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Surficial Geology of the Sebago Lake 7.5-minute Quadrangle, Cumberland County, Maine

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INTRODUCTION

The Sebago Lake 7.5' quadrangle has an area of about 133 km^2 (52 mi^2). It is located in southwestern Maine within the Seaboard Lowland physiographic province, about 32 km (20 mi) west of Portland. Altitudes range from 56 meters (184 feet) at the extreme southeastern corner of the map, to more than 178 meters (584 feet) on Oak Hill in the southwestern part of the quadrangle. The topography is gently rolling, punctuated by bedrock knobs and abundant swamps. The Sebago pluton underlies practically the whole northern part of the quadrangle, especially the northern basin of Sebago Lake (Hussey, 1985),which is more than 100 meters (300 feet) deep, where it reflects the intersection of the two major joint sets in the pluton. The pluton is light-gray to pink, medium-grained, non- to slightly foliated, biotite-muscovite granite. The granite is intruded in places by Mesozoic pegmatite dikes and basalt or diabase dikes. In a few places in the quadrangle, there are exposures of roof pendants of metasedimentary rocks that the Sebago pluton intruded during the Mississippian Period about 354 million years ago (Hussey, 1985). The southwestern part of the quadrangle is underlain mostly by folded and metamorphosed Ordovician and Silurian plagioclase-biotite granofels of the Vassalboro Formation. The southeastern part of the quadrangle, including the Lower Bay area and Indian Island, is underlain by northeast-trending folded synformal belts of muscovite-biotite-garnet schist of the Silurian Windham Formation (Hussey, 1985). These units are intruded in places by diabase and basalt dikes. The author observed one large northeast-trending dike that extends from north of Johnson School in Sebago Lake village to the shore of the lake. Another large dike forms the "spine of Indian Island" (John Creasy, personal communication, 1997). The author found rottenstone dike rock exposed in the wave-cut beach cliff on the west end of Indian Island.

The present investigation was carried out as part of a cooperative geologic mapping project funded by the Maine Geological Survey and the U.S. Geological Survey. Two maps are associated with this report. The *geologic map* (Hildreth, 1997c) shows the distribution of the sedimentary units and discusses their age, composition, and origin. It also includes information relating to the geologic history of the quadrangle, such as glacial striation azimuths and radiocarbon dates on fossil organic remains. The geologic map provides the basis for the discussion of glacial and postglacial history presented here. The *materials map* (Hildreth, 1998) shows specific site data used to help compile the geologic map. These data include observations from gravel pits, shovel and auger holes, construction sites, and test borings.

PREVIOUS WORK

Early work on the surficial geology in this part of Maine was done generally at a reconnaissance level and at a smaller scale (Bloom, 1960, 1963; Thompson and Smith, 1977; Thompson and Borns, 1985a, b). Significant sand and gravel aquifers were mapped by Williams and Lanctot (1987). Significant glacial features in the Sebago Lake area, such as marine deltas and lacustrine rhythmites were investigated and discussed in recent years by many workers (Thompson and others, 1989; Thompson and others, 1995a, b). The soil survey of Cumberland County greatly facilitated field work (Hedstrom, 1974). Recent surficial geologic maps of the following neighboring quadrangles were available during compilation of the report: Steep Falls (Gosse and Thompson, 1999a,b); Standish (Gosse, 1999a,b); Naples (Hildreth, 1997a,b); and North Windham (Bolduc and others, 1999a,b).

