ABSTRACT

The Waldoboro Moraine extends for more than 14.2 km along mid-coast Maine. One of the more important localities is at Whitney Corners, where highly fossiliferous glaciomarine clay, the Presumpscot Formation, overlies sandy deposits of the moraine. Fossils in this clay have provided radiocarbon dates for the Late Wisconsinan deglaciation of Maine. Study of the Whitney Corners site affords information on moraine formation, which should have broader implications for the construction of large end moraines in coastal Maine. There are five sedimentary facies within the moraine: the end moraine, the submarine outwash fan, the submarine plain facies, the shallow marine, and a beach facies. Results suggest that the moraine at Whitney Corners was constructed from at least two minor moraines that grew together and that the ice was active, creating thrust faults within the moraine.
INTRODUCTION

Profound changes have occurred in the climate and geography of coastal Maine over the last 20,000 years. Rock that is now at the interface of the ocean and the land has been covered with nearly two miles of ice, submerged as much as 90 meters underneath the ocean, and raised 50 m above sea level during that time.

The periphery of the Laurentide Ice Sheet reached its terminal position on the continental shelf approximately 20,000-22,000 carbon-14 years before the present (\(^{14}\text{C}\) yrs. B.P.). Bothner and Spiker (1980) were the first workers to collect till from the continental shelf. They collected two cores from the margins of Great South Channel, and analyzed them for total organic carbon to provide an age for the till. The total organic carbon method is not as accurate as the AMS method because, in addition to the carbon dating from the glacier’s advance, there might be contamination from older carbon and/or younger carbon. Sources of carbon from the glacial advance may include soils and plants overrun by the ice. Possible contaminants are coal, graphite, fossils, ancient soils, the taproots of trees, and the percolation of recent soluble organic carbon. Bothner and Spiker (1980) thought older contamination was more likely and thus interpreted their dates as upper limits. They place the glacier on Georges Bank at 20,350 +/- 450 \(^{14}\text{C}\) yrs. B.P. or 19,500 yrs. B.P. in corrected \(^{14}\text{C}\) years (Bothner & Spiker, 1980). The method that they used to correct their \(^{14}\text{C}\) dates is not specified. Other workers using total organic carbon dated ice advance over the Stellwagen Basin off Cape Ann to 21,950 +/- 1,350 \(^{14}\text{C}\) yrs. B.P. (Tucholke & Hollister, 1973).

Advances in mass spectrometry have allowed more precise dating. Current technology permits the dating of individual shells, a significant improvement over dating
total organic carbon. Based on this method, King (1996) proposed that the ice advanced onto the Scotian Shelf about 21,000 yrs. B. P.

By around 20,000 $^{14}$C yrs. B. P. the Laurentide Ice Sheet was on the retreat, at least from the Scotian Shelf, if not from other places (King, 1996). LaHave basin was deglaciated by 18,500 $^{14}$C yrs. B. P. (Piper et al., 1990). Gipp & Piper (1989) proposed that the glacier left Emerald Basin off Nova Scotia 17,500-18,000 $^{14}$C yrs. B. P. Farther north, the ice left Stellwagen basin by at least 18,900 +/- 600 $^{14}$C yrs. B.P. (Tucholke & Hollister, 1973).

Meanwhile in the Gulf of Maine the ice was lifting off the Northeast Channel and the ocean was flooding into Georges Basin by 20,000 yrs. B. P. (Schnitker et al., 2001). By 18,000 yrs. B. P. the ice sheet was pinned on Sewell Ridge and icebergs and heavy pack ice continually covered Georges Basin, prohibiting primary productivity (Schnitker et al., 2001). By 17,000 yrs. B.P. calving had pushed the ice front back such that the glacier was no longer resting on Sewell Ridge and the ocean had flooded into Jordan, Rodgers, and Wilkinson Basins. The glacier continued to recede and reached the present coasts of Maine and Nova Scotia 14,000-14,800 $^{14}$C yrs. B.P. (Dorion, 1997; King, 1996; Schnitker et al., 2001).

While the ice was retreating subaqueous outwash of sediments from subglacial streams resulted in sand and thick mud sequences in the Gulf of Maine, which continued to form as the glacial grounding line migrated north. There are two models for the formation of the rhythmic mud deposits in the Gulf of Maine. Oldale (1989) proposed that they were created by suspension settling of meltwater plumes. The drainage system of the ice sheet conducted water to its base and eventually discharged it into the ocean.
Water flowing within a glacier moves fast and can transport large clasts as bedload. In subaerial streams, the cross-sectional area enlarges with increasing quantity of water, thus creating floods. This is not possible within the constrained glacial plumbing system because ice limits the cross-sectional area. Thus to accommodate the greater quantity of water it must flow faster, and hence may transport larger particles than subaerial streams. When this rapidly moving water encounters the relatively stagnant ocean it quickly loses its inertia, dropping the large particles at the glacier’s margin. Finer grains, such as sand and mud, travel further before deposition. Oldale’s (1989) model argues that repeated pulses of meltwater plumes produced the rhythmically laminated glacial-marine mud in the Gulf of Maine.

Schnitker and Jorgensen (1990) proposed a second model for the deposition of the glaciomarine mud. They believe that the thick layers of mud observed in the Gulf of Maine are the result of sediment melting out of icebergs drifting overhead. The fact that ice entrains rocks of all sizes is well established by the striations and glacial polish that cover areas that have been glaciated by temperate ice. When part of the ice sheet breaks off it carries numerous pieces of rock frozen to its sole. As the ice melts these fragments fall out, carpeting the marine landscape (Schnitker & Jorgensen, 1990).

Recent research (Schnitker et al, 2001) supports the second hypothesis. They described a sedimentary sequence of till and proximal glaciomarine sediment to distal glaciomarine sediments and postglacial mud layering the bottom of the gulf. The species of foraminifera and diatoms preserved within this sediment and their ages indicate that the ice sheet retreated from its maximum position on Georges Bank in stages. First, ocean water flows into a basin forming an ice shelf over it. The shelf remains stable as
long as its terminus is anchored on a ledge. Once ablation processes have forced the ice shelf off a ledge, however, it quickly calves back to the next one (Schnitker et al, 2001).

