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

OPEN-FILE NO. 97-61

Title: *Surficial Geology of the Great East Lake 7.5-minute Quadrangle, York County, Maine*

Author: *Jon C. Boothroyd*

Date: *1997*

Financial Support: Funding for the preparation of this report was provided in part by the U.S. Geological Survey Cooperative Geological Mapping (COGEO-MAP) Program, Cooperative Agreement No. 14-08-0001-A0868.

Associated Maps:
Surficial geology of the Great East Lake quadrangle, Open-File 97-46
Surficial materials of the Great East Lake quadrangle, Open-File 98-171

Contents: 9 p. report

Maine Geological Survey
Open-File 97-61

Surficial Geology of the Great East Lake 7.5-minute Quadrangle, York County, Maine

Jon C. Boothroyd
Department of Geology
University of Rhode Island
Kingston, Rhode Island 02881

INTRODUCTION

Surficial mapping in the Great East Lake 7.5' quadrangle was conducted during the summer of 1991 as part of the COGEOMAP program of the Maine Geological Survey and the U.S. Geological Survey. The purpose of this program and its successor, the STATEMAP program, is to provide detailed geologic information for use by the general public, and municipal, state, and federal agencies, and fundamental background information for site-specific studies. A surficial geologic map (Boothroyd, 1997) and a surficial materials map (Boothroyd, 1998), both at 1:24,000 scale, have been compiled. The materials map shows the thickness and composition of surficial sediment at points where surface and subsurface observations were made. The geologic map shows the distribution of geological units and features that record the geological history of the quadrangle. This report describes the surficial deposits that were mapped in the quadrangle, and presents the glacial, deglacial, and postglacial history of the quadrangle.

PREVIOUS WORK

Early descriptions of the surficial deposits in the study area are found in Stone (1899) and Leavitt and Perkins (1935). A regional overview of the glacial history in southwestern Maine can be understood by reading Bloom (1960, 1963), Borns (1973), Smith (1982, 1985), Thompson (1982), and Thompson and Borns (1985a,b). The surficial geology of the Great East Lake quadrangle has been mapped previously at reconnaissance level by Bloom (1960) and Smith (1977). Wetlands mapping of the Great East Lake quadrangle is published in draft form by the National Wetlands Inventory, U.S. Department of the Interior.

LOCATION, TOPOGRAPHY, AND DRAINAGE

The Great East Lake 7.5' quadrangle is located between 43° 30'00" and 43° 37'30" N latitude and 70° 52'30" and 71° 00' W longitude on the border of Maine and New Hampshire in southwest York County and southeast Carroll County respectively (Figure 1). It includes part of each of the communities of Acton, Shapleigh, and Newfield in Maine, and Milton and Wakefield in New Hampshire.

Elevations within the quadrangle range from 478 feet (146 m) at Loon Pond in the southeast corner of the quadrangle to 941 feet (287 m) above sea level (asl) at Bond Mountain (Maine) in the northeast corner and 1080 feet (329 m) at Davis and Oak Hills (New Hampshire) in the west-central section. Most of the quadrangle has moderate relief, however; the maximum relief of approximately 440 feet (134 m) occurs between Mirror Lake and Bond Mountain in the northeast corner of the quadrangle. Approximately 20% of the quadrangle is covered by lakes; the three largest are Great East Lake, Square Pond and Balch Pond. All of the quadrangle is above the late-glacial marine limit, which approaches an elevation of 295 feet (90 m) in nearby quadrangles (Koteff and others, 1993).

There is a moderate northwest-southeast trend to the topography in the form of streamlined hills in the study area, which reflects the regional ice-flow direction and not the underlying structure of the bedrock. Bedrock hills comprised of plutonic rocks, such as Gerrish Mountain, have been somewhat modified by erosion and deposition from the Laurentide Ice Sheet.

The two major drainages are the south-flowing Salmon Falls River that rises in Great East Lake and forms the Maine-New Hampshire border in the southern half of the quadrangle, and the east-flowing Little Ossipee River that rises in Balch