PREGLACIAL AND GLACIAL HISTORY

Southwestern Maine probably experienced several advances of the Laurentide continental ice sheet during the Pleistocene Ice Age, but virtually all evidence of previous glaciations in the area was obliterated during the last glaciation (late Wisconsinan) when the continental glacier advanced from the northwest across the area to a terminal position on the continental shelf. Glacial erosion within this area is noticeable mainly as glacial striations on freshly exposed bedrock surfaces. Some ramp-and-pluck topography on bedrock knobs, including a few roche moutonnées in conjunction with the striations, definitely record southeastward movement of the ice. It should be noted that glacial striations weather rapidly and survive only a very short time (generally only a few tens of years) after exposure to surface elements in this climate; those along the shore of Sebago Lake are on bedrock surfaces recently stripped of overlying surface sediments by wave action (probably related to the altitude of the lake's being artificially raised by the modern dam). Most other striations were found on recently excavated bedrock surfaces. Generally, the striations indicate a south-southeast direction of ice flow; some variations can be attributed to local deflection around irregularities of the bedrock topography. At one locality on Route 114 southeast of Wards Cove, two sets of striae were measured as 150^{o} and 163^{o}; it was not clear which set was older. This relationship is consistent with similar intersecting sets found elsewhere in southwestern Maine (Hildreth, 1999a-d). Some previous workers in the Kennebunk area have interpreted similar features as evidence of a glacial readvance, but the idea has been challenged and the controversy is ongoing (Smith, 1982).

After reaching its terminal position on the continental shelf, the late Wisconsinan ice sheet began to recede between 15,000 and 17,000 years ago Shells collected from glaciomarine sediments deformed by ice shove in the Freeport area (east of Sebago Lake) have a radiocarbon age of 14,045 yr B.P. (Weddle and others, 1993). The ice sheet terminus is inferred to have reached the Sebago lake quadrangle by about that time.

According to Smith (1999a,b), "Two indirect effects of glaciation had a very strong bearing on the character of ice retreat and the deposition of the glacial sediments in this portion of the coastal zone. First, the great weight of the Laurentide continental ice sheet depressed the crust beneath the glacier significantly below its present level throughout the region. Secondly, as glaciers expanded worldwide, water was trapped on land as ice, causing sea level to be lowered by several hundred feet. Later, as the ice began to melt and retreat, water was returned to the ocean and sea level rose immediately. At the same time, the crust began slowly to rebound to its original level. The interaction of these effects resulted in submergence of the entire Maine coastal zone for a period of several hundred years following the retreat of the ice."

The Sebago Lake area lies at or near the limit of maximum marine submergence in Maine (Figure 1). This transgressive sea level surface has been mapped by measuring the elevations of the topset-foreset contact in deltas deposited by glacial meltwaters in the late Wisconsinan sea (Thompson and others, 1989). The Sebago Lake marine delta at the south end of the lake has a foreset-topset contact elevation of about 91 m (300 ft) above sea level (Thompson and Smith, 1977; Thompson and others, 1989). Another topset-foreset contact at about 94.5 m (310 ft) elevation in unit Pmd_2 was measured at a pit off Boundary road. Other deltaic deposits at East Sebago (Figure 1) on the west shore of Sebago Lake have been interpreted to be either lacustrine or marine and have a "topset-foreset contact" at 98 meters (320 feet) above sea level (Thompson and Borns, 1985a). Relatively thick marine silt and clay (Presumpscot Formation) deposits were found only in the extreme southeastern corner of the Sebago Lake quadrangle, at the toe of the Sebago Lake marine delta. However, recent studies indicate that thick probable marine silt-clay deposits underlie the southeastern part of Sebago Lake (Robert Johnston, personal communication, 1966). In addition, thin silt-clay (1-3 ft thick) deposits were found capping marine delta deposits of unit Pmd_5 north of Rich Millpond (Site 316). This discovery would move the previously drawn marine limit shown on Figure 1 (from the state surficial geologic map of Thompson and Borns, 1985) a few kilometers northward. Elsewhere, where Presumpscot deposits might be expected, rhythmic-bedded silt and clay deposits (Plss) characteristic of lacustrine environments were found in scattered exposures around the shore areas of the lake. Also, recent studies indicate the deep northern part of the lake basin contain probable lacustrine silt-clay rhythmites. Thus, the late-glacial sea appears to have entered the Sebago Lake area. "The northwestern part of Sebago Lake actually extends below sea level, with a maximum water depth that exceeds 100 m [328 ft]. An ice blockage would have been required in this part of the lake to exclude the sea ......, because marine deltas and clay deposits do occur along the eastern and southern margins of Sebago Lake" (Thompson and Borns, 1985b).