The retreat of the Muir Glacier from its little ice age position in Glacier Bay, Alaska illustrates this. Based on the historic record, the glacier retreated on average at 258 m/a (meters per annum) over the 70 m deep entrance sill to Muir Inlet and 1250 m/a over the basins of the inlet (Seramur et al, 1997). Given this is in a fjord no more than 2.5 km wide (Seramur et al, 1997), retreat may have been quicker over the basins of the Gulf of Maine.

Thus, the Laurentide’s margin would pause or slow over the sills and quickly calve back over the basins. This process of retreat was repeated until the shallow-water, coastal environment was reached.

Large masses, such as mountain belts and ice sheets, depress the lithosphere. When the ice sheet melts, the mass is removed and the underlying ground rebounds as part of the process of reaching tectonic equilibrium. Likewise, when an ice sheet forms mantle material flows out from under it in order to reach equilibrium. This creates a flexural bulge in the crust that surrounds the glacier (Daly, 1934). When the ice sheet retreats this feature follows it. In Maine, the passing of this glacial forebulge coincides with the timing of a sea-level lowstand of 55 m bsl (below sea level) (Barnhardt et al, 1995).

A result of this isostatic depression is that when the ice retreated past today’s coast, it was 60-70 m bsl. The ocean reached as far as Millinocket. This body of water is called the DeGeer Sea (Lougee & Lougee, 1976). The elevation of the marine limit (the maximum level reached by the ocean) varies across the state because northwestern
regions were under a greater ice burden (Thompson et al, 1989). Near the coast it about 70m while inland it may be greater than 128m (Barnhardt et al, 1995).

The first study to create a relative sea-level (RSL) curve for coastal Maine was Schnitker (1974). It was based on previously published dates and new seismic work. Schnitker determined that isostatic rebound averaged 19 mm/yr 13,000-12,300 $^{14}$C yrs. B. P., which is much quicker than global sea-level rise. Thus, relative sea level fell along the coast of Maine.

In 1975, Stuiver and Borns modified Schnitker’s work. They dated organic remains from the near-shore environment of the retreating DeGeer Sea and determined that the margin of the ice sheet was north of central Maine by 12,700 $^{14}$C yrs. B. P. The regressing ocean stood at the modern shoreline about 12,100 $^{14}$C yrs. B. P. (Stuiver and Borns, 1975).

Belknap et al (1987) further improved the precision of the RSL curve. They dated carbonaceous materials from ice-proximal settings and determined that isostatic rebound begin 13,830-13,200 $^{14}$C yrs. B. P. Furthermore, they placed the ocean at 60-80 m asl (above sea level) at 12,500 $^{14}$C yrs. B. P. and at the modern coast at 11,300 $^{14}$C yrs. B. P. Kelley et al. (1992) further refined the RSL curve; they discovered that marine transgression had begun by 14,090 $^{14}$C yrs. B. P. in Casco Bay.

One of the best indicators of elevated relative sea level is the Presumpscot Formation. It is a bluish-gray, poorly sorted, silty glacial-marine clay that is poor in clay minerals and rich in quartz, feldspars, and metamorphic minerals. Marine fossils commonly occur within it. The Presumpscot Formation represents finely ground lithic fragments- “rock flour,” that was injected into the ocean meltwater from the ice sheet.
The rock flour then settled, veneering the ocean bottom. The Presumpscot is a good stratigraphic marker because of its widespread occurrence and distinctive characteristics.

As the Laurentide Ice Sheet melted, it deposited sediment onto the landscape. Where the glacier slowed its retreat or readvanced, it generally deposited more rock fragments than in regions where recession was rapid. The pile of sediment created at the margin by this process is termed a moraine. There is a 40 km-wide belt of moraines along the Maine coast from Lincoln County to the New Brunswick border (Thompson & Borns, 1985). Most moraines within this belt are small washboard moraines, also known as DeGeer moraines. Some, however, are large stratified moraines (Smith et al, 1982).

There are some trends in the morphology of moraines within this belt. The DeGeer moraines and the best-developed large moraines are only found below the marine limit. Thus, there is a relationship between moraine development and the aqueous environment. The axes of moraines are perpendicular to local glacial striations. The moraines are generally concave outwards over hills and convex down valleys. This suggests that the ice may have been using the topographic highs for pinning points and the valleys were acting as calving bays (Donner, 1995). The axes for the small and large moraines are generally approximately parallel to each other (Smith et al, 1982).

The compositions of these moraines are somewhat abnormal and a result they have been termed “morainal banks” (Hunter and Smith, 2001). Strictly speaking, moraines are composed entirely of till (Adam Lewis, per. comm., 2003 BU field camp) whereas morainal banks are “any sediment pile that accumulates at the grounding line, through a wide variety of depositional and deformational processes,” (Hunter and Smith, 2001). At least some of the DeGeer moraines are composed entirely of diamicton
(Bingham, 1981), but many of the moraines in this region have a substantial component of stratified sediment. The stratified moraines were formed by jet processes along the grounding line of a tidewater glacier terminating in an ice cliff (Hunter et al, 1996). Variations in the sizes of these morainal banks are due to the duration of time that the glacier grounded at that position and sediment supply (Hunter and Smith, 2001).

Meltwater issuing from a tidewater glacier can be under a high hydrostatic head in which case it may form a jet of turbid sediment-laden water. The meltwater rises towards the surface when it encounters the marine environment because of its inferior density. Hunter et al (1996) reports that jet processes are responsible for the development of morainal banks.