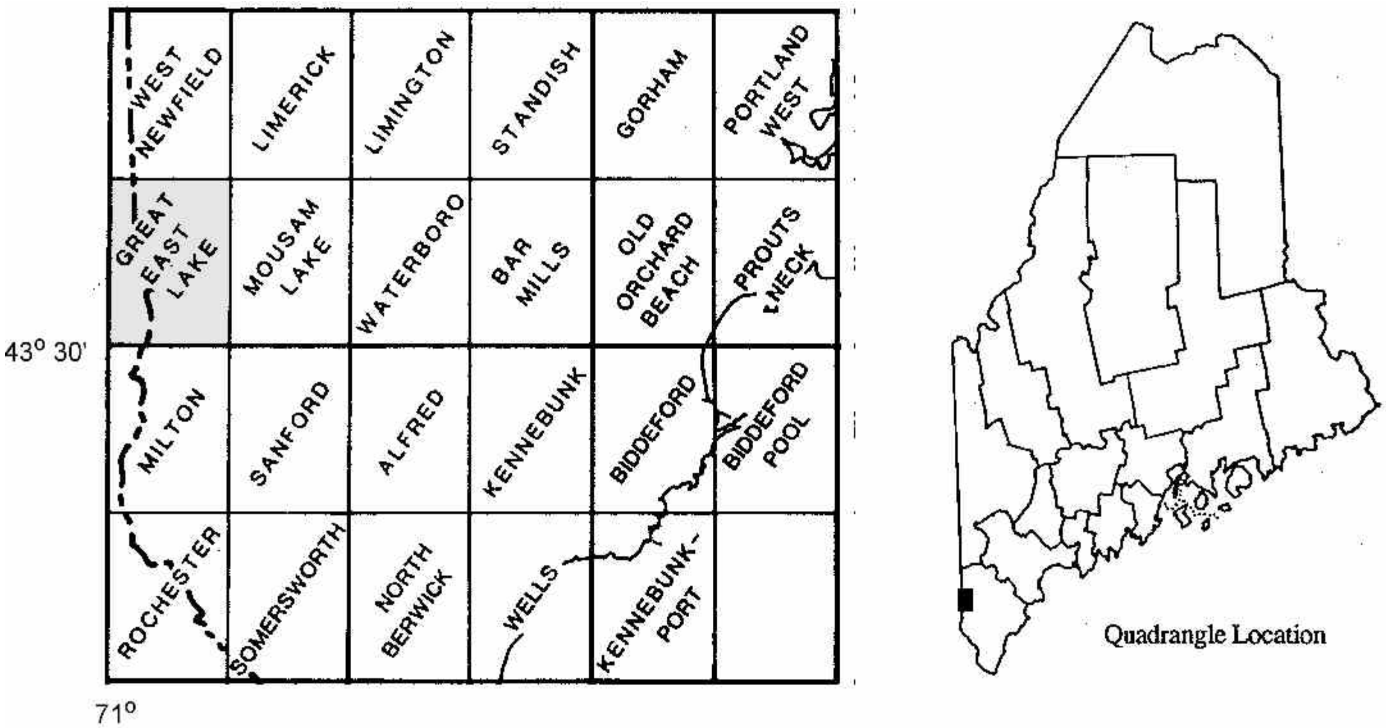

Figure 1. Location map of the Great East Lake quadrangle.

Pond in the northern part of the quadrangle. Minor streams include Heath Branch in the southeast and many unnamed brooks that drain into, or out of, wetlands.

BEDROCK GEOLOGY

The bedrock geology of the Great East Lake and neighboring quadrangles has been mapped by Hussey (1968, 1985), Hussey and Pankiwskyj (1975), Gilman (1972, 1978), and summarized in Osberg and others (1985). Most of the quadrangle is underlain by multiply-deformed, stratified Siluro-Devonian metamorphic rocks of the Rindgemere Formation which is part of the Shapleigh Group (Hussey, 1985). Rock types include quartz-feldspar-biotite schist and calc-silicate gneiss. The metamorphic rocks are intruded by several small, unnamed granite plutons of Devonian age.

SURFICIAL GEOLOGY

Bedrock and Thin-Till Areas

Bedrock crops out primarily as ledges along the flanks of hillsides and as small, discontinuous exposures in roadcuts. It is shown as a dark gray color on the geologic map, and by the notation rk (rock) on the materials map. One set of glacial striae was located (trend 140^{o}), courtesy of W. Thompson, on a bedrock pavement just south of the South Acton road near Loon Pond. Although only a cursory search was done due to time constraints, other promising bedrock pavements that may show striae exist at the road junction on Acton Ridge and near the town commons of the village of Acton.

Thin-till areas were not delineated because of the difficulty of discerning such stratigraphy from aerial photographs or surface indications. An inferred thin-till area is located in the extreme southeast corner of the quadrangle and most likely occurs over the higher parts of Gerrish, Gile, and Bond Mountains.

Till Mantle

Till (Pt) comprises the surface unit (crops out) over approximately 50 percent of the area mapped and includes most, but not all, upland areas. The till is commonly a slightly-to-moderately compacted, light brown to dark-yellowish brown diamicton that consists of a non-stratified mixture of silt, sand, pebbles, cobbles, and boulders. The morphology and sedimentary characteristics of this unit suggest an ablation and/or debris-flow mode of emplacement.

Inferred thick deposits of till form streamlined hills oriented northwest-southeast. Hubbard Ridge and unnamed hills north of Acton village are excellent examples. The uppermost stratigraphy of these hills is comprised of the above described diamicton, suggesting a thick ablation mantle over the underlying lodgement till and bedrock.

Hummocky Moraine Deposits

Hummocky moraine deposits (map unit Phm) are irregularly-shaped mounds and small hills with up to 40 feet (12 m) of internal relief and 120 feet (37 m) of total relief that are comprised of interstratified debris-flow till and ice-marginal fluvial and lacustrine deposits. Individual beds range from 2-6 feet (50 cm to 2 m) in thickness. Internal structure shows abundant evidence of collapse and remobilization of sediment after initial deposition, probably by melting of buried ice. Large boulders up to 6 feet (2 m) in diameter often occur on the surface of, or within, the moraines. These deposits are inferred to mark former ice-marginal positions and are particularly prevalent, although not limited to, the Salmon Falls River drainage and around Great East Lake. These deposits are probably similar to those identified as stagnation moraine by Thompson and Borns (1985a), but may imply a more active ice margin although ice-push features have not been identified.

Glacial Fluvial Deposits

Glacial fluvial deposits are present in the quadrangle as eskers (Pge), as small irregular areas of ice-marginal sand and gravel (Pgi), as fan-shaped high-gradient features or flat-topped lower gradient plains (Pgf), and as undifferentiated deposits of stratified sand and gravel (Pg). Some lower-gradient plain deposits are undoubtedly delta plain (topset) beds deposited over underlying delta slope (foreset) beds, but lack of deep exposures makes identification difficult.

Eskers and esker systems: Here are some basic definitions after Ashley and others (1991) and Warren and Ashley (1994). An esker is an elongate ridge parallel to either regional ice flow or valley axes, and comprised of stratified material. An ice-tunnel is a subglacial or englacial tunnel containing a river transporting water and sediment. An ice-tunnel deposit is sediment deposited within a subglacial ice tunnel. And finally, an esker system is an array of eskers traceable up or down the inferred regional ice gradient, over drainage divides, and down valley axes. The importance of understanding the definitions is that not all eskers were deposited in ice tunnels (Ashley and others, 1991), but most ice-tunnel deposits are morphologically eskers.