The present author accepts the interpretation of an ice block in Sebago Lake and proposes that the majority of lacustrine deposits in the Sebago Lake area are graded to a col at 95-98 meters (310-320 feet) above sea level southwest of East Sebago (Figure 1) to the west of this quadrangle, or over a notch in the ice block in the lake. The morphology in the valley headed by the East Sebago col consists of a southwest-trending bouldery ridge (Thompson and others, 1995a, Stop 6) that could be an erosional remnant of till or other material left by the erosional force of a massive volume of meltwater using this valley as a spillway for the late glacial lake in the Sebago Lake-Naples area, called glacial Lake Sebago (Hildreth, 1997a,b). Meltwater draining through this spillway entered the Saco River valley to the southwest, which was presumably free of ice at the time. How long glacial Lake Sebago existed is uncertain. One section of rhythmic silt-clay deposits near Songo Lock (Naples quadrangle, Hildreth, 1997a,b) contains more than 130 rhythmites (varves) which indicate a lake of at least 130 years' duration. Glacial Lake Sebago probably existed for some time after the ice block melted out of Sebago Lake, because the lake is dammed by the glaciomarine ice-contact Sebago Lake delta at the south end, and crustal rebound was delayed following retreat of the ice margin from the area. It is not certain when the East Sebago col was abandoned as a spillway, but when it was, one or two temporary