The proximal zone of a turbulent jet is where the gravitational forces are less than the jet’s inertia. The trajectory of flow is determined by original pipe flow dynamics and the conduit orientation. The size of the proximal zone is a function “of the momentum decay rate and the rate of ambient fluid entrainment” (Hunter et al, 1996). As the flow loses competence, particles rapidly fall out of suspension. This adds a downward flow component, enhancing the decay of inertia and velocity.

Morainal bank deposits reflect the jet processes that produced them. If the jet discharges at a steep angle or if the discharge is small, the jet may only contact the bottom near the conduit. If it discharges at a shallow angle or if the discharge is large, the jet may remain in contact with the sea floor for up to 13D, where D is the diameter of the conduit (Hunter et al, 1996). A jet may also impinge on the bottom when a morainal bank grows into a high profile feature. This is most likely to happen when the grounding line retreats from a morainal bank or readvances (Hunter et al, 1996).
Further away from the conduit, suspension settling is important, which produces cyclopsam and cyclopel couplets. Cowan and Powell (1990, 1991) propose that each couplet represents a tidal cycle. During flood tide there is more turbulence, which permits the suspension of sand while during slack and ebb tide there is not enough turbulence to do this.

The subject of this study, the Waldoboro moraine, is located in Knox and Lincoln counties in coastal Maine. Belknap (1979) described the stratigraphy of Whitney Corners South gravel pit, part of the Waldoboro moraine, as consisting of 2.5 m of ice-contact stratified drift, overlain by 5 m of barren Presumpscot Formation, overlain in turn by 5 m of fossiliferous Presumpscot Formation, that is finally covered with 2 m of gravelly sand with modern soil on top. Belknap (1979) hypothesizes that the lack of macrofossils in the lower portion is due to colder and/or fresher conditions that later abated.

Moraines similar to the ones in Maine are found in other regions visited by temperate marine glaciers. Seramur et al (1997) studied Muir Inlet, Alaska, U.S.A. by high-resolution seismic-reflection methods and observed four facies in the glacial-marine deposits. Facies A had discontinuous, contorted, and mounded reflections. Morphologically facies A is in the shape of a wedge that thins distally. It is interpreted as the deposits of slumps, debris flows, and slides from the grounding line. Facies A lies under, and horizontally grades into, facies B. Facies B’s internal reflectors are semi-continuous, convergent, and offlapping. These either terminate at the sea floor or grade into facies C. Facies B is also morphologically in the shape of a fan or wedge. It is interpreted to be formed of interbedded sediment gravity flows and suspension deposits. Above facies B is C, which has continuous, parallel, and onlapping internal reflectors. Its
morphology is ponded, filling basins, and it is interpreted to be suspension deposits also interbedded with sediment gravity flows. Seismic facies D has chaotic, mounded, and discontinuous internal reflectors and morphologically take the form of ridges, which have been interpreted as “glacitectonically deformed proglacial deposits” (Seramur et al, 1997). The same processes that formed these facies are almost certainly also responsible for the development of the Waldoboro Moraine. Seramur et al (1997) writes, “these stratified ridges are similar to morainal banks in New England that are described as ‘stratified moraines’.”

One difference between the morainal banks of Maine and the stratified ridges of the Muir Inlet is their asymmetry. Both large and small moraines in Maine dip more steeply on their distal sides while the Muir Inlet moraines are steeper on their ice-contact side (Smith et al, 1982; Seramur et al, 1997). A possible explanation is wave modification of the Maine moraines because the Alaskan moraines have not rebounded through the surf.

The majority of Maine’s moraines are not large stratified moraines, but small DeGeer moraines (Smith et al, 1982). This type of moraine is also common in south-central Sweden (Strömberg, 1965). These moraines usually occur in clusters and their formation is almost certainly periodic, perhaps annual, Strömberg (1965) though, found little evidence to support the annual assumption in south-central Sweden. In Maine the case for annual formation seems stronger, although it is still not prudent to assume each represents a different year.
On a macroscopic scale, 200-500 m high bedrock hills and small ponds dominate the landscapes of Knox and Lincoln counties. A more detailed examination reveals that many of the hillsides and valleys are striped with moraines. These moraines are an integral part of the landscape. There are literally hundreds of moraines in the area. Most of these are small, but some are quite large, as much as 20 m high (Smith et al., 1982). How did these moraines form? Why are some significantly bigger than others? Was the ice active, stagnant, or readvancing? How much of the moraines are diamicton versus stratified marine onlap and offlap deposits? These are important questions for understanding how ice recession occurred from the Maine coast and for placing radiocarbon dates in the correct context. This study addresses these questions by a detailed investigation of the Waldoboro Moraine as exposed at Whitney Corners.

**Methods**

I studied the stratigraphy of the Waldoboro Moraine in two gravel pits in Warren, Maine. They are located at latitude 44° 10’ N, longitude 69° 18’ 45” W and are on the Union, Maine 7.5’ Quadrangle, figure 1. A map of Whitney Corners was produced by compiling a tracing of air photographs and a survey of Whitney Corners North created with the Department of Geological Science’s Sokkia Set 4B total survey station, figure 2. This formed the basis for plotting, compiling, and correlating the stratigraphic sections. The surface expression of the moraine was studied, as seen on topographical maps, figure 3, as well as the stratigraphy exposed in the gravel pits in order to learn how they were formed. In this study, I propose a model for the glacial and glacial-marine sedimentation
in mid-coast Maine that produced the well-known Waldoboro Moraine. The model uses the characteristics of the various sedimentary units present in the Whitney Corners Moraine as the primary source of information. The sediment lithofacies were identified by their color, particle size, and stratigraphic relationships. Particle size was measured using product 3070-6 from Hubbard Scientific, Inc, a set of six sieves plus a bottom pan that collects silt and clay. For more information on methods used to measure particle size and conversion into phi units please see Appendix C. Stratigraphic logs and cross-sections were created to show the geometric relationships of the lithofacies.