Esker systems are the most spectacular geologic features in the quadrangle, forming sharp-crested sinuous ridges up to 100 feet (30 m) in relief and up to 5,500 feet (1,700 m) in segment length. There is 100-800 m longitudinal separation between segments, and some segments are parallel in a semi-reticulate pattern. Esker systems can be traced over drainage divides and include meltwater channels eroded in the till mantle. Some systems trend NW to SE across the quadrangle and are parallel to ice-flow indicators such as streamlined hills, whereas others are within, and follow the courses of, present stream valleys. Stratigraphic sequences exposed in borrow pits indicate that clast-supported boulder gravel with a coarse sand matrix (average largest long (L) axis of the 10 largest clasts in a sample is up to 50 cm) is an important lithofacies. This lithofacies is interpreted as having been deposited in an ice-tunnel environment.

Esker ridges form elongate peninsulas and islands in Great East Lake and Balch and Square Ponds and a sublacustrine ridge in Square Pond. The Square Pond delineation was aided by a bathymetric map provided by the Square Pond Association of homeowners (Square Pond Association, unpublished). Other, smaller systems (in relief and segment length) exist in the Hussey Hill area of South Acton and in the Little Ossipee River drainage system between Balch and Shapleigh Ponds. Good internal exposures are not common; the best are: (1) the Pepin pit, with active, working faces just southwest of Square Pond; (2) a large abandoned series of pits with a few good faces located along the extreme southeastern shore of Great East Lake; and (3) the Acton town pit in South Acton.

Ice-marginal sand and gravel: These deposits (map unit Pgi) exist as scattered high terraces against till-mantled hillsides; the most notable deposit is at the Acton town landfill, north of Acton village.

Glacial-fluvial sand and gravel: These deposits (map unit Pg) are characterized by either somewhat hummocky morphology or by some internal interbeds of diamicton. Final depositional surfaces of the units suggests fluvial deposition along ice-filled valleys with debris-flow till deposited from adjacent ice and till-mantled hillsides and abundant burial of ice blocks. The deposits are much larger in area than units mapped as Pgi; the best examples are in the northern part of the quadrangle north of Balch Pond and adjacent to Gile and Bond Mtns. (map unit Pgbp).

Glacial alluvial fans and plains: High-gradient glacial alluvial fans (map unit Pgf) drain off the till uplands in several localities with gradients of up to 18 m/km (95 ft/mile) and clast sizes of gravel boulders up to 30 cm (1 foot) long axis. The best examples of high-gradient fans are to the southeast of Acton village and west of Hubbard Ridge in the southeastern part of the quadrangle and west of Square Pond in the east-central region.

Lower-gradient glacial alluvial plains (map unit Pgf) may be fan-shaped in part, but occur at lower elevations along a given valley than do the high-gradient fans. Gradients range from 6 m/km (30 ft/mile) to over 10 m/km (50 ft/mile); the average largest of 10 clasts range from 10-30 cm (4 in - 1 ft) long axis. Good examples of alluvial plains surround Square Pond (Pgfsp), surround Moose Pond southeast of Acton Ridge (Pgfmp), and exist between Mirror Lake and Bond Mtn. in the northeast corner of the quadrangle (Pgfml). Some of these plains may indeed be delta plains but the absence of exposures of underlying delta slope beds do not allow this interpretation to be confirmed.

Glacial Lacustrine Deposits

Glacial lacustrine deposits (map unit Pld) are present as delta plain (topset) beds and as limited exposures of delta slope (foreset) beds. Delta plains are characterized by flat-topped, low gradient surfaces usually dipping less than 6 m/km (30 ft/mile). Deposits are located in the Salmon Falls River drainage as a series of deltas extending northward to, and including the plain north of, Great East Lake. Delta-slope beds were not observed in any exposures, but the deposits were mapped as deltas based on the low gradients, especially in the area of the aptly named Flatground Road, and test pits showing coarse sand lithofacies indicating a distal or lower energy fluvial environment.

Another series of delta plains (map units $Plmd_{1-3}$) grade southeast and east to several levels of an interpreted glacial Mousam Lake. Delta-slope beds are well exposed in several pits in the Mousam Lake quadrangle (Meglioli and Thompson, 1997a,b, and personal communication, 1991). Mousam Lake delta plains flank Hubbard Ridge in the southeast and form the plain south of the village of North Shapleigh. Seismic lines run by Lanctot and Tolman (1985) across the delta plain south of North Shapleigh record a depth to bedrock of up to 166 feet (50 m), indicating a substantial thickness of delta slope and/or lake-floor sediment. A seismic line in map unit $Plmd_3$, northeast of Mud Pond and east of Gile Mtn., gave a depth to bedrock of 126 feet (38 m) (Lanctot and Tolman, 1985) indicating a significant thickness of lake deposits. The Square Pond glacial-fluvial system probably also grades to a level of glacial Mousam Lake, but delta slope evidence is lacking.

The most improbable delta (map unit Pldwl) is located south of Horn Pond and southwest of Wilson Lake and consists of a high hummocky surface with delta-plain beds of coarse gravel (clasts up to 20 cm long axis) overlying delta-slope beds of pebbly gravel to fine sand. Excellent exposures, up to 15 m (50 ft) high in two active pits, showed a topset-foreset contact at an approximate elevation of 620 feet (189 m) and multiple delta lobes.

Postglacial Pleistocene and Holocene Deposits

Wetlands: Holocene wetlands have been mapped as fresh-water marshes (Hwm), as fresh-water swamps (Hws), or as undifferentiated fresh-water wetlands (Hw). Most of the marshes and undifferentiated wetlands contain some open-water areas. Wetlands occupy poorly drained low areas on the glacial fluvial surfaces everywhere in the quadrangle. Many are undoubtedly kettle-hole fills, and mantle former glacial lake bottoms in the Salmon Falls valley.