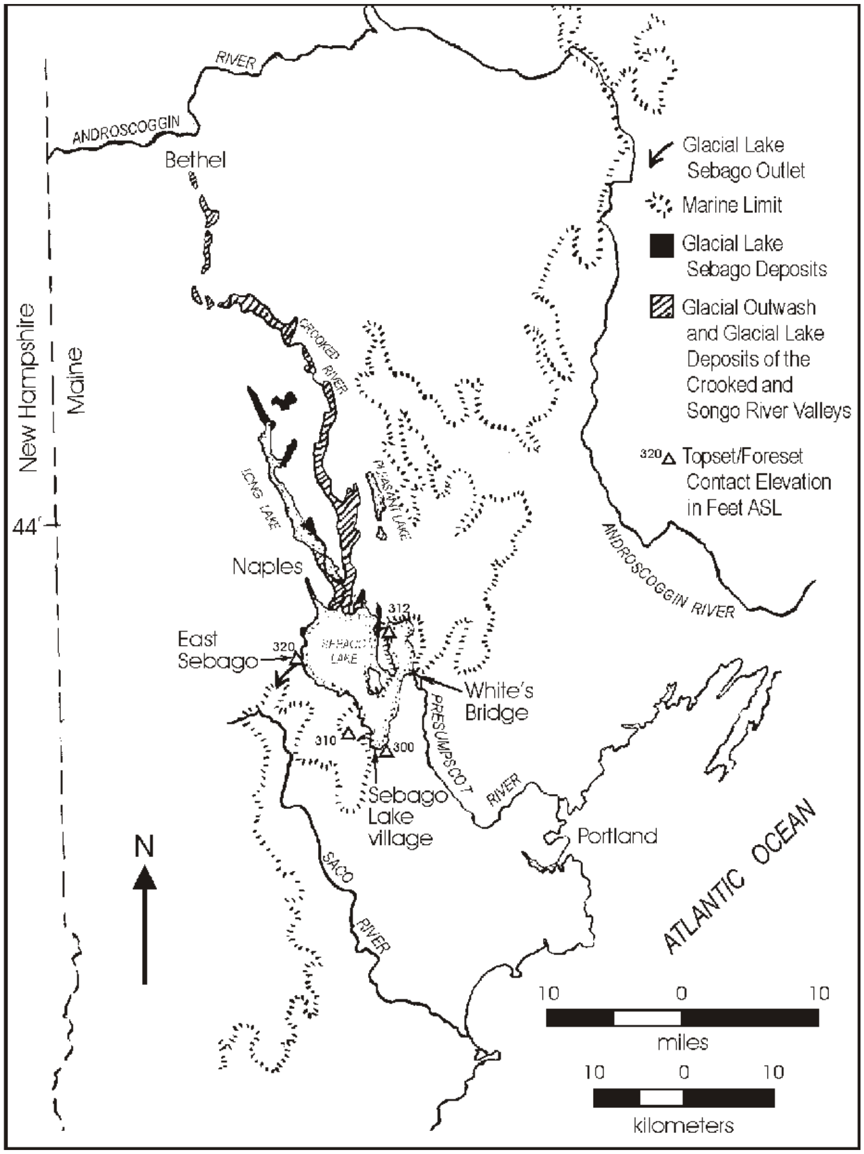

Figure 1. Map of western Maine showing features discussed in the text. Modified from the Surficial Geologic Map of Maine (Thompson and Borns, 1985a).

spillways were carved very briefly through unconsolidated erodable materials at the south end of the lake; and, ultimately, a modern spillway was carved through till deposits at Whites Bridge in the North Windham quadrangle, where the lake drains into the Presumpscot River (Figure 1). The channel at Whites Bridge is bottomed in bedrock at about 253 feet asl (Beth Lewis, personal communication 1997).

As mentioned earlier, the present 89-meter (267-foot) altitude of the lake is artificially raised by about 10 to 14 feet by a dam. The preglacial drainage for the Sebago Lake basin probably followed a route to the south end of the lake (Hildreth, 1997a,b) which contains a buried bedrock valley, as indicated on side-looking radar surveys of the U.S. Geological Survey (unpublished data, 1995). This buried valley is filled by the Sebago Lake marine delta. This evidence supports Caldwell and others' (1985, p. 52) observation that deposits of glacial streams in Maine form a dendritic pattern that may represent preglacial drainage. Thus the preglacial Androscoggin River may have drained from the Bethel area southward down the Crooked River valley (Figure 1), through Sebago Lake and southward to the Portland area. This subject requires further investigation beyond the scope of this report.

As summarized by Thompson and Borns, 1985b), "The offlap of the sea from southern Maine began soon after the late Wisconsinan ice margin had receded to the marine limit. The marine submergence reached its maximum extent at about 13,000 yr B.P., and it is likely that isostatic crustal uplift was already causing relative sea level to fall by this time. The latter in-