![Map of Maine showing the location of Whitney Corners, marked W.C. on the map. Modified from Belknap (1979).](image)

**Figure 1.** A map of Maine showing the location of Whitney Corners, marked W.C. on the map. Modified from Belknap (1979). For a larger scale map of Whitney Corners please figure 2 or 3.
Figure 2. A map of Whitney Corners based on air photographs and surveying. Gray shaded regions represent the gravel pit walls. Section WCN 10 and WCS 1 were removed after study. WCS 3 is a bench shoveled out of the wall, thus the line approximately perpendicular to the arrow. Variations in the width of the road are the result of overhanging trees and variable shoulders.
RESULTS

Study Area

The gravel pits are situated on either side of Maine Route 235 immediately west of the intersection with the Old Augusta Road, also known as Whitney Corners, figure 2. When traveling south on 235 Whitney Corners North is to the right and Whitney Corners South is to the left. George C. Hall & Sons, Inc owns both gravel pits. Whitney Corners is in Warren, Maine about 100m from the Waldoboro town line on Maine Route 235.

The surficial geology of the surrounding area is dominated by series of sub-parallel moraines. The vast majority of these moraines strike ENE-WSW and are small. The moraine at Whitney Corners, however, strikes WNW-ESE and is approximately 800 m long and 20 m high. It is the most northerly in a series of three large moraines that occur between Whitney and White Oak Corners, about 2 km to the SE, figure 3.

About one kilometer north of Whitney Corners is Clary Hill. It is 200 m high and composed of bedrock. There are no mapped moraines on the hill, although it is till-covered, figure 3.
**Figure 3.** A revised portion of the Maine Geological Survey’s Reconnaissance Surficial Geology of the Union Quadrangle, Maine (Thompson and Smith, 1978). Whitney Corners is located in the center of the figure. The red line represents this study’s interpretation of where the axis of the Moraine lies. See map key below for symbol definitions.

- **Qs** - swamp and tidal-marsh deposits
- **Qp** - Presumpscot Formation
- **Qg** - glacial-stream deposits
- **Qmg** - end-moraine deposits
- **Qt** - till

Letter symbols for material exposed in gravel pits:
- **b** - boulder gravel
- **c** - cobble gravel
- **s** - sand
- **t** - till

These horizontal bars indicate exposed bedrock.

These black lines indicate moraines. The black triangles point in the down ice direction.

One Kilometer
*Whitney Corners North Sections*

**Section Two.** Section Two trends roughly northwest southeast along the west edge of the gravel pit, figure 2. The section is approximately ten meters long and five meters high. The stratigraphy consists of a layer of well sorted, massive, coarse- to medium-grained sand at least three meters thick, figure 4. In the upper two meters of this unit there are occasional concentrations of coarse sand and fine gravel. Two meters of interbedded oxidized Presumpscot Formation and sand occur above the sand unit, figure 5. These sand and clay lamiae are on the scale of millimeters to centimeters. Steep faces prevented detailed examination of these upper two units.

![Figure 4. Whitney Corners North Section Two, note the white hat at bottom of exposure in the center for scale. The line indicates the contact between the sand below and the Presumpscot Formation above.](image-url)
Figure 5. A stratigraphic log of Section Two at Whitney Corners North showing sand being overlaid by the clayey silt of the Presumpscot Formation.

Section Four. Section Four is a stratigraphic log taken from the eastern portion of the gravel pit, figure 2. The stratigraphy consists of sorted angular/subangular sand, which fine upwards, figure 6. About three to four meters above the base of the section, figure 7, fine-grained well-sorted sand is interbedded with oxidized layers of the Presumpscot Formation six to ten millimeters thick. The sand layers are 10-50 cm thick. Above the interbedded sand/silt are one to two meters of the oxidized Presumpscot Formation. It has thin, millimeter or less, laminations of very fine sand within it, figure 8. Above the Presumpscot Formation is more sand with thin interbedded layers of silt, figures 6 and 7.

Section Ten. Section Ten is from the northeast portion of the pit, figure 2. The stratigraphy consists of a three-meter thick unit of the Presumpscot Formation with interbedded well-sorted, fine-grained sand, figure 9. At the bottom of the unit the Presumpscot Formation is composed mostly of sand with pockets of clay. The amount of Presumpscot Formation relative to the sand increases upwards until only the Presumpscot Formation, approximately 2.8 m thick, is present. Overlying the Presumpscot is another unit of sand, figure 9.
Section Thirteen. Excavation removed section ten, along with much of the surrounding sediment. Section Thirteen was taken at the fresh exposure. At the base of this section, there are 1-6 meters of fairly well-sorted, coarse- to fine-sand, part of which exhibits climbing ripples, figures 10 and 11. In one location within this sand there are lenses of angular coarse sand and gravel that are vertically stacked upon each other, figures 12 and 13. This body of sand has been overridden by one to three meters of thrusted diamicton, figures 14-17. There is an erosional contact that extends distally from the thrusted diamicton, figures 16 and 17. This suggests that the erosion is related to the thrusted diamicton. This erosional contact separates the previous sand body and a second, which is 5-6 meters of stratified fine gravel to sand, figures 16-21. In addition to overlying the first sand unit, the second also carpets the top and backside of the thrusted diamicton, figures 14, 15, and 17. Above the second sand there are one to two meters of massive brown silt, figures 18 and 22. Capping the exposed section is the Presumpscot Formation, figure 22. It is three to four meters thick at this locality and lacks fossils.
Figures 17 and 18 provide a view of the entire section, showing all these bodies and their spatial relationships except the lenses of angular coarse sand and gravel.

Figure 7. A photograph of Whitney Corners North Section Four. Note the green Army surplus jacket on top of the backpack for size. The exposed material is on the right side of the photograph.
Figure 8. A photograph of the upper right of figure 7 showing oxidized Presumpscot Formation with interbedded fine sand. Note folding shovel for scale.

Figure 9. A stratigraphic log of Section Ten showing a body of sand fining into the Presumpscot Formation, which in turn is overlain by sand.
Figure 10. Climbing ripples within the earlier, eroded sand of Section Thirteen. This is the only example of climbing ripples that was found at Whitney Corners, they are rare in the glaciomarine environment (Ashley et al., 1991). The photograph is taken facing the ENE and ripples indicate water flow to the right, away from the ice front.

