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GLACIAL GEOLOGY OF THE PORTLAND - SEBAGO LAKE AREA

by

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INTRODUCTION

The area covered by this trip is located in Cumberland County in southwestern Maine. It encompasses part of the coastal lowland, from Portland to Sebago Lake, and the hilly terrain around the north side of Sebago Lake. The Portland 1:100,000 quadrangle shows the entire area, while the Surficial Geologic Map of Maine (Thompson and Borns, 1985) provides an overview of the Quaternary deposits. Two of the stops in this trip (Stops 1 and 3) were previously included in the 1995 Friends of the Pleistocene itinerary, and the reader is referred to the Friends guidebook for discussion of the area west of Sebago Lake (Thompson and others, 1995). NEIGC Trip B3 will visit an area just to the east of today's trip, and the combination of these two excursions presents a broad cross-section of the late Pleistocene glacial geology in this part of Maine.

The localities described here show contrasting glacial deposits that formed in glaciomarine and terrestrial environments. The authors' current field work in southwestern Maine will provide a framework for discussion of problems relating to the timing and modes of deglaciation. Most of the sediments seen on the trip were deposited by glacial meltwater during the recession of the late Wisconsinan ice sheet. In the coastal lowland, the retreating ice margin was in contact with the sea and deposited a variety of glaciomarine sediments. The accumulated evidence shows that the marine-based ice margin was active, but details of sedimentary processes and the chronology of deglaciation are the subjects of ongoing research. The precise relationship between ice retreat and changing sea level is being studied to help provide clues to late-glacial climate change and isostatic crustal response to deglaciation.

The central part of the field trip area straddles the inland limit of late-glacial marine submergence (known as the "inland marine limit" in contrast to the "upper marine limit", which is the maximum altitude reached by the sea in any particular location). This part of Maine has proven to be one of the more difficult areas in which to determine the location of the inland marine limit. Glaciomarine deltas occur around the east, south, and west sides of Sebago Lake, but sediments that appear to be lacustrine rhythmites are seen just north of the lake. The lake itself is over 90 m deep in places, and the floor is locally below sea level. The trip will examine recent research on the sediments beneath the lake basin and their bearing on the position of the marine limit.

In the hills and valleys surrounding the northern part of Sebago Lake, recession of the last ice sheet produced a variety of ice-contact meltwater deposits. These include eskers, deltas, and deposits of uncertain origin. The inland marine limit has not been located with confidence in the Raymond area, northeast of Sebago Lake. For example, it is not clear whether marine waters entered the Panther Pond - Crescent Lake valley, or if remnant ice excluded the sea from this valley. The upper surfaces of ice-contact sand and gravel deposits in this area have approximately the same elevation as the marine-limit plane extrapolated from deltas to the south and east. These include a delta (or fan) between Crescent Lake and Panther Pond, which will be examined at Stop 6. However, no marine muds are known to occur in Raymond. The northernmost delta of presumed marine origin is located along Route 302, just south of Raymond village.

Some unusual ice-contact deposits occur in the valleys of Raymond, Gray, and New Gloucester. Cross-valley ridges of sand and gravel can be seen on the Raymond Quadrangle topographic map, in the vicinity of Crescent Lake, Raymond Pond, and Little Sebago Lake. Detailed surficial mapping of the Raymond Quadrangle is currently in progress, and hopefully will clarify the depositional environment of these features and their position with respect to the ice margin. Another intriguing area is the northeast part of the Raymond Quadrangle, where there is an abrupt east-west transition from smooth, glacially streamlined topography to an exceedingly hummocky terrain. The significance of this hummocky moraine to the mode of deglaciation will be discussed at Stop 8.

Surficial geologic mapping in New England has shown that it is often possible to use the morphosequence concept to reconstruct positions of the retreating late Wisconsinan ice margin (Koteff and Pessl, 1981). In Maine this concept has been extended to include the various ice-marginal deposits of the glaciomarine enviroment, as well as terrestrial fluvial and lacustrine morphosequences (Thompson and Koteff, 1995). The pattern of meltwater channels and ice-contact deposits suggests that systematic northward recession of the glacier margin continued when the ice had withdrawn inland from the marine limit. Major questions remain to be answered concerning the area north of Sebago Lake, however. Can we find evidence for sustained active ice flow? Are there any end moraines? What was the chronology of ice retreat?

PREVIOUS WORK

Borns (1989) has summarized the history of Quaternary geologic investigations in Maine. The first in-depth study of Quaternary deposits in the state, including the Sebago Lake region, was conducted by G. H. Stone (1899). Stone's investigation of the "glacial gravels of Maine" was largely concerned with esker systems and related ice-contact features, but he also described the other types of glacial deposits and provided many new insights into their origin. Stone compiled the first map showing successive ice-margin positions during the deglaciation of Maine. He believed that the last ice sheet continued to flow actively during at least the early stages of thinning and recession (Stone, 1899, p. 271).

Stone often compared his models with observations of modern glacial processes, and in some cases his theories have survived the test of time better than work that followed in the early 1900's. He described the process of end-moraine deposition in the coastal lowland as resulting from stillstands of an active glacier margin, to which debris was conveyed from a thin basal zone of debris-rich ice (p. 275-276). Many of Stone's interpretations of meltwater deposits have been improved by later workers, but he correctly interpreted Sebago Lake as being dammed by a glaciomarine delta (p. 242-243). He also commented at great length on the origin of Maine eskers ("osars").

The next study that described the glacial geology of the Sebago Lake area was published by H. W. Leavitt and E. H. Perkins in the mid 1930's. Their three-volume series combined a statewide survey of road materials with descriptions of glacial and postglacial sediments. They also compiled an accompanying map showing the surficial geology of Maine. Leavitt and Perkins (1935) recognized that numerous "moraine banks" and ice-contact "recessional deltas" indicated the progressive retreat of the ice margin during deglaciation of Maine's coastal zone (p. 194). However, they described the moraines as having been deposited by meltwater from the "stagnant marginal zone" of the glacier (p. 44). The proximal part of the glaciomarine delta at the south end of Sebago Lake was considered to be one such moraine.

Leavitt and Perkins (1935) pointed to kame terrace sequences farther inland as evidence that "In the hilly western portion of the State, the last ice remained as narrow tongues along the valley floors, and wasted away in place" (p. 193-195). The latter statement is pertinent to the heated controversy among New England glacial geologists, which peaked in the 1930's, regarding the mode of glacial retreat. Previous assumptions that an active ice margin had receded northward from New England were essentially replaced for several decades by the model of widespread simultaneous stagnation and downwastage of the ice sheet (e.g. Flint, 1930; Goldthwait, 1938).

In the 1940's the Maine Geological Survey investigated the economic potential of glaciomarine clay deposits. As part of this project, L. Goldthwait (1949, 1951) published two reports describing the marine clays of the Portland-Sebago Lake region. He considered problems relating to the deposition of the clays, including the number of units and the timing of marine submergence relative to deglaciation. Goldthwait concluded th one basic clay unit, the upper part of which is oxidized to a brownish color, in contrast to previous worke regarded the brown and blue clays as being stratigraphically distinct. Although he thought that marine tr postdated ice retreat in this part of Maine, Goldthwait proposed that the Sebago Lake basin was still occu remnant ice during the submergence of areas around the lake.

A. L. Bloom (1959) wrote a popular guide to the geology of Sebago Lake State Park, in which h late-glacial and postglacial deposits at the north end of the lake. Bloom (1960, 1963) also carried out the detailed studies of glaciomarine sediments and glacial isostasy in southwestern Maine. He described the end moraines that occur abundantly in the zone of marine submergence, and coined the name "Presumps Formation" for the glaciomarine muds (Bloom, 1960). This formation name was derived from the Presu River in the Portland-Westbrook area, near which Bloom found some of the best exposures. The name h generally used by later authors for glaciomarine muds throughout southern Maine. Bloom (1963) though marine transgression lagged behind deglaciation in Portland, but caught up with the receding glacier mar inland, where large ice-contact deltas were deposited into the sea.

Borns and Hagar (1965) and Borns (1967) concluded that the sea was in contact with the retreat Wisconsinan ice margin in central and eastern Maine. Borns' work also demonstrated that the ice was sti the system of end moraines was deposited in the eastern part of the coastal zone. His deglaciation model extended to southwestern Maine during the following decade, when the Maine Geological Survey began of reconnaissance surficial quadrangle mapping. Field work for this program by Borns, B. G. Andersen, Smith, and W. B. Thompson, together with aquifer mapping by G. C. Prescott, Jr. (USGS), provided the ongoing investigations of glaciomarine sediments in the coastal zone (e.g. Thompson, 1979). Stuiver an (1975) compiled radiocarbon ages from the marine deposits to obtain an updated chronology of deglacia resulting crustal uplift.