Alluvial fans: Small alluvial fans (map unit Qaf) were mapped in several locations in the quadrangle; one example is at the east end of Wilson Lake. They are interpreted to have been formed by postglacial drainage off till-mantled hill slopes. Some are presently active, probably during extreme rainfall events.

Fluvial deposits: The lowest terraces adjacent to the Little Ossipee River in the North Shapleigh area are interpreted as fluvial sediment (map unit Qst) deposited during the downcutting of the river in postglacial times.

QUATERNARY GLACIAL AND POSTGLACIAL HISTORY

Glacial Geology

Background: The glacial deposits in the Great East Lake quadrangle were derived from the last advance and retreat of the Laurentide Ice Sheet which covered Maine and the Gulf of Maine during its maximum extent during late Wisconsinan time (Thompson and Borns, 1985a). Streamlined hill azimuths in the quadrangle vary within narrow limits of 130-160^o and are in agreement with azimuths in adjacent 7.5-minute quadrangles (Smith, 1977), and azimuths summarized for extreme southwestern Maine on the state surficial map (Thompson and Borns, 1985a). These azimuths indicate a regional ice-flow direction from northwest to southeast across the Great East Lake quadrangle, from New Hampshire into southwestern Maine, when the ice-sheet margin was offshore of the present coast of Maine. An isostatic uplift profile of the land, derived from topset-foreset contacts of marine deltas (Koteff and others, 1993), suggests greater uplift in a direction of 331.5^o which is in agreement with the streamlined hill data as an indicator of regional ice gradient.

Ice recession from the Gulf of Maine probably began around 17,000 yr B.P. and the ice margin had retreated to near the Kennebunk area on the present coast by about 14,000 yr B.P. based on an uncorrected ^{14}C date on marine shells (Smith, 1985). The Ogunquit-Wells-Kennebunk area is directly down the regional ice-sheet gradient from the Great East Lake quadrangle. As the ice margin retreated northwest away from the present coast, it remained in contact with marine waters of the Gulf of Maine. The synglacial Wisconsinan sea penetrated inland up the Salmon Falls River drainage as far as the Milton quadrangle to the southwest and up the Saco River and tributaries drainage as close as the Waterboro quadrangle to the east. Ice-margin retreat up the ice flowlines toward the Great East Lake area passed through the Wells, North Berwick, and Sanford quadrangles.

Deglaciation of the Great East Lake area occurred during systematic retreat of an active ice margin fronted by a narrow, probably 1,000-3,500 ft (300-1,000 m) wide, stagnation zone. This mode of retreat led to the deposition of a series of fluvial and lacustrine morphosequences (Koteff and Pessl, 1981), which have been used to reconstruct former ice-margin retreatal positions. The correlation diagram of morphosequences (Figure 2) is arranged for convenience by drainages, generally from west to east and from south to north.

The till mantle (Pt) is the oldest Quaternary sediment deposited in the area. As stated previously, no exposures or test holes encountered identifiable lodgement till although the streamlined, drumlinoid hills such as Hubbard Ridge arguably were constructed by lodgement processes. Thus ablation and/or debris-flow till is the oldest mapped unit. The till mantle is certainly time transgressive, especially the debris-flow diamictons, as expressed on the correlation diagram (Figure 2).

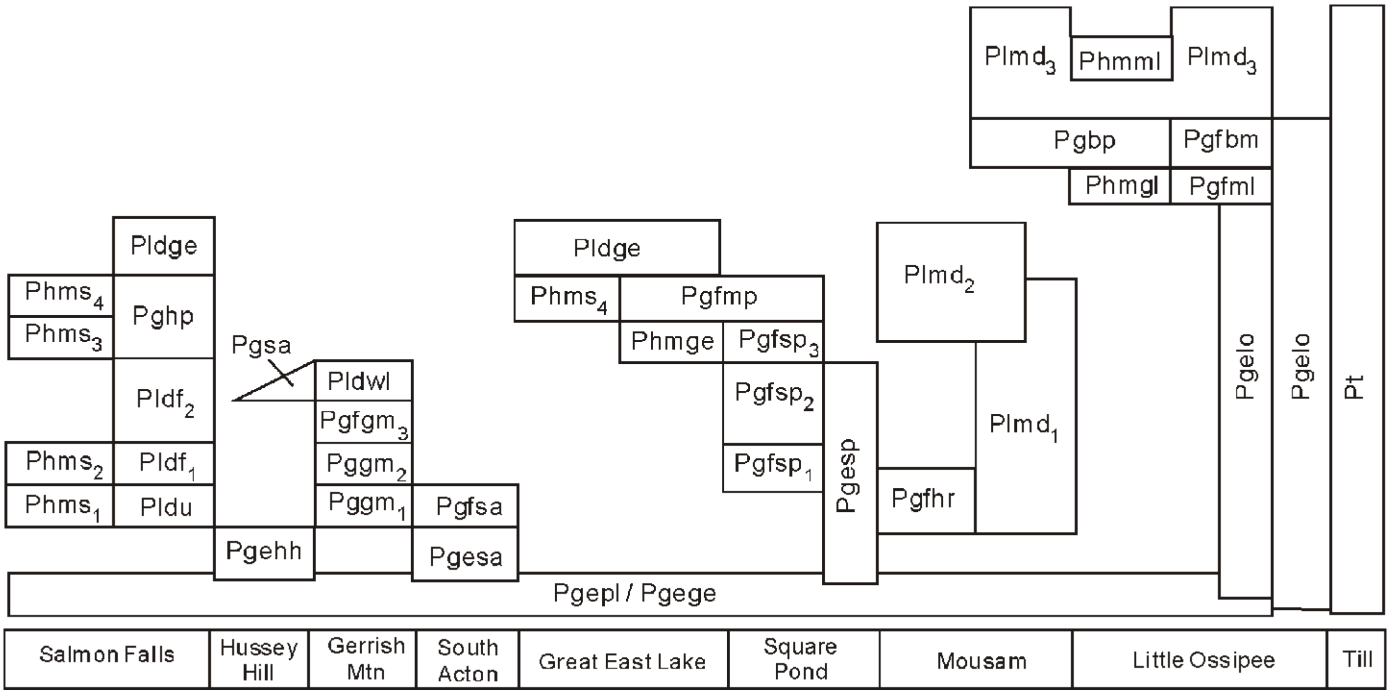

Figure 2. Correlation diagram of morphosequences in the Great East Lake quadrangle. The diagram is arranged by drainages, generally from west to east and from south to north.