Figure 11. A diagram of the distribution of sediment sizes in the first sand of Section Thirteen, Whitney Corners North. For a discussion of methods please see Appendix C.
Figure 12. Clast supported gravel lenses (upper center) within the older sand of Section 13, Whitney Corners North. Note the folding shovel for scale on the left.

Figure 13. Grain size distribution of the stacked “lenses of angular coarse sand and gravel” in the first sand of Section Thirteen, Whitney Corners North. For a discussion of methods please see Appendix C.
Figure 14. Photograph of Section Thirteen looking northwards showing diamicton over deformed sand beds. The second sand overlies the diamicton both in the upper right and a short distance above the large boulder on the left. Note the shovel in the scree left of center for scale.

Figure 15. A closer view of the diamicton and underlying stratified sand. Note Dad’s folding shovel on the right, which I later broke, for scale. This photograph corresponds with the left half of figure 14. About one meter above the large boulder on the left is the undeformed stratified second sand body.
Figure 16. The erosional contact between the two sand bodies at Whitney Corners North Section Thirteen. Note the red and black backpack for scale on the left. The older sand is coarser grained and has a gray appearance while the newer sand is brown and finer grained. Protruding into the photograph at the upper left is the diamicton thrust over stratified sand. The erosional contact between the sands leads back to the thrust diamicton suggesting that the erosion was related to it.

Figure 17. The left half of Section Thirteen, looking NE. This photograph shows the relationships between the diamicton overriding stratified sand, the erosional contact, and the second sand.
Figure 18. The right half of Section Thirteen showing stratified sand dipping off one deposit of diamicton just off the photograph to the left and climbing presumably another one to the right. Note the black backpack in the center for size. View is to the east. The backpack is on the second sand unit. To the upper right from the pack is a dark brown layer, the silt, and above that is a deep gray unit, the Presumpscot Formation.

Figure 19. A histogram of grain size in the lower potion of the second sand of Whitney Corners North Section Thirteen. For a discussion of methods please see Appendix C.
Figure 20. A histogram illustrating the grain size of the middle portion of the second sand of Whitney Corners North Section Thirteen. For a discussion of methods please see Appendix C.

Figure 21. Range of grain size for the upper portion of the second sand of Whitney Corners North Section Thirteen. For a discussion of methods please see Appendix C.
Figure 22. A photograph showing the contact between the brown silt and overlying Presumpscot Formation at Section 13. The contact has been traced in white. Note the white cigarette lighter at center for scale.

Whitney Corners South Sections

Section Uno. Section Uno is oriented roughly perpendicular to the axis of the moraine, figure 2. It consists of alternating layers of coarse and medium sand with an occasional pebble, figure 23. Each layer is usually 3-4 mm thick with the thickest not more than 20 mm. In places the layers are depressed and draped around the pebbles, figure 23. Most pebbles are about 1 cm in diameter. Section Uno was subsequently removed by excavation.
Section Dos. Section Dos is approximately underneath the axis of the moraine, figure 2. The stratigraphy consists of a sequence of gravel, sand, and clay, figure 24. The gravel is slightly stratified and poorly sorted fine- to medium-grained, figure 25. Its total thickness is at least 1 m, but is not absolutely known because the bottom of the unit is not exposed. The stratigraphic layers are one to three centimeters thick. This unit fines upward into poorly sorted gravel and interbedded coarse- to medium-grained sand. Particle size in the gravel is as much as four centimeters in diameter. The gravel beds are 10-15 cm thick and the sand 15-30 cm thick. Overlying this sand/gravel unit are three meters of alternating gray sand and gravel. The sediments continue to fine upward. Above the sand and gravel are two meters of stratified sand with lamiae ranging from 1-100 mm thick depending on location in the unit. Thinner beds are generally located
Figure 24. A stratigraphic log of Section Dos in Whitney Corners South showing a progression from gravel through sand to the clayey silt of the Presumpscot Formation, which is overlain by reddish sand.

higher in the unit. The gray sand fines into two meters of the oxidized Presumpscot Formation, figure 26, which has a blackish film deposited in it, a common occurrence in the oxidized Presumpscot. The Presumpscot is overlain by a massive, poorly sorted, reddish-brown sand that is at least one meter thick. The red coloring is interpreted to be the result of deposition by Fe-rich groundwater.

Figure 25. The contact between the gravel and stratified gravel-sand in Section Dos, Whitney Corners South, white Philmont hat for scale. This photograph also demonstrates the northward dipping layers that are found both in Sections Dos and Tres.
Figure 26. The contact between the gray sand and the oxidized Presumpscot Formation in Whitney Corners South Section Dos. Note the white Philmont hat for size.

**Section Tres.** Section Tres runs north south along the east wall of the gravel pit and is interpreted to cut the moraine axis at a highly acute angle, figure 2. For most of this exposure’s length the stratigraphy dips to the south, but at the very northern end it dips to the north, figure 27. These beds appear to dip at shallow angles, a result of cutting the moraine axis at an acute angle and a two-dimensional exposure.

The lowermost unit of Section Tres is gray, stratified sand, figure 28. The layers dip as described above. This sand fines upwards into the Presumpscot Formation, which is massive, gray, and fossiliferous at this exposure. The upper portions have been oxidized brown and it coarsens upwards into a reddish-orange sand, figure 29. This is the same reddish sand as in Section Dos; it is interpreted to be a marine regressive deposit. Overlying the red sand is a gravel body that first coarsens upwards and then fines, figure 30. It is found only at the southern end of this exposure and clast size ranges between three millimeters to about five centimeters. It is exposed horizontally only ten meters at this outcrop; it is not continuous along the whole length of the section. The deposit is poorly sorted, shallowly dips to the SW, and is at the very crest of the moraine. This
gravel body is interpreted to be a beach. Compare Figure 30 with Figure 31, a photograph of a paleo beach from a textbook.

