4 ft.
Log by U.S. Geological Survey.

	Depth (feet)	Thickness (feet)
Soil	0 - 2	2
Clay, silty, some very fine sand	2 - 17	15
Clay, silty, sandy, possible organics.	17 - 22	5
Clay; and medium to very coarse sand	22 - 27	5
Sand, medium to very coarse	27 - 37	10
Sand, fine to coarse; some medium to coarse	37 - 47	10
Sand, fine to coarse; some organics.	47 - 67	20
Silt, clayey and very fine sand	67 - 88	21
Clay, gray	88 - 111	23
Till	111 - 117	6
Refusal (bedrock)	at 117	