Since the 1980's there has been much research on the glaciomarine deposits in southwestern Ma comparison with published studies of "subaqueous outwash" in the St. Lawrence Lowland of Canada (R Romanelli, 1975), it was realized that submarine fans are common in this region and form a major comp many end moraines (Smith, 1982; Thompson, 1982). Recent work has focused on detailed facies analys deposits (e.g. Retelle and Bither, 1989; Smith and Hunter, 1989). The glaciomarine deltas have also bee in more detail and yielded information on the configuration of the upper marine limit and late-glacial sea history of Maine (Thompson and others, 1989; Crossen, 1991; Koteff and others, 1993).

Smith (1985) analyzed the available radiocarbon ages from glaciomarine deposits, and propose receding late Wisconsinan ice margin did not reach the inland marine limit in central Maine until about 1 B.P. However, dated marine shells from sediment cores indicate that the ice withdrew to Gould Pond in Maine by about 13,300 yr B.P. (Anderson and others, 1992) and even farther north (Mattaseunk Lake) in Penobscot Lowland by 13,400 yr B.P. (Dorion, 1994). All ages given here are in radiocarbon years, and shell ages have not been corrected for the "reservoir effect". The magnitude of this correction has yet to determined for coastal Maine, but studies in the North Atlantic region suggest that at least 400 years shou subtracted from the marine radiocarbon ages to make them comparable with terrestrial ages (Mangerud a Gulliksen, 1975; Bard, 1988; Broecker and others, 1988).

While many new radiocarbon ages have been obtained for eastern Maine through the University MGS EPSCoR Program, the deglaciation chronology in the western part of the state is still in an early sta documentation. Until recently, the oldest limiting age on glacial recession in southwestern Maine was 1 100 yr B.P. (QL-192), from shells collected by J. T. Andrews at a coastal bluff in Kennebunk (Smith, 19 on *Portlandia arctica* shells now indicate ice retreat as far north as Scarborough by 14,800 yr B.P. (H. W Jr., pers. comm.), and Freeport by 14,000 yr B.P. (Weddle and others, 1993).

SUMMARY OF LATE-GLACIAL HISTORY

As noted above, the subsequent recession of the last ice sheet caused the glacier margin to reach southwestern Maine by 15,000-14,000 years ago. Although eustatic sea level was over 100 m lower at this time (Fairbanks, 1989), isostatic depression of the region resulted in marine submergence of lowland areas as the ice withdrew. Subsurface data from ice-contact glaciomarine deltas indicate that they were deposited in shallow water (less than 100 m and often only 20-40 m deep) and thus formed along a grounded tidewater-glacier margin (Thompson and others, 1989). The orientations of end moraines and other ice-marginal deposits show that the direction of glacial retreat was north to north-northwest. Exposures in end moraines often reveal ice-shove structures and lodgement till with erosional basal contacts, demonstrating that the ice remained active in the marine environment (Smith and Hunter, 1989).

Hundreds of end moraines were deposited in the Portland-Sebago Lake area. Especially fine examples are seen in Buxton, Gorham, and Windham. These moraines commonly occur as clusters of parallel ridges. Many of them are more-or-less concealed beneath younger ice-marginal deposits (fans and deltas) or a veneer of glaciomarine mud (Presumpscot Formation). The moraine ridges in coastal Maine are generally 1-15 m high. They range in width from 5-15 m to over 100 m in the large stratified moraines. Lengths range from 50-100 m to several kilometers. Many of the examples near Portland are minor (DeGeer) moraines, which are typically just a few meters high and up to several hundred meters long. The moraines show considerable variability in composition and depositional process. The smaller ones may consist entirely of glacial diamict, including till facies deposited by lodgement and subaqueous debris flows, but many moraines contain sand and gravel deposited as submarine fans (Stop 1).

Larger individual submarine fans are also common in the zone of marine submergence. Diamict lenses and coarse gravels occur in the ice-contact parts of these deposits, which formed at the mouths of glacial ice tunnels. Distal facies usually consist of well-stratified sand interbedded with Presumpscot Formation muds. Fan deposition occurred through several processes, including traction currents of sediment-laden meltwater discharged from the tunnel mouths (density underflows), slump-generated turbidity currents, and settling of fine sediments from interflow or overflow plumes (Retelle and Bither, 1989).

Glaciomarine deltas formed in the shallow ocean waters bordering the Sebago Lake basin (Stop 2), and in the Saco River valley. They are coarse-grained Gilbert-type deltas, with fluvial topset beds (delta-plain deposits) overlying foreset beds deposited on the prograding delta front. Many of the deltas in Windham and around the southern part of Sebago Lake were formed at the ice margin, often where it was pinned against bedrock strike ridges or other topographic highs. These ice-contact deltas probably received most of their sediment from ice tunnels. Eskers connect with the proximal margins in some cases. The surveyed elevations of the topset/foreset contacts define the upper marine limit, which is at a present elevation of about 90-95 m (higher to the northwest) in the Sebago Lake area (Thompson and others, 1989; Thompson and Koteff, unpub. data).

As the glacier margin continued to retreat, a different assortment of meltwater deposits formed inland from the marine limit. They include esker systems and other glaciofluvial deposits, as well as glaciolacustrine deltas and fine-grained lake-bottom sediments (Stop 5). Glacial meltwater channels are commonly found in the hilly terrain of interior southwestern Maine. Three types of channels occur in this area: (1) Proglacial channels formed where meltwater streams drained through cols in the hills adjacent to the ice margin, or incised earlier meltwater deposits in valleys. These channels sometimes became later spillways for lakes that were dammed on their proximal sides as the ice continued to retreat. (2) Lateral channels were cut into till deposits on hillsides adjacent to valley ice tongues (Stop 7). They slope obliquely along the hillside with profiles that probably conform to the former gradient of the ice margin, and often occur in groups that reflect the thinning and retreat of the ice. (3) Engorged channels formed where meltwater streams plunged down under the ice. They may trend directly downslope and typically are incised in glacial sediments on the lee sides of hills.

Following the recession of the last ice sheet, postglacial streams began to erode the glacial deposits. This downcutting often formed terraces at intermediate elevations between the original outwash surfaces and today's flood plains. Examples of these stream terraces can be seen along the Crooked River, north of Sebago Lake. Wind action in late-glacial time formed sand dunes, which were derived from the glacial meltwater deposits. The dunes typically occur on the downwind (east) sides of valleys. Much of the eolian sand is rather coarse grained. It has blown up onto the valley walls, and may obscure underlying contacts between till and water-laid deposits.

ACKNOWLEDGEMENTS

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ROAD LOG

Assembly time and place: Friday, October 6, 1995. 8:30 AM. Rear of the large parking lot behind Verrillo's Restaurant in Portland, adjacent to Exit 8 on the Maine Turnpike. The *Maine Atlas*, published by DeLorme Mapping Co. and available in many stores, is highly recommended for following the road log. Your driving distances may vary slightly from the cumulative mileages given below, depending on the amount of driving in some of the larger gravel pits, turn-arounds, etc. However, the distances between points in the road log are generally accurate. **Note:** *Nearly all of the stops are located on private property. Permission must be obtained from the owners for any future visits!*

Mileage

0.00	Turn left out of Verrillo's parking lot, onto Riverside St.
0.15	Turn R onto Larrabee Rd.
0.55	Turn R onto Business Rte. 25 and go W into town of Westbrook.
1.25	Keep R (straight ahead) at yellow blinkers.
2.10	Turn R at light, onto Bridge St. (= Methodist Rd.) and proceed N
5.50	Turn R into the Toppi Pit.

STOP 1: TOPPI PIT, Westbrook (45 minutes; Portland West Quadrangle)

Leader: Woodrow Thompson

This stop is located in Westbrook, in the Mill Brook valley between Methodist Road and U.S. Route 302. The north-south valley has been filled with glaciomarine sediments, but till is exposed on the higher ground on either side. The elevation of the upper marine limit in this area during deglaciation was approximately 285 ft (87 m) (Thompson and others, 1989). Numerous end moraines occur just north and west of the Toppi Pit (Figure 1). Exposures at this stop and other nearby pits indicate that many other moraines are buried beneath the marine sediments along Mill Brook. The dissected upper surface of this valley-fill (the former sea floor) can be seen along the power line as we drive into the Toppi Pit. The features to be examined at this stop include (1) a large expanse of glacially abraded bedrock, and (2) a sequence of glacial and glaciomarine deposits that record the recession of the marine-based late Wisconsinan ice margin from the Mill Brook Valley.