Figure 27. A schematic cross-section of Section Tres. All dips in this figure are approximate.

Grain Size Distribution of Whitney Corners South Section Tres, "the Gray Sand"

Figure 28. Shows the range of grain size in the gray sand of Section Tres of Whitney Corners South. For a discussion of methods please see Appendix C.
Grain Size Distribution in the "Reddish Sand," of Section Tres of Whitney Corners South

Figure 29. This figure shows variations in grain size in the reddish sand of Whitney Corners South Section Tres. For a discussion of methods please see Appendix C.

Figure 30. A deposit interpreted to be a beach. There is no observable imbrication, but grain-size coarsens and then fines, the stratigraphic layers dip to the SW, the clasts are rounded, and it is located on the moraine crest. Where the shovel is laying, the sediment is sand with some clay, but within half a meter it has coarsened into a coarse, poorly sorted gravel that in another half a meter has fined into fine gravel. Compare with figure 31 below, literally a textbook example.
**Figure 31.** A textbook example of a paleo beach from Nichols (1999). Notice how grain size coarsens upwards and then fines and that the material overlying the coarsest sediment is still coarser than the sediment at the bottom of the photograph and compare with figure 19. Mechanical pencil for scale.

**Section Cuatro.** Section Cuatro is at the southeastern end of the gravel pit, figure 2. The section is about 7-8 meters high and consists of interbedded sand and gravel, figure 32. At the southern end of the exposure what appeared to be a channel was observed, figure 33. A deposit of sand with a gravel lag cut and fills the surrounding interbedded sand and gravel. It is not clear what produced it, but a process related to submarine jets or a debris flow seems likely. Also to be seen at this location is an erosional contact between two units of sand and gravel, figure 34. In all cases a close inspection was not made due to slope instability.
Figure 32. A photograph of Section Cuatro, which consists of alternating layers of sand and gravel. Note geologist for scale.

Figure 33. A cut and fill channel structure within the interbedded stratified sand and gravel of Whitney Corners South Section Cuatro. Trees for scale.
Figure 34. Dipping sand gravel layers on the right being cut by a second unit of sand and gravel at Section Cuatro. Note the geologist for scale.
DISCUSSION

Origin of Units

The diamicton was deposited either directly from the glacier or fell through water (waterlain till). It is composed of unstratified boulders, gravel, sand, silt, and clay. It some places it has been reworked by active ice. This is known because of the thrust fault placing till onto bedded sand. An erosional contact extends distally from the end of the thrusted till sheet separating two units of gravelly sand. While it seems clear that the erosional event is related to the thrusted till, the exact process that eroded the earlier sand and gravel remains obscured. Perhaps the ice sheet retreated and meltwater jet(s) impinged on the moraine, or perhaps the ice sheet overrode the moraine and subglacial water remobilized the sediment.

At this point it would be misleading to give a definitive answer, however, the first possibility seems most likely. A close inspection of figure 10 shows that the first sand unit extends upwards in front of the thrusted till. For clarity, a tracing of figure 10 has been produced, figure 35. This would seem to eliminate the second possibility, why would that portion of the first sand not also have been eroded if the glacier had advanced further? Also, if the erosion was the result of the ice sheet overriding the moraine, why are there no boulders, rocks too massive to be transported by subglacial currents, deposited on the eroded contact?
The stratified drift was not deposited directly out of the ice, but was transported some distance through the water. The distance that it was transported generally depends on its grain size. The gravel was largely deposited a short distance from the conduit, it was probably transported as a bedload (Hunter et al, 1996). Figure 12 shows lenses of angular, clast-supported gravel stack upon one another. This indicates that a meltwater jet was near by and the lens shaped nature of the deposit might be reflecting variable flow conditions. An alternative hypothesis is that the gravel lenses are actually channel lags, but this seems unlikely because no fining upward sequence was noticed and the gravel appears well-sorted.

Sand was carried in suspension and blanketed the submarine terrain for some distance beyond the glacier. Depending on conditions, couplets of cyclopsams and
cyclopels were deposited. As the ice sheet retreated further away, the water at Whitney Corners became quieter and silt and clay fell out of suspension (Hunter et al, 1996). The Presumpscot Formation is a bluish-gray, sandy, silty, clay associated with deglacial marine deposition in Maine, it was deposited at this time.

The Presumpscot Formation and all the sediment below it were either deposited directly by the glacier or as part of the sequence of marine onlap, figure 36, which correlates the various sedimentary logs. Above it, the deposits form a sequence of marine offlap. The majority of the sediment in the layers above the Presumpscot Formation are from glacial and glaciomarine deposits that were reworked.

The upper portion of the Presumpscot Formation has been weathered brown due to oxidation (Belknap, per. comm., 2003). This portion of the formation has purplish black stains through it and is significantly more friable than the unoxidized Presumpscot. Overlying the Presumpscot is fine-grained sand. This might represents a shallowing of the water, the sand being washed down from higher elevations that are freshly exposed. Black stains occur commonly within the oxidized Presumpscot and might be sulfidic staining, the remains of decayed organic matter in a micro-reducing environment (Retelle & Bither, 1989).

Overlying the Presumpscot Formation is sand. In one locality of Whitney Corners South it is stained red, but generally it is gray. It is not known what the source of Fe is that stained the sand. Above the sand, at the moraine crest, the material coarsens upwards into gravel up to 5 cm in diameter before fining again into very coarse sand. The gravel clasts are rounded, poorly sorted, and stratified. The sedimentary beds in this
unit strike roughly SE-NW and dip shallowly to the SW. This material represents a beach that was formed at the moraine crest when it emerged from the water.