Esker systems: Esker systems were the earliest glacial meltwater deposits. The Great East Lake system (Pgege) is interpreted as part of a larger through-going system that includes the Pine River system in New Hampshire as mapped by Goldthwait (1968). Deposits of the Pine River esker system are found in the Great East Lake quadrangle in the northwest corner adjacent to Pine River Pond. Segments of the combined Pine River/Great East system can be traced through Balch Pond, overland east of Acton Ridge to Great East Lake, across Great East Lake, and up over a drainage divide west of Square Pond. An eroded gorge in the till mantle on this divide is interpreted as the continuation of ice-tunnel drainage southeast to Square Pond, where esker segments begin again. The Great East system can be traced southeast to Mousam Lake in the Mousam Lake quadrangle where it merges with segments that trend down the axis of Mousam Lake. A series of esker segments in the western West Newfield quadrangle trend south from Province Lake, through Belleau Lake to Stump Pond in the Great East Lake quadrangle where a Y-shaped segment suggests that the here-named Province Lake system (Pgepl) joins the Pine River/Great East system and is tributary to it. The Square Pond system (Pgesp) is interpreted as a distributary system of the Great East, diverging at the south end of Great East Lake. The Little Ossipee esker system (Pgelo) extending from Balch Pond east to Shapleigh Pond may be a distributary of the Great East system that extends down the Little Ossipee River valley, but the highly discontinuous segments are mostly buried by later deposits and are hard to interpret.

It may be argued that the Great East Lake esker segments are time transgressive and some of them certainly are, as indicated on the correlation diagram (Figure 2). The best example of this are delta slope(?) beds deposited over a core of ice-tunnel deposits at the south end of Great East Lake at Grant Rd. However, the abundance of ice-tunnel deposits in the individual segments, and the large clast sizes of the gravel, argue for a subglacial river system with a discharge greater than can be realized by meltwater from the narrow stagnation-zone margin in the vicinity of individual segments. Much more important is the fact that the Great East Lake esker system can be traced upstream and downstream into adjacent quadrangles and can be traced over drainage divides and includes meltwater channels eroded in the till mantle. The system trends northwest to southeast across the quadrangle, parallel to regional ice-flow indicators such as streamlined hills. This trend suggests that the Great East Lake esker system was active as a through-going series of ice tunnels when Laurentide ice was thick enough to maintain a regional ice flow from northwest to southeast across the quadrangle.

The Hussey Hill (Pgehh) and South Acton (Pgesa) esker systems consist of small, low ridges oriented northwest-southeast, which is also down the slopes of the till-mantled hillsides. These small systems probably represent local flow and deposition in ice tunnels as the ice thinned over Hussey Hill. No regional interpretation is implied.

Salmon Falls drainage: The Laurentide ice thinned over the bedrock-controlled topography and morphosequences formed as ice retreated up pre-existing valleys. Hummocky moraine ($Phms_1$) was deposited at, and in front of, an ice-marginal position just north of the village of Milton Mills, most likely in the stagnation zone adjacent to active ice. A small, partially collapsed, high delta (Pldu) was probably deposited at this same time as ice pulled away from the valley wall at Gerrish Mtn. Road. An active pit indicated a 6-8 m (20-25 ft) section of dipping beds with climbing-ripple cross-stratification in medium sand interpreted as delta-slope deposition.

As ice retreated up the valley, hummocky moraine ($Phms_2$) was deposited adjacent to an ice-marginal position, and a delta ($Pldf_1$) formed in a lake dammed by previously deposited hummocky moraine at Milton Mills. No pits are exposed in the delta, but test holes indicated coarse, pebbly sand along Flat Ground Road (named Heath Rd. in NH). Ice then retreated further up the valley to a probable position across Heath Road. This position is postulated based on deposits east of Gerrish Mtn. discussed below. Deposition of another delta ($Pldf_2$) probably began at this time; deposition of $Pldf_2$ continued as Salmon Falls drainage at Wilson Lake and Horn Pond became ice free, and hummocky moraine ($Phms_3$) at the south end of Horn Pond was deposited. The delta ($Pldf_2$) received sediment from the Horn Pond drainage (Pghp) as ice retreated to the margins of the present Great East Lake.

Gerrish Mtn.-South Acton drainage: Ice retreat from the extreme southeast corner of the quadrangle led to deposition in an early arm of glacial Mousam Lake ($Plmd_1$). Flow down alluvial fans (Pgfsa, Pgfhr) carried sediment to the Mousam delta plain. The fans gathered meltwater from drainage off Hussey Hill and through meltwater channels cut in the till mantle on the heights south of Acton village. A steep alluvial fan ($Pgfgm_3$) became active as ice retreated to an ice-marginal position at the north end of Hubbard Ridge and to an upland adjacent to Gerrish Mtn. Loon Pond was occupied by a large ice block as the Mousam delta accumulated around it.

Ice thinning and probable stagnation in the higher valleys around Gerrish Mtn. led to the deposition of a complex series of glacial fluvial and perhaps some lacustrine deposits ($Pggm_1$). Stagnant ice occupied the present site of Mellion airport and certainly blocked part of the erosional valley leading to sequence $Pgfgm_3$. The deglacial history and relationship of these sequences is not well understood. A probable ice-marginal position was established north of Mellion airport that allowed deposition of the alluvial plain ($Pggm_2$) on which the airport was built. Deposition may have been into a small lake with ice dams to the south and drainage east through an erosional channel at the present site of the Acton town landfill on Grant Rd., and later drainage southeast where a wetland now exists. However, no delta-front beds are exposed. The glacial-alluvial fan ($Pgfgm_3$) received meltwater from the Mellion airport area at this time.