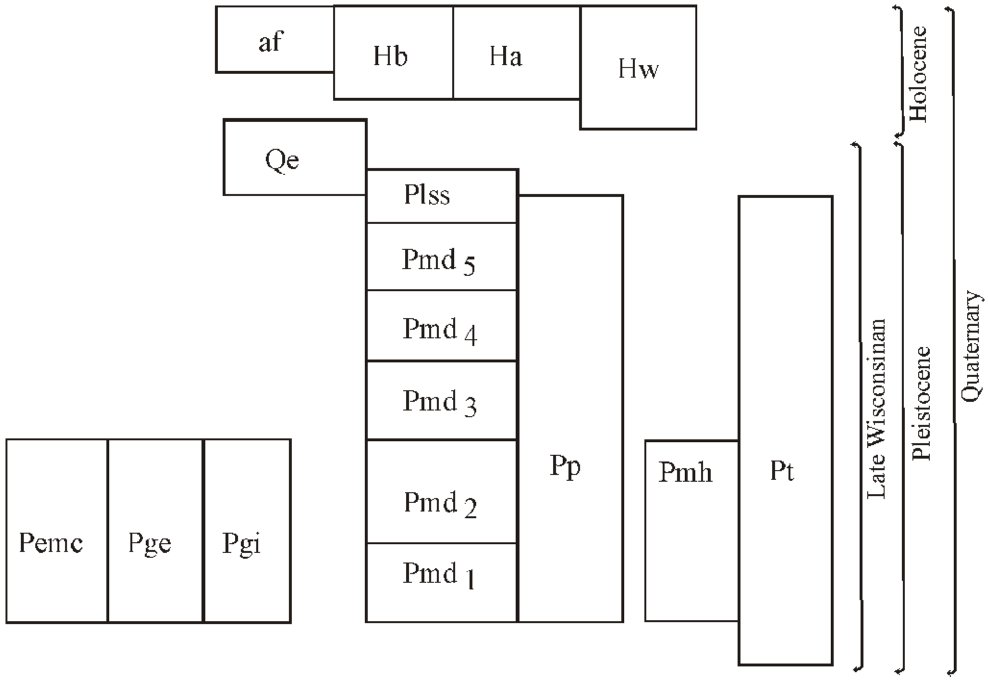

Figure 2. Correlation of map units.

ference is based on the gradient of the plane defined by glaciomarine deltas in southern Maine. The elevation pattern of the deltas indicates a northwest-southeast postglacial tilt of 0.47 m/km [2.48 ft/mi] across south-central Maine.... This value is considerably less than the post-glacial uplift gradient of 0.89 m/km [4.67 ft/mi] obtained ....from glacial Lake Hitchcock deltas in the Connecticut River valley. The probable explanation for this discrepancy is that the sequence of marine deltas in Maine was graded to a falling sea level, thus reducing the apparent crustal tilt as determined from their present elevations."

Most glacial meltwater deposits in the Sebago Lake area are marine delta or marine fan-delta deposits graded to an elevation consistent with the 91-98 meters (300-320 feet) asl maximum marine invasion in this part of Maine. The sea regressed from the Sebago Lake area somewhat before 11,450 yr B.P. This conclusion is based on shells that indicate the approximate offlap of the late Wisconsinan sea at Little Falls, Gorham, southeast of Sebago Lake (Smith, 1985; Thompson and Borns, 1985a).

GLACIAL AND POSTGLACIAL DEPOSITS

The succession of surficial deposits (Pleistocene and Holocene) in the Sebago Lake area is given in the correlation chart (Figure 2) showing the relative ages of the map units.

Till (map unit Pt) occurs throughout the Sebago Lake area; its thickness is variable, as is its composition. The till was deposited from the ice sheet and forms a blanket over the underlying bedrock; it is inferred to underlie younger deposits throughout the area. In most exposures in the Sebago Lake area, this till is light olive gray, sandy, stony, and moderately compact, showing weathering only in the uppermost few feet. The sandy nature reflects its derivation from the Sebago pluton parent material. Some drumlins are found in the Sebago Lake area, but most hills that are drumlin shaped (and oriented in the expected direction for drumlins relative to the direction of striations in the area) have bedrock cores that have been plastered with till; many more of these exist in the quadrangle than do true drumlins.

One particular landform that is composed mostly of till is the hummocky moraine (unit Phm) on the southwest side of the map. This massive to stratified, poorly sorted diamict (till) is characterized by knobby topography, many boulders, and a loose sandy matrix. It appears to be crudely ridged parallel to a nearby end moraine in the Steep Falls quadrangle (Gosse and Thompson, 1999a,b) and probably formed just in front of or near the active ice margin at about the same time as the end moraine complex (Pemc) and eskers (Pge) were being deposited. Pemc appears to contain more sand and gravel than Phm, but less sand and gravel than Pge. Pemc consist of a cluster of closely (and often evenly) spaced ridges of till and/or poorly to well-stratified sediment deposited at the ice margin (Thompson and Smith, 1977). Pge consists of ridges of predominantly gravel and sand, massive to stratified materials deposited in subglacial and englacial tunnels during melting of the glacier. Some or all of the Pge deposits may have been feeders for Pgi deposits in the southwest part of the quadrangle, which consist of proximal ice-contact deposits contemporaneous with a marine delta deposit in the Standish quadrangle, just to the south (unit Pmd_8 of Gosse, 1999a,b). The relationships between the deposits mentioned in this para-