**Model for the Formation of the Whitney Corners Moraine**

The deposits in Whitney Corners North and South can be organized into five facies. Using slightly modified Retelle and Bither (1989) terms, these include end moraine, submarine outwash fan, submarine outwash plain, shallow marine, and beach facies. The end moraine facies assemblage is the heart of the Whitney Corners Moraine. Evidence from Section Thirteen indicates that there are at least two ridges of diamicton within the larger moraine. These ridges are considered part of the end moraine facies because there is no apparent sorting, stratigraphy, or fossils in them, and the shape of the overlying strata indicate a ridge or NE dipping tabular morphology.

Meanwhile, further from the jet, gravel was being deposited as a bedload and sand was falling out of suspension. These deposits are part of a submarine outwash fan (Retelle and Bither, 1989). At Section Thirteen there lenses of angular, well-sorted, clast-supported gravel are stack upon each other in the first sand, an indication that a jet with varying flow was operating nearby with. Also at Section Thirteen there is deformed submarine outwash fan sediment underlying thrusted till, an indication of active ice. At the same time, but more distally, interbedded sand and silt were being deposited.

Once the terminus had retreated some, the grain-size deposited at Whitney Corners decreased. Interbedded sand and silt was deposited directly over the submarine outwash fan and end moraine facies. The ice front continued to retreat and silt and mud sized particles fell out of suspension. It was at this point that the Presumpscot Formation
was deposited. Fossils are common in the upper, unoxidized portions of the Presumpscot Formation (Belknap, 1979). The most commonly found fossil at Whitney Corners is *Hiatella artica*, a shallow water species, but other species are also present. Belknap (1979) reports the presence of the deep-water fauna *Serripes groenlandicus*, *Neptunea despecta tornata*, *Chlamys islandicus*, and *Buccinum tenue* as well as the shallow water species *Macoma balthica*, *Mytilus edulis*, *Mya arenaria*, *Polinices heros*, *Mya truncata*, and *Urosalpinx cinerea*. This represents the submarine plain facies because grain size ranges from sand to silty clay with the minor exception of dropstones. In addition, the fossil content and the widespread occurrence of these sediments support the submarine plain conclusion. Indeed, these sediments are observable in all parts of the gravel pits.

As the water shallowed, grain-size coarsened again. Above the Presumpscot is a 1-2 m, well-sorted, massive sand. Given its stratigraphic position, it seems likely that it is associated with marine regression. The source of the sand is unclear; given that the moraine is higher than the immediate surrounding landscape, but the slopes of the bedrock hill with about 60 m of relief approximately 700 m NNE seem a likely source. Erosion and transport may have been by rain, waves, and undersea currents or by strong winds. Given the sand is poorly sorted, figure 29, wind seems unlikely to a significant factor. This sand represents the shallow marine facies. Above this sand body, near the moraine crest, a poorly sorted, rounded (Nichols, 1999), SW dipping, gravel deposit was discovered. No fossils were found in either of these units. The possibility that this sand deposit is the result of previous excavations in the gravel pit seems unlikely given the stratification of the overlying deposit. An alternative hypothesis for the deposit classified
as the beach facies is a gravel lag at the base of a channel viewed at an oblique angle. To complicate matters more, perhaps it is a channel deposit reworked by wave action.

Indeed, a large channel was observed at Section Cuatro, but there are notable differences between these two deposits that make this connection unlikely. First, the deposit labeled as a beach is on the moraine crest unlike the channel at Section Cuatro, which is part way down the moraine’s front. Secondly and more importantly, the gravel lag at the base of the channel is in sharp contact with the underlying sand unlike the deposit at Section Tres, which fines upwards into the gravel, figures 30 and 33. These are the final facies in the model.

**Orientation**

The Whitney Corners moraine is orientated more NW-SE than most of the other moraines in the Waldoboro Moraine. About 0.7-1.5 km NNE of Whitney Corners is Clary Hill, which is a bedrock high with about 150 m of relief. This provides an explanation for the unusual shape of the Whitney Corners moraine. The hill provided a grounding line for a short time while the ice retreated in the surrounding lowlands. This caused the orientation of the Whitney Corners moraine to swing around to more WNW-ESE as compared to moraines previously deposited, figure 3 shows the axis of the Whitney Corners moraine in red/gray and some of the other moraines within the Waldoboro Moraine in black. This finding is compatible with Donner’s (1995) study of the Dixmont Hills, a region that begins a few kilometers north of Whitney Corners. Donner determined that the islands in that region of the DeGeer Sea notably influenced the glacial margin as it retreated (Donner, 1995).
Figure 36. A correlation of the stratigraphic sections. The horizontal line connecting sections divides the glacial and glaciomarine sediments from the marine regressive sediments. The gravel body and the lower portion of the sand belong to the submarine outwash fan facies. The upper portion of the sand and the Presumpscot Formation represent the submarine plain facies. All of the sediments on this diagram above the horizontal line belong to the shallow marine facies.
CONCLUSIONS

The littoral, glaciomarine, and glacial stratigraphy exposed at the Whitney Corner’s gravel pits may be organized into five facies assemblages: beach, shallow marine, submarine plain, submarine fan, and end moraine. The end moraine is the oldest and is represented by till. At the same time that the end moraine was being formed, the submarine fan was being deposited at Whitney Corners by gravel bedload and coarse sand falling out of suspension. This sedimentary facies is represented by gravel interbedded with coarse to medium sand. As the ice margin continued to retreat the sedimentary environment at Whitney Corners evolved into the submarine plain facies (Retelle and Bither, 1989). The sediments characteristic of submarine plain are fine-sand, silt, and clay – the Presumpscot Formation, the upper portions of which have been oxidized making it quite friable. Isostatic rebound caused the ocean to retreat and the shallow marine facies to be deposited at Whitney Corners. When Whitney Corners emerged from the surf a beach was formed.

The ice was active at Whitney Corners when the moraine was being formed. There is at least one large thrust fault within the moraine where the glacier pushed a mass of sediment forward and overran part of the moraine. It appears that this was preceded by a retreat, which was probably slight.