Withdrawal of ice to a position just south of Wilson Lake allowed a delta (Pldwl) to accumulate in the area between the ice front and sequence $Pggm_2$. This highly improbable delta, with well exposed delta-slope beds and a topset-foreset contact, has been noted above. Drainage from the small lake may have escaped along the till hill side, now the south shore of Wilson Lake, and overland into the Square Pond drainage to the east. The entire series of morphosequences represents a high set of depositional surfaces stepping down from 730 ft (222 m) ($Pggm_1$), to 700 ft (213 m) at Mellion airport ($Pggm_2$), to a hummocky 650 ft (198 m)(Pldwl). Ostensively, these sequences were being deposited at the same time as the lower delta units in the Salmon Falls drainage.

Square Pond drainage: Early drainage in the Square Pond valley was southeast to glacial Mousam Lake as part of morphosequence $Plmd_1$. An ice-marginal position was established at the present southern boundary of Square Pond and extended southwest to Hubbard Ridge and northeast into the Mousam Lake quadrangle. A hummocky glacial alluvial fan ($Pgfsp_1$) developed that delivered sediment to the early Mousam Lake delta plain ($Plmd_1$). This sequence was deposited around and mostly buried older Great East Lake esker segments. Stagnant ice probably occupied the upper end of the present Mousam Lake adjacent to the alluvial fan (see the Mousam Lake quadrangle).

Retreat of the ice to a mid-Square Pond position allowed meltwater to escape to the southwest through low areas between the Great East Lake esker segments and cut an erosional channel southeasterly along Hubbard Ridge in slightly older Mousam Lake delta deposits ($Plmd_1$). A high-gradient alluvial fan ($Pgfsp_2$) was deposited into a small Square Pond glacial lake. This ice-marginal position may be coeval with that north of Gerrish Mtn. which allowed meltwater from a small lake, now containing (Pldwl), to flow eastward and overland to the high-gradient fan. Meltwater and sediment may also have gathered from the erosional channel west of Square Pond (earlier part of the Great East Lake esker system) out of the Great East Lake basin, as the hill sides emerged from the ice. A low-gradient glacial alluvial fan segment east of Square Pond is included as part of sequence $Pgfsp_2$; it probably received sediment from flow along both margins of the streamlined hill.

An ice-marginal position was established just east of the south end of Great East Lake as evidenced by hummocky moraine deposits (Phmge). This position probably was synchronous with a position established .75 mile (1.5 km) north of Square Pond that extended across the north end of the streamlined hill, south of the village of North Shapleigh, and into the Mousam Lake quadrangle. This position may be synchronous with the retreat of ice in the Salmon Falls drainage to an unmapped position at sequence $Phms_3$. A high-gradient alluvial fan ($Pgfsp_3$) received meltwater and sediment from the Great East Lake basin; a lower gradient outwash plain (likewise part of $Pgfsp_3$) developed to the north of Square Pond receiving meltwater and sediment from the Little Ossipee drainage. The variation in surface elevations of the depositional surfaces east and west of Square Pond argues for ice blocks in the position of Square Pond, a drop in glacial lake elevation, or both.

Mousam Lake drainage: It is apparent from depositional surface elevations of morphosequences $Plmd_{1-3}$ that delta plains were graded to three different surface elevations of glacial Lake

Mousam. Inspection of the Mousam Lake quadrangle, including mapping by Meglioli and Thompson (1997a,b), indicates that there may have been three glacial Mousam Lakes: an earlier, southerly lake at elevation 520 feet (158 m) followed by a later, northerly lake at elevation 570 feet (174 m), and finally by a third lake at about 530 feet (162 m) in the North Shapleigh area. It may be possible to allow a single lake and take up the difference in postglacial rebound, but the linear distance due north at an angle to postulated rebound seems too small to account for the elevation difference.

Deposition ($Plmd_1$) into the southern lake was discussed above as part of the South Acton and Square Pond drainages. Deposition into this stage of the lake in the Mousam Lake quadrangle (520 feet, 158 m level) allowed the building of a morphosequence south along the present Jones Brook drainage to the vicinity of Goose Pond.

Establishment of an ice-marginal position south of the village of North Shapleigh allowed a large delta ($Plmd_2$) to begin deposition into the second glacial Mousam Lake. This delta extended into the Mousam Lake quadrangle where delta slope beds are well exposed in several borrow pits (Meglioli, personal communication, 1991). The proximal delta-plain surface was built to an elevation of 570 feet (174 m) in the Great East Lake quadrangle. Outflow from this lake stage was most likely south along the Jones Brook drainage.

Great East Lake drainage: Withdrawal of ice westward from the Square Pond drainage at hummocky moraine position (Phmge) to a hummocky moraine position in the narrows of Great East Lake ($Phms_4$) must have coincided with ice retreat north of Square Pond to a position running east-west or parallel to the present Little Ossipee River. This resulted in the deposition of a series of steep glacial alluvial fans (Pgfmp) that extended southward in the Moose Pond area to Great East Lake. Outflow was eastward into the Square Pond drainage and hence into the southerly glacial Mousam Lake. Depleted borrow pits show coarse cobble-to-boulder gravel and the fans show a somewhat hummocky surface topography indicating probable buried ice at the time of deposition. There are many old borrow pits in the Great East Lake esker segments in the Moose Pond area which illustrate burial of the earlier esker segments by the later alluvial fan deposits. The apex of the most westerly fan at northeast corner of Acton Ridge may represent the last discharge of water and sediment from the Great East lake ice-tunnel system down the old Great East Lake-Square Pond-Mousam Lake system.