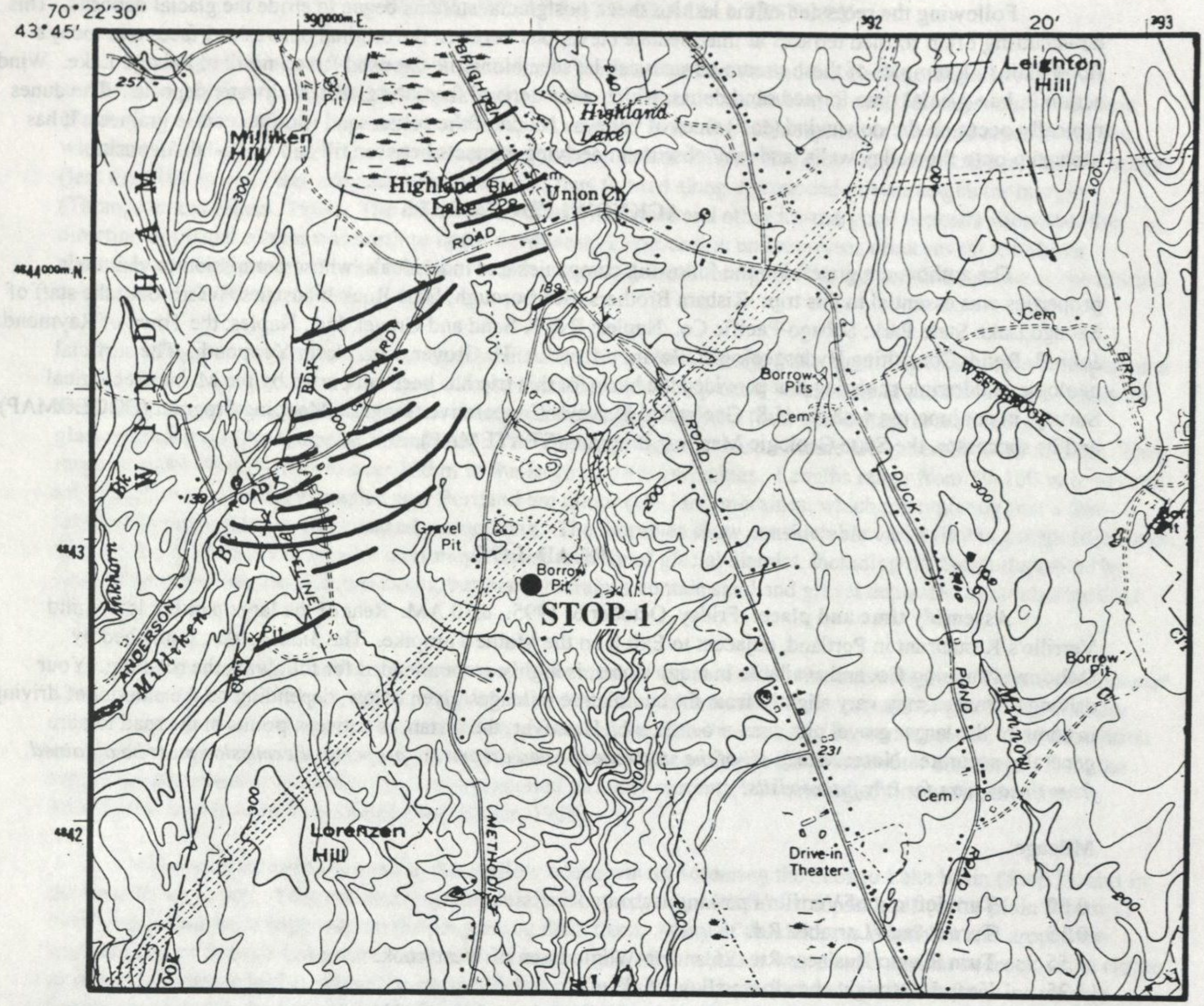

Figure 1. Location of Stop 1 (Toppi Pit, Westbrook). Lines indicate crests of end moraines that are not buried by glaciomarine sediments.

Five major units (including bedrock) are present in the Toppi Pit. The site was previously documented for a Geological Society of America field trip (Weddle and others, 1993). At that time, the eastern part of the pit was being operated on four adjacent levels, each exposing 3-5 m of section. The working faces showed oblique cross-sections through two end moraines. These moraines rested on the striated bedrock surface, and were overlain by submarine fan deposits and glaciomarine mud. The exposures have changed greatly during the last two years. Deposits seen during the 1993 GSA trip were largely removed prior to the 1995 Friends of the Pleistocene visit, while new sections have been opened in both the northern and southern parts of the pit area (Thompson and others, 1995). The basic stratigraphy is unchanged, however, and is typical of end moraine/submarine fan associations formed during the deglaciation of coastal Maine. The units in the Toppi Pit are described below, from oldest to youngest.

Unit 1 - bedrock. The bedrock in the pit floor is chiefly granite and granite pegmatite, with areas of metasediments. The outcrops consist of a series of rock knobs, on which the stoss sides are prominently striated and polished, while the lee sides commonly show a smooth, scalloped surface that presumably resulted from subglacial meltwater abrasion. The striations vary only slightly in orientation across the pit floor, and have an average trend of 167°. This trend is consistent with the east-northeast orientation of local end moraines. Crescentic marks are associated with the striations. On the lee side of one of the prominent rock knobs in the center of the pit, an older set of glacial grooves are preserved on a rust-stained surface. These grooves curve across the lee face, from 120° to 105°. The age and regional significance of this earlier eastward ice flow is not known. An unusual "channel" trends southwest across the bedrock surface near the pit entrance ramp. The origin of this feature is uncertain and may have been a composite of several processes. Some parts of the channel walls are meltwater-abraded, while others are striated or appear to have been plucked along bedrock joints.

Unit 2 - end moraine deposits. Several buried moraines have been exposed (and more-or-less removed) by pit operations. They trend E-W to ENE-WSW across the bedrock surface. These moraines vary in composition from massive glacial diamict (till) with sand laminae, to complexly sheared and interlayered mixtures of till, sand, and gravel. The diamict lithofacies is olive-gray, sandy, stony, non-fissile, and moderately compact. It may include both flowtill and lodgement till. The till contains stones up to 3 m in diameter, some of which are faceted and striated. In some cases, the layered parts of the moraines resulted from minor glacial readvance and mixing of till with proximal submarine fan deposits, in the manner described by Smith and Hunter (1989). This tectonic layering commonly dips toward the proximal sides of the moraines, and together with thrust faults and recumbent folds, indicates ice shove from the north.

Unit 3 - proximal submarine fan deposits. There is overlap in the depositional environments of Units 2 and 3. The distinction between them is not always clear in the field, since some moraines may consist of nothing more than a linear series of submarine fans. Proximal fan deposits not only form a major component of moraines in the area, but also can occur independently. These fan deposits were emplaced where high-energy meltwater streams emerged from the mouths of subglacial tunnels at the glacier margin. In the Toppi Pit, they are composed of massive to well stratified, variably sorted pebble-cobble gravel and sand. Bedding dips at shallow to moderate angles and locally exhibits folding and faulting due to collapse and/or ice-shove. Some of the coarsest fan gravels can be seen in sections along the north wall of the pit. These gravels may be tunnel-mouth deposits. Contacts between Units 3 and 4 range from gradational to sharp and unconformable.

Unit 4 - distal submarine fan deposits. This unit is generally less than 3 m thick, and is not present in all parts of the pit area. It marks a transition between Units 3 and 5 as ice retreat resulted in lower-energy sedimentation from density underflows and settling of mud from overflow plumes. Distal fan deposits in the Toppi Pit consist of well-stratified, interbedded sand, silt, and clay. They show sub-horizontal to gently-dipping planar beds, locally offset by normal faults and convoluted by water-escape structures. Channel-shaped unconformities occur at the base of this unit, within the unit itself, and even along the overlying contact with Unit 5. The channel-fills within the basal and internal channels locally include rip-up clasts of clay derived from erosion of the channel walls. Some of the sand beds in the channels are normally graded; others appear massive. These channel features are inferred to have resulted from submarine slumps and scouring by turbidity currents. Contacts between Units 4 and 5 range from gradational to sharp.

Unit 5 - glaciomarine mud. This unit consists of laminated silt, clay, and minor very fine sand. It was deposited in a quiet-water environment on the sea floor, and is part of the regionally extensive Presumpscot Formation. The observed thickness along the north wall of the Toppi Pit has been as much as 6 m. *Portlandia arctica* shells recently collected in this part of the pit have a radiocarbon age of 10,375 ± 80 yr BP (AA-10159). This age is anomalously young, since the *Portlandia* shells are typical of ice-marginal environments in coastal Maine and often yield ages older than 13,000 yr BP. The sample in question was found to be contaminated by reprecipitated carbonate.

The Toppi Pit is now owned by Risbara Brothers in Scarborough. Much of the 1995 excavation activity has been in the northern part of the pit. A moraine that formerly crossed the north-central part of the pit has been removed, leaving only scattered boulders on the bedrock floor. Fan deposits and overlying Presumpscot Formation are still well exposed in the high face on the north edge of the pit. Sections in the east-central part of the pit expose a fining-upward series of deposits that define an ice-margin position (probably a buried moraine). In this area, the deepest cut shows bouldery till with sand lenses, and a higher section shows diamict (flowtill?) lenses interbedded with sand and gravel. These morainal sediments are overlain by distal fan beds and glaciomarine mud (Presumpscot Formation).