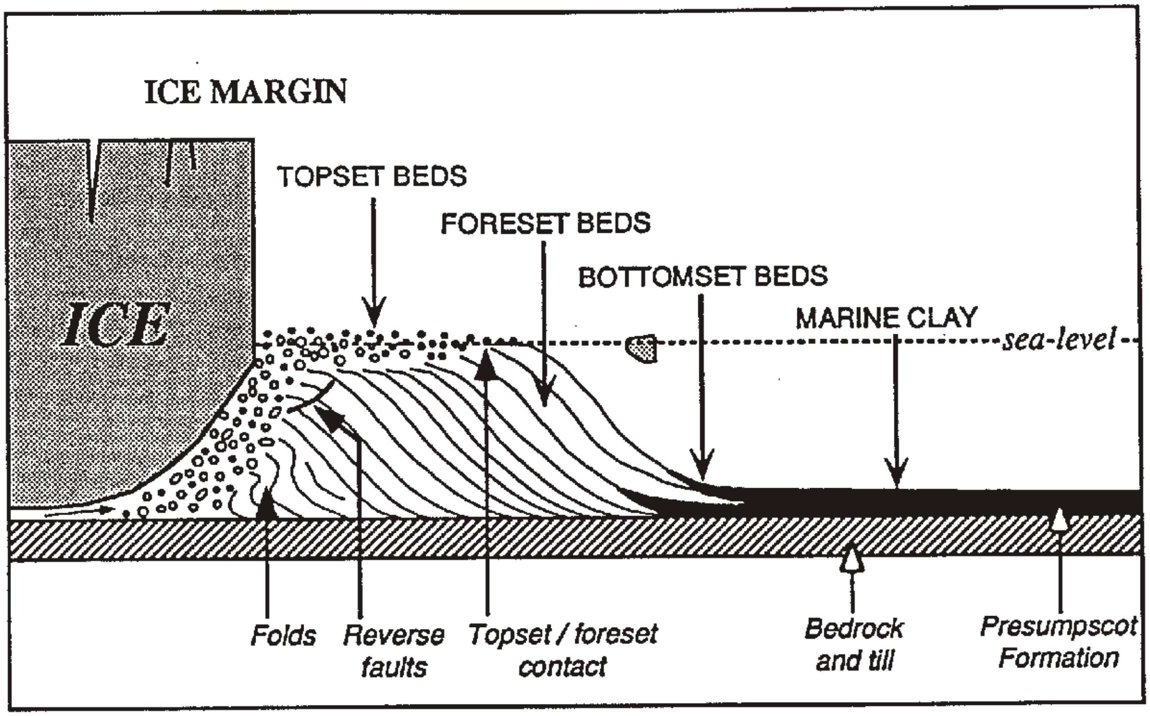

Figure 3. Vertically exaggerated diagram showing the components of an ice-contact delta environment. Small arrow under the ice indicating the flow direction of the sediment-laden meltwater could also represent an esker channel which feeds the delta. Normal faults and large-scale folding are evidence of deformation at the ice-contact portion (back slope) of the delta. Topset beds shown are predominantly comprised of cobble gravels; Foreset beds: sand; and Bottomset beds: silt (from Gosse, 1994, Figure 5).

graph could bear further detailed study beyond the scope of this report.

Glaciomarine delta and fan deposits form the majority of the stratified glacial outwash deposits in the quadrangle. Meltwater that flowed southward into the late-glacial sea deposited these materials in contact with or beyond adjacent ice as ice-contact marine delta and fan deposits. Five separate units were identified and delineated. Pmd_1 is a classic marine delta, referred to herein as the Sebago Lake marine delta. A cross section through this delta from north to south fits a diagram given in the Standish quadrangle report (Gosse, 1999a,b, Figure 5) and reproduced herein as Figure 3. Modern Sebago Lake occupies the area where the word ICE is on Figure 3. The foreset slope of this delta is very well preserved, and Presumpscot Formation (Pp) composed of marine silt and clay is exposed in the lowland at the toe of the slope in the southeast corner of the quadrangle. Cross sections at right angles to shoreline parts of $Pmd_{2,\ 3\ \text{and}\ 5}$ would also approximate this diagram in the same way, except that foreset slopes and Presumpscot Formation deposits are missing or completely buried in most of the area.