The mid Great East Lake ice-margin position is tentatively correlated with similar hummocky moraine deposits ($Phms_4$) bordering the southern lake margin north of Horn Pond as discussed above. Retreat of the ice from the western end of Great East Lake to a hummocky moraine position south of Balch Pond, allowed the deposition of a delta (Pldge) into a glacial Great East Lake. Almost all of this deposit is in New Hampshire, thus was not examined in detail except to note that the source of meltwater was the Pine River-Province Lake esker system because the delta is surrounded on the east by till uplands with no large drainage sources. Drainage probably was down the present Salmon Falls River Valley.

Little Ossipee Valley drainage: Ice-margin retreat into the Little Ossipee River valley caused a shift of meltwater from a series of southeast-trending systems to an easterly drainage down the Little Ossipee River valley. A glacial fluvial system (Pgbp) received meltwater and sediment from a steep-gradient alluvial fan (Pgfbm) with a source overland from the West Newfield quadrangle and from various sources to the west, north of Balch Pond. This system was deposited in an ice-choked Little Ossipee valley and partially buried earlier esker segments (Pgelo). The sequence east of Gile and Bond Mtns. (Pgfml) may have been similarly deposited at this time.

The final morphosequence to be deposited in the Great East Lake quadrangle is a lower delta surface ($Plmd_3$) along the Little Ossipee River east of Balch Pond that correlates with glacial Lake Mousam deposits in the Mousam Lake quadrangle (Meglioli and Thompson, 1997a,b). Part of sequence $Plmd_3$, in the extreme northeastern corner of the quadrangle, had a source in the West Newfield quadrangle and continues into the Mousam Lake quadrangle.

Implications for Regional Deglacial History

The late glacial history of the quadrangle may be divided into two sequences of events: (1) the creation and maintenance of the large throughgoing ice-tunnel systems, especially the Pine River/Great East Lake system; and (2) the systematic deglaciation of the quadrangle by stagnation-zone retreat with the deposition of morphosequences. The Pine River/Great East Lake ice-tunnel system existed during late glacial time when regional ice was thick enough to maintain flow from northwest to southeast. Downstream, the ice-tunnel system is inferred to continue to the glacial-marine deltas of the Sanford-Wells area reported by Koteff and others (1993). The implication is that, similar to the ice-tunnel systems of eastern Maine (Ashley and others, 1991), the Pine River/Great East system, and other subparallel systems in other quadrangles (Boothroyd, 1995; Thompson and Borns, 1985a), contributed meltwater and sediment from east-central New Hampshire to the deltas at the marine limit in southwestern Maine, a distance of up to 50 km. Meltwater and sediment would have been transported from the Ossipee area of east-central New Hampshire when these areas were still ice covered. If this is true, then the ice margin positions for southwestern Maine reported by Thompson and Borns (1985a) must be modified because they show the Great East area ice-free by 14,000 yr B.P., whereas the coastal delta locations are still ice-covered.

More recent interpretations (Koteff and others, 1993) place the ice margin on the present southwestern Maine coast between 14,500 and 14,000 ^{14}C yr B.P. The ice margin was at the glacial-marine deltas in southwestern Maine about 14,000 yr B.P. when the Pine River/Great East system is interpreted to active. Rapid deglaciation took place in the 100-200 years around 14,000 ^{14}C yr B.P., based on evidence of delta elevations and positions of Koteff and others (1993), as the ice margin retreated from the coastal marine deltas to the uplands of the Great East Lake and surrounding quadrangles. The regional ice-tunnel systems were deranged as the ice thinned and the margin retreated across the quadrangle, allowing deposition of fluvial and lacustrine morphosequences.

Postglacial Geology

Melting of residual ice, after the ice margin had retreated out of the area, and runoff of meteoric water resulted in downcutting into till slopes and the ice-proximal slopes at the heads of morphosequences. An extensive set of man-made dams on most of the drainages have submerged many of the Holocene deposits of the valley bottoms beneath pond and lake waters. However, postglacial fluvial terrace surfaces are well displayed in the Little Ossipee River valley near the village of North Shapleigh. Wetland marshes developed on the former glacial lake floor in the Salmon Falls drainage, and mixed marsh and swamp wetlands developed in most kettleholes and some larger ice-block basins. Present runoff is gathered in tributary streams that flow to either the Salmon falls River on the west, the Mousam River to the southeast, or the Little Ossipee River in the northern part of the quadrangle.

Economic Geology

Sand and gravel mining operations have concentrated on the ice-tunnel deposits of the esker segments. Many abandoned and depleted borrow pits attest to past activity. The largest, presently active operation is the Pepin and Sons pit adjacent to Square Pond. This pit, with several active faces up to 30 ft (10 m) high in ice-tunnel deposits, maintains an active crushing and screening operation. There are other small operations, many in mostly mined-out areas around Moose Pond, which supply local gravel needs. The only active, bank-run sand supply is the borrow pit in delta-slope deposits south of Wilson Lake that has an active 50 ft (15 m) high working face.

The esker segments in Balch Pond and Great East Lake are prime waterfront building sites for summer homes. In fact, the summer vacation industry is in conflict with sand and gravel mining in some locations in the quadrangle because of noise from gravel crushers and truck traffic on secondary unpaved roads.

ACKNOWLEDGMENTS

The staff at the town hall of the Town of Acton provided assistance on land and pit ownership and information to landowners on the nature and scope of mapping. The Square Pond Association of homeowners provided a bathymetric map of Square Pond that aided delineation of esker segments; several members provided access to gated property for mapping purposes. Pepin and Sons, G.W. Mann, R.S. Mann, R.W. Weeks, B. Langley, G. King, and Apple Valley Campground all gave access to working or former borrow pits.