On the south side of the pit, recent digging has exposed sections in another moraine. From bottom to top, the general sequence consists of: (1) bouldery till, which is locally a very stony rubble; (2) proximal and distal submarine fan deposits; and (3) laminated glaciomarine silt, clay, and sand (Presumpscot Formation).

5.90	Turn R out of Toppi Pit and continue N on Methodist Rd.
6.45	Turn L onto U. S. Rte. 302.
11.50	Rotary at jct. of Rtes. 302 and 202. Stay on 302 toward North Windham.
12.45	Turn R onto Varneys Mill Rd.
13.35	Turn L and follow road into Blue Rock Industries pit.

STOP 2: VARNEYS MILL DELTA, North Windham (30 minutes; North Windham Quadrangle)

Leader: Woodrow Thompson

The pit at Stop 2 is located in the southern part of a glaciomarine delta complex (Bolduc and others, 1994) (Figure 2). There are several coalescent deltas in this complex, covering much of the area around the town of North Windham. Meltwater drainage from at least two tunnel (or open channel) systems delivered sediment to the North Windham delta complex. One system is marked by eskers north of town, on the east side of Route 302. The other is indicated by an esker at the south end of Little Sebago Lake. Esker feeders for the earlier-formed deltas probably are buried beneath the delta complex.

The contacts between topset and foreset beds in the North Windham deltas are not well exposed, so it is difficult to make a precise determination of late-glacial relative sea level in this area. Thompson and others (1989; 1995) measured an elevation of 300 ft (91.4 m) on a possible topset/foreset contact in the northeast part of the adjacent Tandberg Pit, but the "topset" gravels may have been reworked by wave action. Marine erosion of delta tops in southwestern Maine commonly has produced shoreline and nearshore deposits that can resemble topset beds, especially in a poor-quality exposure. The contact between these deposits and the underlying eroded foresets is often somewhat lower than the original topset/foreset contact. A section in the Canal Road delta, 3.8 km SW of this stop, indicates an upper marine limit of at least 307 ft (93.6 m); and the regional pattern of marine-limit contours suggests a paleo sea level of about 310 ft (94.5 m) at North Windham (Thompson and others, 1989).

Most of the pits in the North Windham deltas were not very active when this guidebook was prepared. If the Blue Rock pit has been recently worked at the time of our visit, we will examine the delta stratigraphy. Previous exposures near the pit entrance have shown up to at least 12 m of section. Foreset beds comprise most of this thickness. They range from sand to gravelly sand, and dip generally to the south. A gravel unit overlying the foresets may be either the original delta topset gravel, or it may have been wave-modified. Marine muds of the Presumpscot Formation have not been found in the Blue Rock pit (other than imported spoil piles). However, the Presumpscot Formation drapes the front of the delta southeast of here. Laminated lacustrine mud has been exposed in the floor of a kettle at the Tandberg Pit (just south of Blue Rock pit), and poplar twigs in this mud unit were recently determined by AMS dating to have a radiocarbon age of 12,100 +/- 110 yr B.P. (OS-4416) (Thompson and others, 1995).

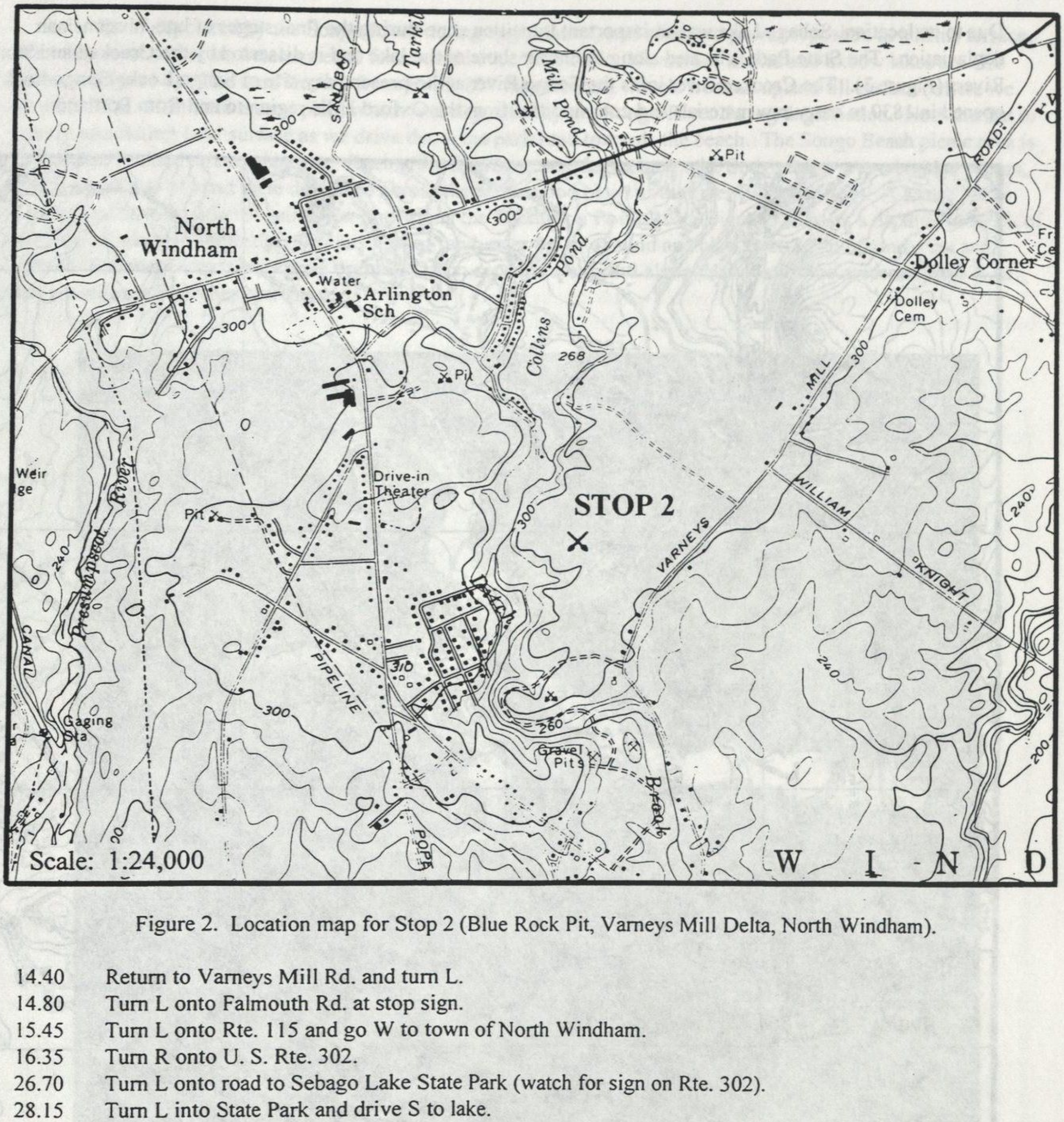

Figure 2. Location map for Stop 2 (Blue Rock Pit, Varneys Mill Delta, North Windham).

14.40	Return to Varneys Mill Rd. and turn L.
14.80	Turn L onto Falmouth Rd. at stop sign.
15.45	Turn L onto Rte. 115 and go W to town of North Windham.
16.35	Turn R onto U. S. Rte. 302.
26.70	Turn L onto road to Sebago Lake State Park (watch for sign on Rte. 302).
28.15	Turn L into State Park and drive S to lake.
29.85	Park in lot for Songo Beach and walk to lake shore.

STOP 3: SEBAGO LAKE STATE PARK - SONGO BEACH, Casco (45 minutes; Naples Quadrangle)

Leader: Robert Johnston

Sebago Lake State Park is situated along the boundary between Maine's coastal lowlands and central highlands (Denny, 1982). The coastal lowlands lie to the southeast with elevations up to 328 ft (100 m) above sea level, while the central highlands to the northwest range in elevation from 328 ft (100 m) to over 4000 ft (1200 m).

Due to its location, Sebago Lake was an important transition zone during the final stages of late Wisconsinan deglaciation. The State Park is located along the north shore of the lake and is dissected by the Crooked and Songo Rivers (Figure 3). The Crooked River joins the Songo River at the present-day site of Songo Lock. Songo Lock opened in 1830 to carry raw materials and commodities from the Oxford Hills region to and from Portland.