One major feature is missing from the diagram in Figure 3—buried ice blocks. Most of the marine delta deposits in the quadrangle have many kettle holes from the melting of these ice blocks. Halfmoon, Snake, and Otter Ponds in Pmd_1 are classic examples of kettle ponds. Some kettle holes are more shallow and are currently filled with freshwater wetland deposits (Hw). Topset-foreset contacts in Pmd_1 were measured at an elevation of 300 ft asl (Thompson and Smith, 1977) at site 179. The present author observed an apparent boulder beach deposit at about 295 ft asl at site 202 in this unit; the boulder deposit may represent wave reworking of the topset beds as sea level dropped. Likewise, much of the surface material in other delta and fan deposits in the quadrangle may be reworked by wave action as sea level dropped. Topset-foreset contacts were observed in only a few places in the quadrangle; one was measured at 310 ft asl (Thompson and Smith, 1977) along Boundary Road in unit Pmd_2. Foreset beds were observed in pits in units $Pmd_{3\ \text{and}\ 5}$, but topset beds were not. Contacts between marine delta deposits are tentative in most places, because distinct heads of outwash are unclear and elevations are very similar. Unit Pmd_4 is delineated based on mapping in the the Steep Falls quadrangle (Gosse and Thompson, 1999a,b) and on shallow sparse exposures in this quadrangle. In only one exposure was there the slightest evidence that the sea overtopped units $Pmd_{2\text{-}5}$; site 316 in unit Pmd_5 had a thin cap of silt-clay that may be marine in origin.

Lakeshore, nearshore, and lake-bottom sediments (Plss) of glacial Lake Sebago form a discontinuous cover as much as 18 meters (60 feet) thick in scattered areas around the margin of the modern lake. They are undifferentiated on the map, because they cover small areas and exposures are scarce. Their presence above the modern lake level indicates that glacial Lake Sebago was at least 10 to 20 feet higher, at least during immediate post-glacial times. A possible beach deposit of boulder gravel at these levels was poorly exposed on the Sebago Lake delta at site 184. Most of this unit is sand and minor gravel, but a few exposures of silt-clay varves were found (site 401 on the west side of Frye Island, for example). In addition, thick lake-bottom deposits cover the bottom of the deep northern basin, which indicates the lake existed for a long time after the ice block that initially occupied it melted out. Also, the thick lake-bottom deposits indicate a long-term, rich supply of rock flour was contributed to the lake basin via the glacial meltwater-swollen Crooked River (Figure 1; Hildreth, 1997a,b) long after the ice front had retreated far north of the lake area. These deposits are associated with glacial Lake Sebago spillways at East Sebago (310-320' asl), over the Lake Sebago delta (290-300' asl), at the north edge of the Lake Sebago delta (280-290' asl), and levels of the lake below this at Whites Bridge before downcutting to the bedrock sill there at 253' asl. Please note that, because of postglacial tilt, the channels in the Lake Sebago delta mentioned above may be overwash channels contemporaneous with the spillway at East Sebago. Also, the spillway at the north edge of the Sebago Lake delta drains into the headwaters of Westcott Brook in the southwestern corner of the North Windham quadrangle (Bolduc and others, 1999a,b), which flows southeastward and joins the Presumpscot River in South Windham in the Gorham quadrangle.

When sea level regressed from the Sebago Lake area, vegetation did not apparently cover the area immediately, because large sections of the south-central part of the quadrangle are coated with windblown eolian sand deposits (Qe) derived from the wind transport of fine- to medium-grained sand on the surface of the marine delta and fan deposits. Some deposits have distinct dune forms, but most are apparently just blanket deposits, primarily on the west slopes of hills, indicating prevailing winds were from the west. Several dunes, however, appear to have migrated over hilltops in the vicinity of Boundary Road and Oak Hill Road. These eolian deposits may be partly contemporaneous with glacial Lake Sebago deposits (Plss) and partly with freshwater wetland deposits, inasmuch as windblown materials are often found at the bottom of many kettle holes in the area (Hildreth, 1997a,b).