The mapping of the quadrangle was aided by on site field discussions with Woodrow Thompson, Robert Newton, Carol Hildreth, Andres Meglioli and Carl Koteff. Insight into mapping concepts was gained from discussion with Janet and Byron Stone and Carl Koteff. An understanding of southwestern Maine glacial geology was enhanced by discussions with Tom Weddle, Woodrow Thompson, and numerous Friends of the Pleistocene and NEIGC field trips. Lastly, many long discussions with Carl Koteff led to a better understanding of the mode and timing of deglaciation.

Drafts of this report were critiqued and improved by Woodrow Thompson and Tom Weddle.

REFERENCES CITED

Ashley, G. M., Boothroyd, J. C., and Borns, H. W., Jr., 1991, Sedimentology of Late Pleistocene (Laurentide) deglacial-phase deposits, eastern Maine: an example of a temperate marine, grounded ice-sheet margin, *in* Anderson, J. B., and Ashley, G. M. (editors), Glacial marine sedimentation - paleoclimatic significance: Geological Society of America, Special Paper 261, p. 107-125.

Bloom, A. L., 1960, Late Pleistocene changes of sea level in southwestern Maine: Maine Geological Survey, 143 p.

Bloom, A. L., 1963, Late Pleistocene fluctuations of sea level and post-glacial crustal rebound in coastal Maine: American Journal of Science, v. 261, p. 862-879.

Boothroyd, J. C., 1995, The Pine River and other esker systems of southwestern Maine and south-central New Hampshire: implications for regional deglaciation: Geological Society of America, Abstracts with Programs, v. 27, no. 1, p. 31.

Boothroyd, J. C., 1997, Surficial geology of the Great East Lake quadrangle, Maine: Maine Geological Survey, Open-File Map 97-46.

Boothroyd, J. C., 1998, Surficial materials of the Great East Lake quadrangle, Maine: Maine Geological Survey, Open-File Map 98-171.

Borns, H. W., Jr., 1973, Late Wisconsinan fluctuations of the Laurentide Ice Sheet in southern and eastern New England, *in* Black, R. F., Goldthwait, R. P., and Willman, H. B. (editors), The Wisconsinan Stage: Geological Society of America, Memoir 136, p. 37-45.

Gilman, R. A., 1972, Mesozoic plutonic-volcanic rocks of the Newfield quadrangle, Maine: Maine Geological Survey, Open-File Report 78-10, 20 p.

Gilman, R. A., 1978, Bedrock geology of the Newfield 15' quadrangle, Maine: Maine Geological Survey, Open-File Report 72-1, 16 p.

Goldthwait, R. P., 1968, Surficial geology of the Wolfeboro-Winnepesaukee area, New Hampshire: N. H. Dept. of Resources and Economic Development, 60 p., 2 15' maps.

Hussey, A. M., II, 1968, Stratigraphy and structure of southwestern Maine, *in* Zen, E-an, White, W. S., Hadley, J. B., and Thompson, J. B., Jr. (editors), Studies of Appalachian geology: northern and maritime: Interscience Publishers, New York, p. 291-301.

Hussey, A. M., II, 1985, The bedrock geology of the Bath and Portland 2 degree map sheets, Maine: Maine Geological Survey, Open-File Report 85-87, 82 p.

Hussey, A. M., II, and Pankiwskyj, K. A., 1975, Preliminary geologic map of southwestern Maine: Maine Geological Survey, Open-File Map 75-19.

Koteff, C., and Pessl, F., Jr., 1981, Systematic ice retreat in New England: U. S. Geological Survey, Professional Paper 1179, 20 p.

Koteff, C., Robinson, G. R., Goldsmith, R., and Thompson, W. B., 1993, Delayed postglacial uplift and synglacial sea levels in coastal central New England: Quaternary Research, v. 40, p. 46-54.

Lanctot, E. M., and Tolman, A. L., 1985, Hydrogeologic data for significant sand and gravel aquifers, in part of York County, Maine, Map 3: Maine Geological Survey, Open-File Report 85-92, scale 1:50,000.

Leavitt, H. W., and Perkins, E. H., 1935, Glacial geology of Maine, Vol. 2: Maine Technology Experiment Station, Bulletin, v. 30, Orono, Maine, 232 p.

Meglioli, A., and Thompson, W. B., 1997a, Surficial geology of the Mousam Lake quadrangle, Maine: Maine Geological Survey, Open-File Map 97-59.

Meglioli, A., and Thompson, W. B., 1997b, Surficial geology of the Mousam Lake 7.5-minute quadrangle, York County, Maine: Maine Geological Survey, Open-File Report 97-74, 6 p.

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

Smith, G. W., 1977, Reconnaissance surficial geology of the Newfield 15' quadrangle, York County, Maine: Maine Geological Survey, Open-File Map 77-15, scale 1:62,500.

Smith, G. W., 1982, End moraines and the pattern of last ice retreat from central and south coastal Maine, *in* Larson, G. J., and Stone, B. D. (editors), Late Wisconsinan glaciation of New England: Kendall/Hunt Publishing Co., Dubuque, Iowa, p. 195-210.

Smith, G. W., 1985, Chronology of Late Wisconsinan deglaciation of coastal Maine, *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. 29-44.

Square Pond Association, 1989, Bathymetric map of Square Pond: (unpublished).

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

Thompson, W. B., 1982, Recession of the late Wisconsinan ice sheet in coastal Maine, *in* Larson, G. J., and Stone, B. D. (editors), Late Wisconsinan glaciation of New England: Kendall/Hunt Publishing Co., Dubuque, Iowa, p. 211-228.

Thompson, W. B., and Borns, H. W., Jr., 1985a, Surficial geologic map of Maine: Maine Geological Survey, scale 1:500,000.

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

Warren, W., and Ashley, G. M., 1994, Eskers of Ireland: Journal of Sedimentary Research, v. 45, p. 433-448.