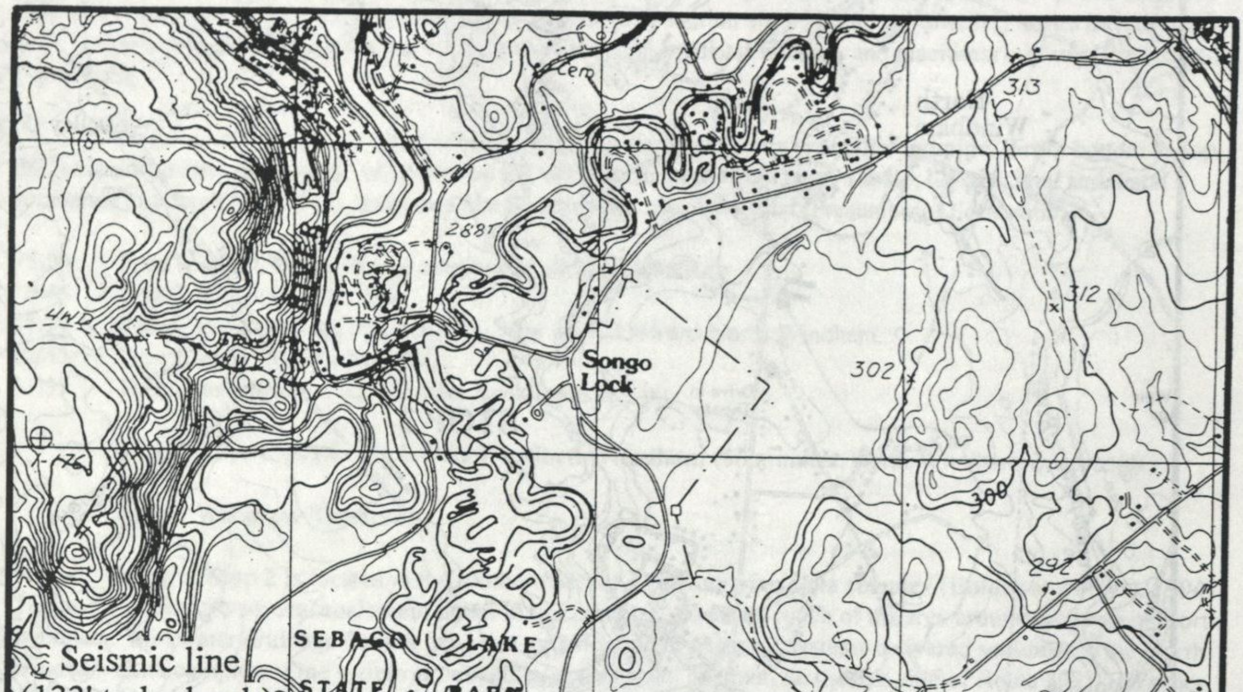

Figure 3. Map showing location of Stop 3 (Songo Beach, Casco) and nearby monitoring well and seismic line.

Sand deposited by the Songo River during deglaciation, and sand and gravel deposited as a kame terrace, make up most of the surficial material found within the State Park. Numerous kettles and oxbow lakes are also present (Figure 4). The road leading from Route 302 into the park travels from an upland till surface (where we departed Rte. 302) onto a sand plain which was deposited by the Songo River during deglaciation. Note the flat to gently undulating land surface as we drive down the park road towards the beach. The Songo Beach picnic area is located on braided stream deposits. During the final stages of deglaciation the Songo River was a braided stream, and thick sheets of sand were deposited across the entire flood plain of the river (Bloom, 1960). A Maine Geological Survey seismic-refraction line, along the Thompson Point Road (Figure 3), shows a depth to bedrock of 40.5 m. A nearby monitoring well has 7 m of sand, over 8.5 m of sand and clay, over 3.7 m of sand, clay and gravel. Excellent exposures of the braided stream deposits are found along the banks of the modern Songo River, but we will not visit them on this trip.

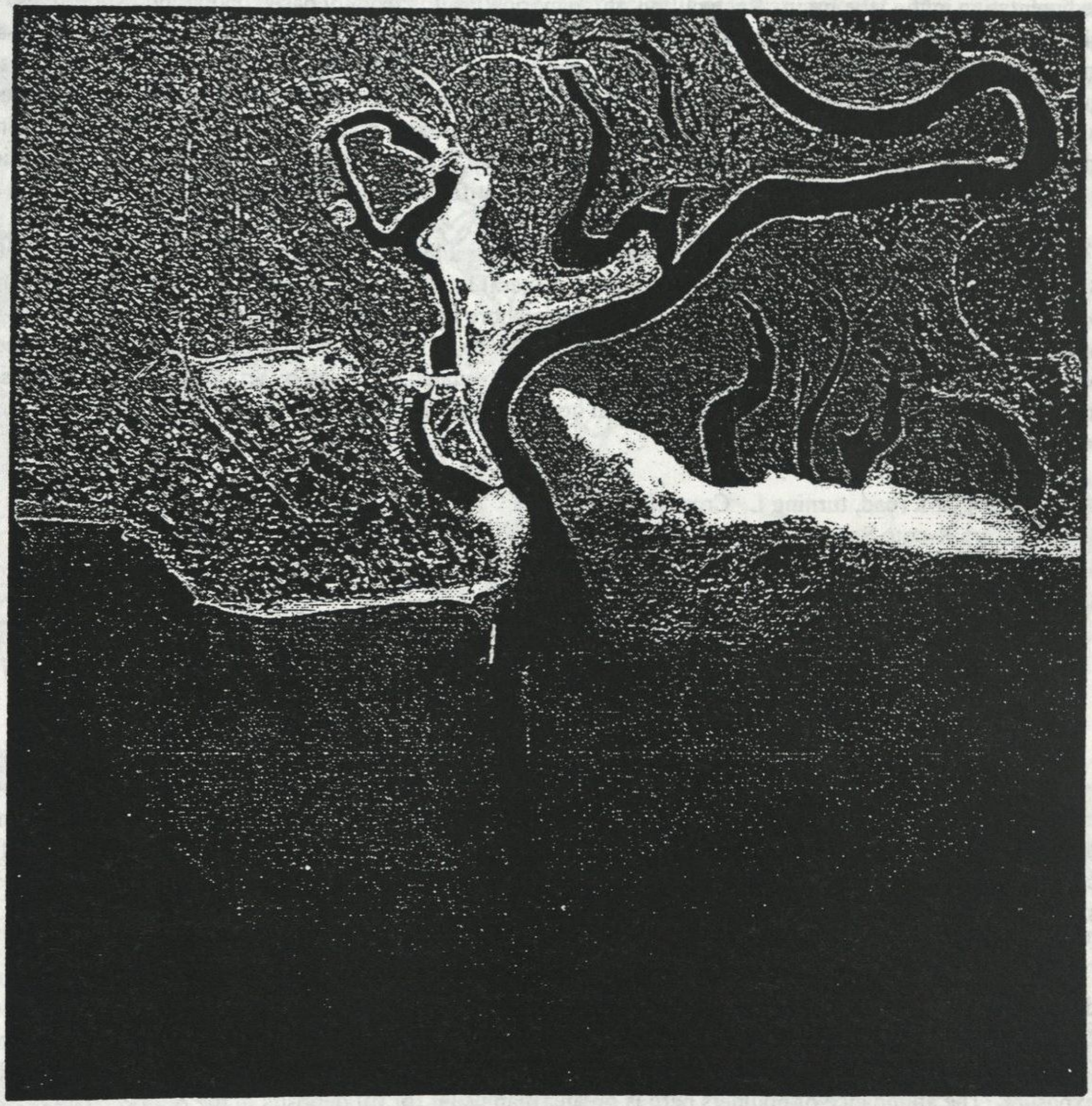

Figure 4. Aerial photograph, taken 10/26/63, showing the Songo River entering Sebago Lake. The extent of the Songo River delta, meander scars, and oxbow lakes are clearly seen.

Erosion of sand at Songo Beach in recent years has concerned park users and park personnel. In 1990, the Maine Geological Survey, in cooperation with the Maine Bureau of Parks and Recreation, initiated a beach profiling study to determine the causes of erosion on Songo Beach. Over four years of beach profiles have been analyzed to determine the dynamics of sand movement on the beach. To date, no net loss of sand to the beach has been documented, but there has been movement of sand due to seasonal fluctuations of water level. Profiles at additional sites around the lake are presently being studied for insights into the causes of beach erosion.

The inland marine limit in Maine marks a sea-level highstand at approximately 14-13 ka. It was inferred to cross Sebago Lake near Frye Island by Thompson and Borns (1985) on the Surficial Geologic Map of Maine, dividing the lake into a northern glacial-lacustrine basin and a southern glacial-marine basin. In a study to examine the accuracy of the mapped marine limit in the lake we analyzed the nature of glacial-lacustrine and glacial-marine sedimentation in the lake basin. Recognition of the marine limit is usually based on mapped shorelines, glacial-marine deltas, and the distribution of glacial-marine sediments. We collected 52 sq. km. of side-scan sonar images, 50 km of seismic reflection profiles, and one piston core. Side-scan sonar records show coarse sand and gravel and extensive boulder fields at an inferred grounding-line position near Frye Island, where the marine limit was drawn. ORE Geopulse seismic reflection profiles reveal a basal draping unit similar to glacial-marine units identified off the Maine coast. Later channels cut more than 20 m into the basal stratified unit. In addition, till and a possible glacial-tectonic grounding-line feature were identified.