Deposits of Holocene age are generally associated with modern streams, wetlands, and lake shorelines. Freshwater swamp (Hw) deposits, characterized by accumulations of decayed organic matter, are found scattered throughout the area. Alluvial deposits (Ha) of variable thickness and composition underlie the flood plains of most modern streams. It should be noted that swamp deposits and alluvial deposits are coincident along many stretches of the stream flood plains in this area. Modern beach deposits (Hls) have formed along scattered stretches of the modern lake shoreline. The beach at the south end of Frye Island has shown signs of erosion, which has been attributed to seasonal fluctuations of Sebago Lake's water level (Thompson and others, 1995a, b). The present author has observed much modern erosion along the shoreline of Sebago Lake, where fresh exposures of striated bedrock are common, especially on the shores of islands. The shoreline erosion around the lake may be attributed to wave erosion of materials above the normal lake level due to the damming of the lake.

Finally, areas have been mapped as artificial fill (af) where the original ground surface is covered by a substantial thickness of imported materials, both manmade and natural, that have been used by man to fill depressions, or where the surface has been so altered by construction as to obliterate the natural landscape.

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APPENDIX
(Refer to surficial materials map [Hildreth, 1998] for locations)

Site Number

179 Large, semi-active pit east of Sebago Lake village. Contains some artificial fill and is partly regraded. This is a relatively old pit. Near the bottom of the pit, about 10 feet below the top, at the northern end, 2 feet of p, c, s overlay 4 feet of foreset beds composed of sand and pebbles alternating with silt-clay beds. The foreset beds dip southeast to southwest.

184 On the banking above Lake Sebago, just north of Otter Ponds, appears to be evidence of three terrace levels. Terrace level 1 is at 4-5 feet above the lake and its surface is composed of s,p. About 8-10 feet above the lake is terrace level 2 whose surface is composed of boulders. About 14-20 feet above the lake is terrace level 3, whose surface is composed of b,s,p. These may represent major stillstands of glacial Lake Sebago. Further investigation for such terrace levels around the lake is suggested.

202 Active gravel pit just west of word "GORDON" in the southeast corner of the map. One foot of windblown fine sand and silt over 1 foot of pebbles and sand over 1 foot of sand over 2-5 feet of boulders. The next 10 feet below this is covered, below which is 40 feet of sand and pebble gravel. The boulder layer may indicate a beach deposit at a stillstand of the regressive sea in this area. Apparent foreset beds dip in the direction of 120^{o} azimuth. Topset-foreset contact not observed.

Site Number

246 Indian Island, cove on west side. Beach is pebbles and sand. Wave-cut bank contains rottenstone composed of crumbly diabase dike rock, which forms the "spine of Indian Island," according to John Creasy (personal communication, 1997).

316 Marietta Pit, east of Route 114 in unit Pmd_5 northeast of Rich Millpond. 1-2 ft windblown s,st over 2-5 p,s,c,b (boulders appear to be drop stones). This unit is draped over underlying deposits, which consist of 2 feet of st, fs, cy (also draped), which overlie 10 feet of sand and gravel subaqueous fan deposits. The 2 feet of draped silt, fine sand, and clay are interpreted to be marine and the overlying 2-5 feet of coarse drape materials are interpreted to be offlap facies developed by waves reworking earlier deposits.

317 Relatively inactive on opposite side of Route 114 from site 316. 10 feet of p,s,c and fs. Apparent foreset beds dip toward azimuth 160^{o}. No topset-foreset contact observed.

379 Relatively inactive pit northwest of site 317 on the west side of of Route 114. Contains abundant spectacular bedrock outcrops with good striations measuring average 170^{o} azimuth. Materials variable: 2 p,c,s / 1 s, fs / 2 cg + s, fs / 2 d (till). Foreset beds 12 feet below the top of the pit dip in direction of 220^{o} azimuth. No topset-foreset contact observed. Overall, the pit is about 20 feet deep.

401 Varve locality in wave-cut bench on Frye Island.