Paleoshorelines rim the nearshore basins, indicating a lower lake level (11 m) below the present lake level. Slumps and possible spring disruptions are found in several locations. Slumping has carried fines into the deep basins, while wave-washed sand and gravel covers nearshore basins. The top seismic unit in the lake is an onlapping Holocene lacustrine unit. Total sediment thickness is much greater in the southern basin. The northern basin, > 97 m deep north of the marine limit, appears to have been occupied by an ice mass. Retrieved sediments include 12 m of rhythmites, and sieving and total organic analysis of the core showed no microfossil/macrofossil evidence and little organic material.

31.55 Exit park road, turning L. Cross river.
31.80 Turn R onto Songo Locks Rd.
33.05 Turn L into parking area for Sebago-Pacific Co.

STOP 4: SEBAGO-PACIFIC TILL PIT, Naples (30 minutes; Naples Quadrangle)

Leader: Carol Hildreth

This pit is located about 1.6 km north of Songo Lock and the juncture of the Crooked and Songo Rivers. It is owned by Sebago-Pacific, Inc., who are excavating the till hill to expand their parking area. Permission to visit must be gotten from the owner, who is located at the site. The pit exposes 2-6 m of massive glacial diamict (till) that is light olive-gray, sandy, stony, and moderately compact. The pit face is fairly steep on account of the compactness. The till does not seem to display any fissility, and only a very faint stratification was observed in one small section.

This till is fairly typical of the till deposited by the most recent (late Wisconsinan) glaciation in Maine. It is derived mostly from rocks of the Sebago Batholith (Mississippian light-gray, medium-grained, non-to-weakly foliated biotite-muscovite granite), which is the predominant rock type underlying the area. Angular boulders (some as much as 3 m in diameter) composed of fresh unweathered Sebago granite are common throughout this exposure. The abundance of boulders here is greater than usual for till deposits in the region. The reason for this is unknown. A less common rock type here is Mesozoic basalt or diabase from dikes that intrude the Sebago Batholith. Some of the dike rocks display various stages of development of weathering rinds.

33.15 Exit pit and continue N on Songo Locks Rd.
34.20 Turn L onto U. S. Rte. 302.
34.70 Turn R onto Rte. 11.
35.50 Turn L onto Edes Falls Rd.
36.60 Keep R at fork (stay on main road to Edes Falls)
37.40 Turn L into gravel pit.

STOP 5: EDES FALLS PIT, Naples (45 minutes; Naples and Casco Quadrangles)

Leader: Carol Hildreth

This large pit is located on the border between the Naples and Casco quadrangles (Figure 5). It is owned by P & K Sand and Gravel, Inc., of Naples, from whom permission is necessary to enter. The pit is a long north-south trench that is 6-12 m deep and extends for about 0.5 km along the west side of the Crooked River valley. It

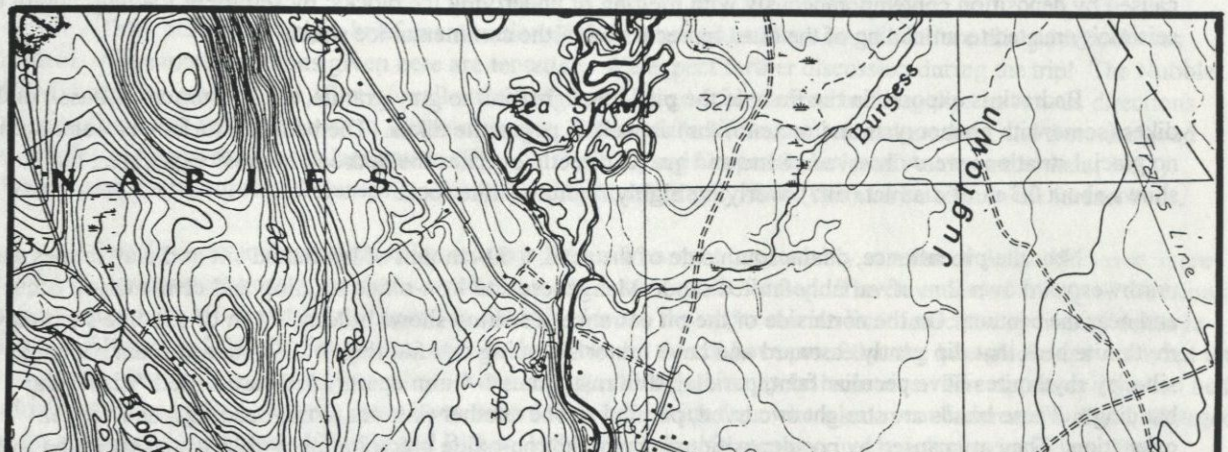

Figure 5. Map showing location of the Edes Falls Pit (Stop 5) in the Crooked River valley.

has been excavated in a relatively flat-topped terrace (elevation approximately 330-350 ft [99-105 m]) composed of glaciofluvial and glaciolacustrine deposits.

The primary focus of this stop is to investigate the nature and origin of the glaciolacustrine sediments. These thin-bedded silty rhythmites appear to overlie the glaciofluvial deposits on the east side of the terrace, and occupy depressions in the terrace surface at elevations of about 350 ft down to 320 ft (105-96 m). About 2 km south of here in another pit, similar well-bedded silt deposits at elevations of 270-300 ft (82-91 m) underlie very coarse sand that is fluvially cross-bedded. Other similar deposits have been noted at many places in the Crooked and Songo River valleys (Thompson and Smith, 1977; Thompson and others, 1995). They may indicate that a remnant glacial ice mass was present in the Sebago Lake basin, damming a late-glacial lake in this valley to the north. Later melting of the ice mass would have allowed the gradual downcutting of the Crooked and Songo Rivers to their present levels. Another possibility is that a drift dam formed in a narrow constriction somewhere between this pit and Sebago Lake. Most of the lake beds show evidence of slumping and/or faulting, which may have been caused by deposition contemporaneously with melting of underlying ice blocks; by sediment loading; and/or by seismicity related to unloading of the crust by recession of the continental ice sheet.

Bedrock is exposed in the floor of the pit. It is light pink to gray granite, cut by numerous basalt or diabase dikes (some with phenocrysts and/or xenoliths) as well as pegmatite dikes. The bedrock surface is waterworn and no glacial striations were observed. Sand and gravel directly overlies the bedrock in most exposures, but one cut shows about 0.3 m of diamict (till?) overlying highly fractured dike rock.

Near the pit entrance, on the south side of the road, a 60-cm unit of laminated silt and clay drapes gently northwestward over 2 m of variably faulted sand. Manganese and iron-oxide staining and cementation occur along and near the contact. On the north side of the pit entrance, a section shows at least 1.5 m of silt-fine sand-clay rhythmite beds that dip gently eastward and have minor slumping and faulting in discrete sediment packages. The silt-clay rhythmites have peculiar faint, parallel, thin rusty lines 1-4 mm apart, which are called "Liesegang banding". These bands are straight or curved, parallel to one another (but not to the bedding), and vary in orienation. They are caused by postdepositional rhythmic iron-oxide precipitation within water-saturated rock or sediment.

At the western edge of the pit, across from the entrance, the upper 6 m of section consists of silt-sand rhythmites that are 2-5 cm thick and have been offset by minor extensional block faults. Overall, the beds dip gently east or are horizontal. At the far western edge of this part of the pit, 9 m of fluvial pebbly-sand beds (with very minor pebble-cobble gravel and a few boulders) display large-scale cross stratification, including cut-and-fill channels more than 6 m across.

At about the center of the pit, there is a 15-m wide section containing the following units (from top to bottom): about 2 m of concave, slumped and folded, thin-bedded silt, clay, and fine-sand rhythmites; about 3 m of slumped and faulted sand; about 60 cm of undisturbed horizontally-bedded silt and clay; and 60-90 cm of thin-bedded sediments with Type B climbing ripples indicating deposition by south-flowing currents. A short distance south of here, on the west side of the pit, there is a 30-m long section of silt-clay rhythmites near the top of the exposure, but the remainder of the west face shows fluvial sand deposits indicating southward flow. However, the upper part of the opposite (east) side of the pit exposes 1.5-6 m of thin-bedded lacustrine silt and sand.

In the center lower level of the pit, there is 3 m of sand with some pebbles and cobbles, showing fluvial bedding with cut-and-fill structures and fluted troughs indicating south-flowing currents. These sand beds contain several very angular dropstone cobbles and small boulders. This section also contains a 60-cm cobble gravel bed.

At the north end of the pit, the east wall is 12 m high and very steep. The upper 6 m consists of thinly laminated silt, fine sand, and clay, which appears to be draped into a shallow depression at least 15 m long; while the upper 6 m of the west wall (at the same height, but slumped and much less steep) consists of sand, silt, and clay that is horizontally to cross-bedded and shows features indicating deposition by south-flowing streams.

37.50 Exit pit, turning R (S).
37.70 Turn L at stop sign. Cross river and follow road S to return to Rte. 11.
39.05 Turn L onto Rte. 11.
41.25 Turn R onto Rte. 121.
44.45 Turn L onto Plains Rd.
46.10 Turn L and follow dirt road into pit.

STOP 6: NUBBLE HILL PIT, Raymond (30 minutes; Raymond Quadrangle)

Leader: Michael Retelle

Time permitted only a brief examination of the exposures at Stops 6 and 8 before this guidebook was printed, so the interpretations given here are tentative. We expect further discussion during the trip! The Nubble Hill Pit exposes up to about 10 m of well-stratified sand. Large-scale foreset bedding dips in various directions ranging from east through south to west-northwest. Some of the beds show normal grading, and there are good examples of ripple-drift cross lamination (Type A, Type B, and Draped varieties of Ashley and others, 1985). Water-escape structures and slumps resulting from sediment gravity flows can also be seen in the foreset beds.

The foresets indicate deposition in a ponded environment, presumably as a fan or delta. However, there are no obvious topset beds to mark the water level when the deposit formed. The elevation of the top of the deposit is approximately 310 ft (94.5 m) (Figure 6). This is close to the upper marine limit indicated by nearby deltas in Gray and Raymond (W. B. Thompson, unpub. data), but we do not have proof that the late-glacial sea extended into the Panther Pond - Crescent Lake valley. Alternatively, the deposit may be lacustrine. The ripples and graded beds, which indicate traction currents, have been recorded in submarine fans where sediment-laden meltwater discharged at the mouths of ice tunnels (Retelle and Bither, 1989), and are also common in glaciolacustrine deltas. These features are comparitively rare in glaciomarine deltas in Maine, where flow separation is thought to have occurred due to density contrasts between marine waters and glacial meltwater (Ashley and others, 1991). However, such contrasts could have been insignificant in valleys near the marine limit (e.g. at this locality), where meltwater influx may have greatly reduced local salinity. In short, the sedimentary structures in this pit may not conclusively indicate the environment of deposition.

Another interesting feature at this stop is the abundance of very large angular granite boulders in the north side of the pit. These boulders seem to be "floating" in the sand, and digging under some of them has revealed little or no disturbance of the underlying bedding. Many large boulders are present in the woods north of here, including some that are perched on top of other boulders. They probably were plucked from ledges on the southeast face of Nubble Hill, but it is unclear how the boulders in the pit were deposited.

46.35 Exit pit road and turn L onto Plains Rd.
46.45 Turn R onto Rte. 85.
47.05 Turn L onto Dryad Woods Rd. (goes to E shore of Crescent Lake).
47.60 Park at edge of field on L side of road (do not block road). Walk N along E side of field to woods at N corner. Pick up trail and follow it W through woods (along stone wall) for a short distance to gap in wall on R. Go through gap in wall and walk NNW down steep hillside to bottom of ravine.

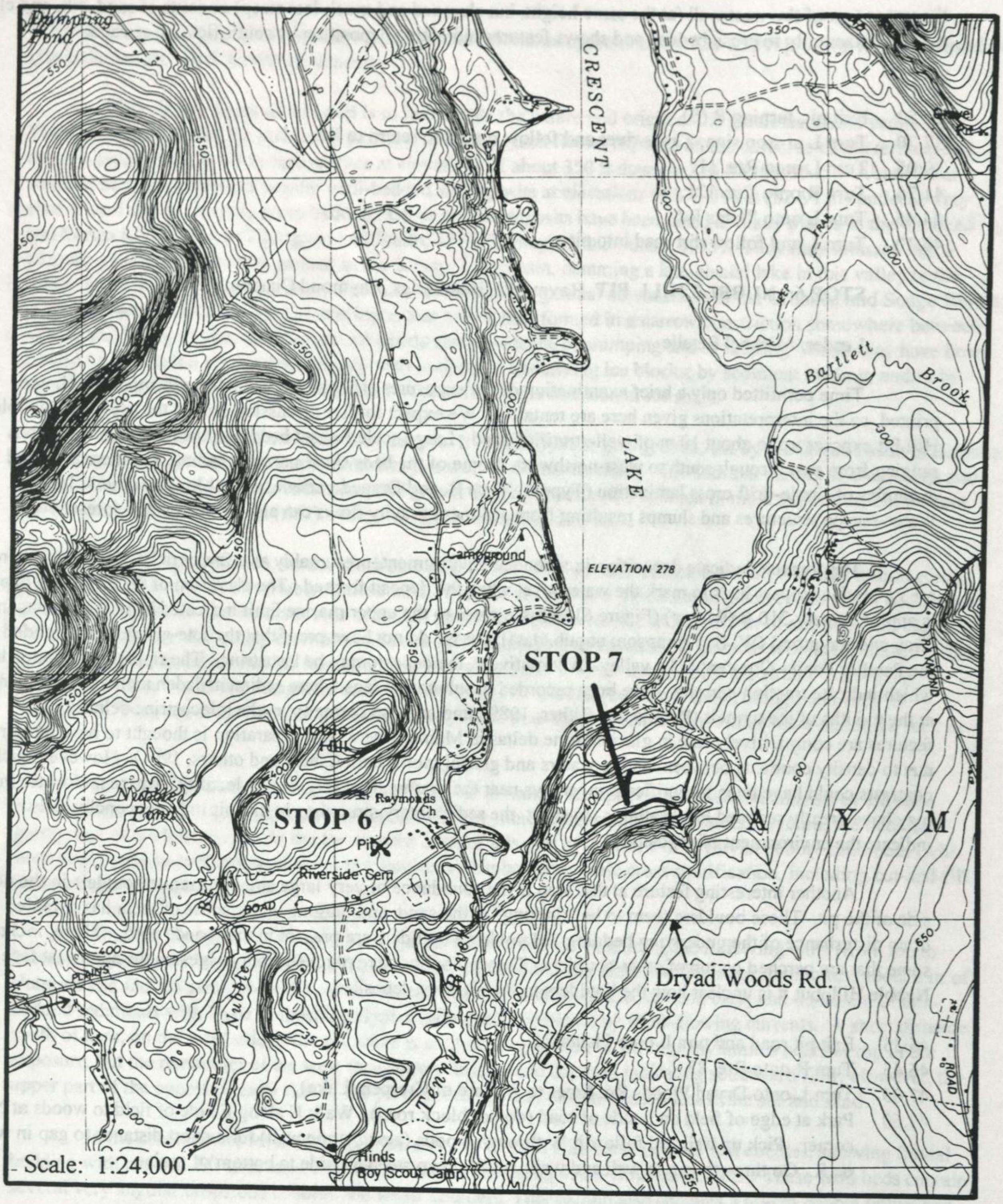

Figure 6. Map showing locations of Stop 6 (Nubble Hill Pit) and Stop 7 (meltwater channel) in Raymond.

STOP 7: MELTWATER CHANNEL, Raymond (45 minutes; Raymond Quadrangle)

Leader: Michael Retelle

Glacial meltwater channels have been found on many hillsides above the marine limit in southwestern Maine. Good examples of these channels occur in the Raymond Quadrangle, including the ones in the vicinity of Stop 7 (Figure 6), as well as the group located on the same hillside about 0.6 mi (1 km) northeast of here, and a third group northeast of Raymond Pond. These channels appear to be the lateral type, having formed along the sides of ice tongues that occupied the Crescent Lake and Raymond Pond valleys. They are incised into the thick till deposits that typically have accumulated on stoss slopes of hills in this region.

Meltwater flowed southwest in the Raymond channels, but the ends of the channels are perched well above the present valley floors. Evidently, the streams flowed off the glacier (perhaps issuing from tunnel mouths), followed the valley wall for a short distance, and then re-entered the ice. They may have initially flowed right along the ice margin, but then were incised in the till. Thinning and recession of the ice sheet opened lower drainage routes, and the earlier channels were abandoned. Regardless of whether the channels conform strictly to the shape of the former ice margin, they show the general direction of glacial retreat. In areas where morphosequence deposits are scarce, this type of meltwater channel is a useful indicator of the deglacial sequence.

Walk back to cars and continue along road toward lake.

48.25 Turn around at bend in road near lake shore (or sooner if possible) and return to Rte. 85.
49.45 Turn L onto Rte. 85.
50.60 Turn L onto Raymond Hill Rd.
51.60 Turn R onto Valley Rd.
54.55 Turn R onto North Raymond Rd.
55.85 Turn L onto Pond Rd.
56.55 Turn R and follow gravel road to the Grover Pit.

STOP 8: GROVER PIT, New Gloucester (30 minutes; Raymond Quadrangle)

Leader: Michael Retelle

Stop 8 is located in a distinctive terrain consisting of very hummocky topography. On the topographic map, this terrain is abruptly bounded to the west by the glacially streamlined till surface that we crossed on North Raymond Road (Figure 7). The hummocky area is above the limit of late-glacial marine submergence, with elevations between 350 and 600 ft (107-183 m). It is further distinguished by the many boulders on the ground surface. The glacial sediments in this area probably represent some kind of ice-disintegration zone, with a complex mixture of till and meltwater deposits. Ice-channel fillings (eskers?) on the north side of Notched Pond indicate meltwater drainage southeastward into the Gray Quadrangle, apparently feeding the Crystal Lake glaciomarine delta. Ongoing mapping in the Raymond and Gray Quadrangles will focus on the nature of this drainage system.

A section in the north end of the Grover Pit shows about 8 m of very coarse, poorly sorted, massive to faintly bedded gravel. Granitic bedrock is exposed in the floor of the pit. Lithologies in the gravel include granite, granite pegmatite, a wide assortment of dike rocks, and a small percentage of metasediments. Much of the bouldery sediment is texturally close to being a diamict, with silty-sand matrix between the stones. At the west end of this exposure, a sharp-crested ice-channel filling (probably an esker) can be followed back into the woods to the northwest. In places, the esker has many boulders on its crest, and there is a small kettle pond on the northeast side.

Another esker segment trends south-southeast through the western part of the Grover Pit. A section though this deposit exposes about 10 m of poorly sorted pebble-boulder gravel, similar to the material seen in the north end of the pit. Where bedding is visible, it is steeply collapsed in places. Most of the gravel seems to have

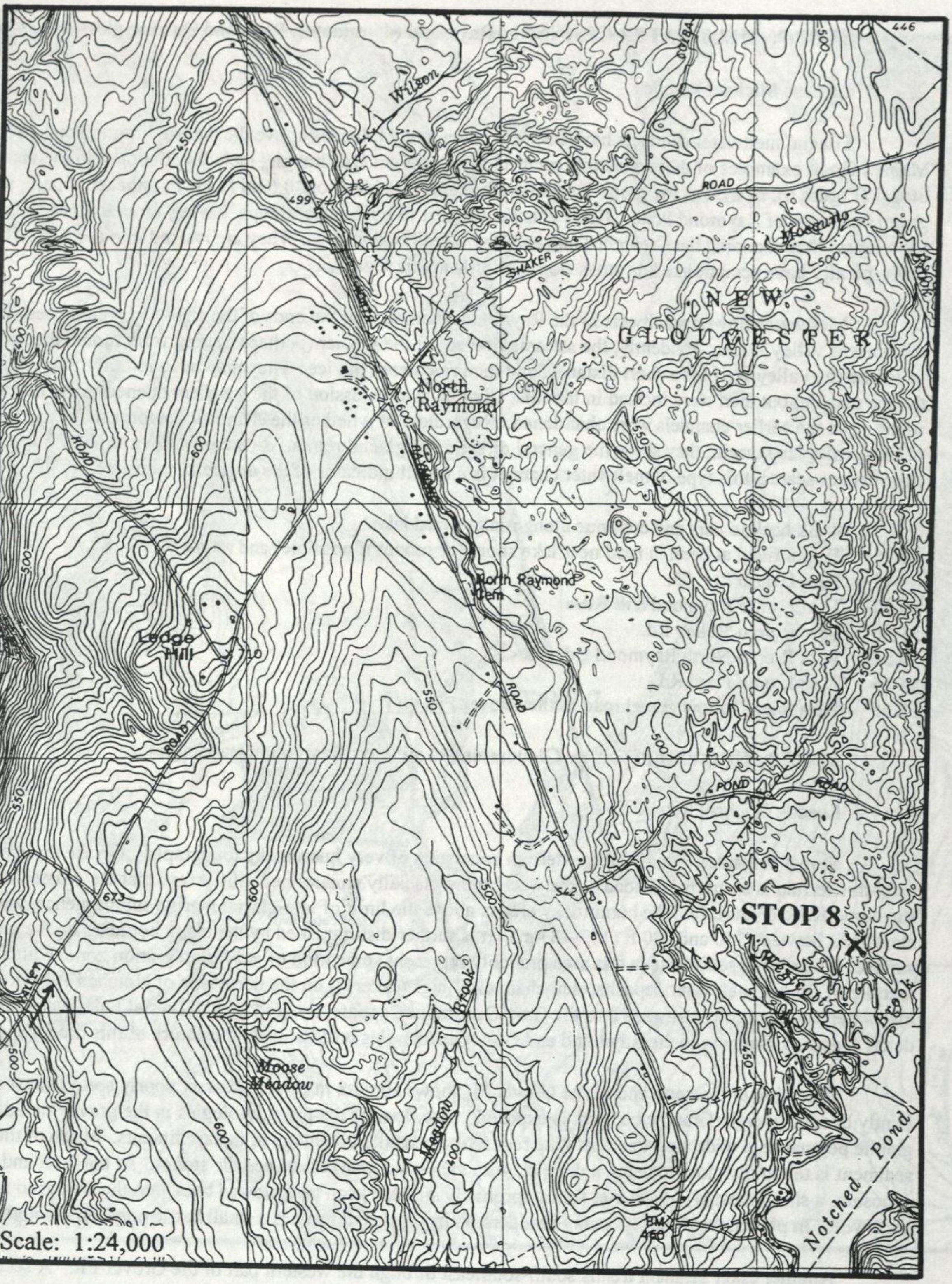

Figure 7. Map showing location of Stop 8 (Grover Pit, New Gloucester) and the contrasting glacial landforms east and west of North Raymond Road.

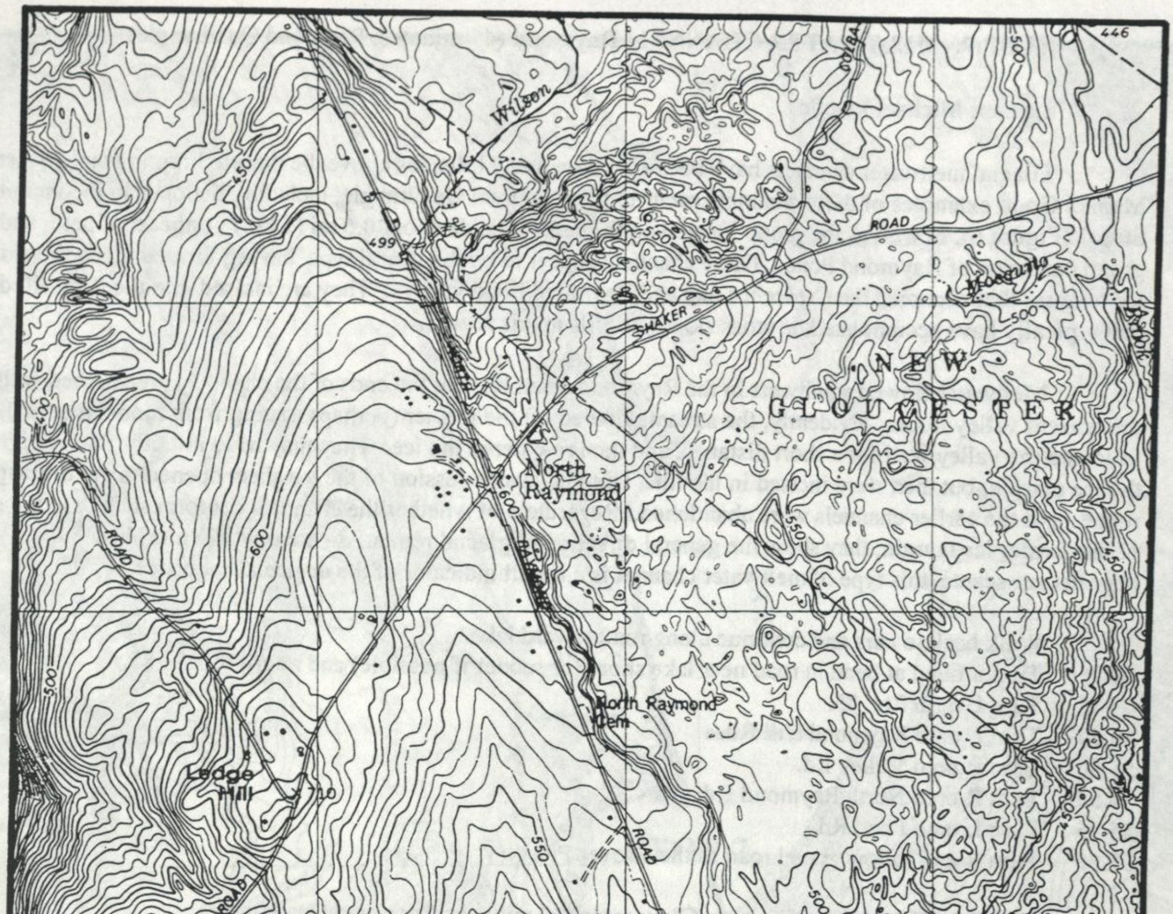

Figure 7. Map showing location of Stop 8 (Grover Pit, New Gloucester) and the contrasting glacial landforms east and west of North Raymond Road.

been dumped rapidly into a channel in the ice, with only minor sorting by stream action. We invite discussion as to what depositional environments are represented in this pit.

END OF TRIP

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