Very little of the moraine’s volume is occupied by till or moraine deposits proper. Most of the moraine is actually stratified sediment associated with the submarine fan and plain of Retelle and Bither (1989), which corresponds with the marine fan of Ashley et al.
(1991). There are at least 2 closely spaced, mounds of till at the core of Whitney Corners that were covered with outwash until they became one ridge of sand and gravel.
REFERENCES CITED


Thompson, W. B. and Smith, G. W., 1978, Reconnaissance Surficial Geology of the Union Quadrangle, Maine: Maine Geological Survey, scale 1:24,000.


APPENDIX A

Richard A. Becker’s Reading List

Gilgamesh  translated by Herbert Mason
The Sea-Wolf  Jack London
Moby-Dick  Herman Melville
Treasure Island  Robert Louis Stevenson

“Worlds Without End,” p. 10-12 of the April 1997 issue of National Geographic

The Best of College Acapella

The Very Best of Dire Straits  Dire Straits
“Ian Chittenden’s House Design”  Ian Chittenden

Air War Pacific: The Fight for Supremacy in the Far East: 1937 to 1945  Christy Campbell

Personal Memoirs of Ulysses S. Grant  Ulysses S. Grant

Fighting for American Manhood: How Gender Politics Provoked the Spanish-American and Philippine-American Wars  Kristin L. Hoganson

A People’s History of the United States: 1492-Present  Howard Zinn

The Landmark Thucydides  Edited by Robert B. Strassler

The Middle Ground: Indians, Empires, and Republics in the Great Lakes Region, 1650-1815  Richard White

Maine: The Pine Tree State from Prehistory to the Present  Edited by Richard W. Judd et al
An air photograph of Whitney Corners. The resolution is one pixel equals one meter. These photographs are from http://terraserver.microsoft.com/default.aspx which was accessed on May 12, 2003. North is up. The left two thirds of the photo was taken in 1997 and the right third in 1996.
APPENDIX C

Discussion of the methods used to determine grain size

Particle size was measured using product 3070-6 from Hubbard Scientific, Inc. That product is a set of six sieves with mesh sizes of #5 (gravel), #10 (fine gravel), #35 (very coarse sand), #60 (coarse sand), #120 (medium sand), and #230 (fine sand), plus a bottom pan that collects silt and clay. Size represents the number of openings per linear inch of mesh. The descriptive terms that accompany the mesh sizes are Hubbard Scientific’s. Once the mesh had sorted the samples their mass was determined using an electronic balance in the sedimentology laboratory of the Department of Geological Sciences of the University of Maine. The balance was zeroed prior to use and it was noted that its inspection sticker was still valid. For the purpose of reporting this study, these mesh sizes were converted to Krumbein’s (1934) phi scale. The first step in the process was to convert the mesh size into millimeters. An inch is defined to be 25.4 mm long, thus the following formula was applied.

\[ \text{mesh size} = \frac{25.4 \text{ mm}}{(#)} \]  \hspace{1cm} \text{formula (1)}

Where:
\# = the number of openings in the mesh per linear inch

The formula for converting from millimeters into phi units follows.

\[ \Phi = -\log_2 D \]  \hspace{1cm} \text{formula (2)}

Where:
D = the diameter of the sediment

It was necessary, however, to apply the following formula because the TI-89 calculator only works in base \( e \) and 10. To do this the following generic formula was applied:

\[ \log_h a = \left( \frac{\log_{10} a}{\log_{10} h} \right) \]  \hspace{1cm} \text{formula (3)}
Where:

\[ h = \text{the base being converted to} \]

The mesh size in millimeters is then substituted into formula (3) for \( a \) and two for \( h \).

\[ \Phi = \frac{\log (\text{mesh size in mm})}{\log 2} \]

formula (4)

It is recognized that this procedure does not account for the thickness of wire in the mesh, but lacking a means to measure the wire, it will remain an inherent error in the reported grain sizes. The reported phi number was arbitrarily limited to two significant figures.

<table>
<thead>
<tr>
<th>Hubbard Scientific Mesh Size</th>
<th>Hubbard Scientific grain size name</th>
<th>Phi size</th>
<th>Udden-Wentworth grain size name</th>
</tr>
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<tbody>
<tr>
<td>5</td>
<td>Gravel</td>
<td>&lt; -2.3</td>
<td>Pebbles (gravel)</td>
</tr>
<tr>
<td>10</td>
<td>Very coarse sand</td>
<td>-2.3 to -1.3</td>
<td>Granules (gravel)</td>
</tr>
<tr>
<td>35</td>
<td>Coarse sand</td>
<td>-1.3 to 0.46</td>
<td>Very coarse sand</td>
</tr>
<tr>
<td>60</td>
<td>Medium sand</td>
<td>0.46 to 1.2</td>
<td>Medium sand</td>
</tr>
<tr>
<td>120</td>
<td>Fine sand</td>
<td>1.2 to 2.2</td>
<td>Fine sand</td>
</tr>
<tr>
<td>230</td>
<td>Very fine sand</td>
<td>2.2 to 3.2</td>
<td>Very fine sand</td>
</tr>
<tr>
<td>Bottom pan</td>
<td>Silt and mud</td>
<td>&gt; 3.2</td>
<td>Very fine sand and mud</td>
</tr>
</tbody>
</table>
AUTHOR’S BIOGRAPHY

Richard A. Becker was born in Rockport, Maine on March 19, 1981. He grew up in Union, Maine, a Midcoast Maine town with one flashing light and two farm tractor dealerships. He graduated from Medomak Valley High School in Waldoboro in 1999 along with his friend and fellow Unionite Matthew A. Jura. He matriculated at the University of Maine during the fall of 1999 and lived in Colvin Hall that year where he met his good friend of four years, Heidi A. Crosby. He is a member of Alpha Phi Omega, the Senior Skull Society, Phi Alpha Theta, Phi Kappa Phi, Phi Beta Kappa, and the Geology Club. He anticipates graduating in August 2003 with a BA in History and a BS in Geological Sciences. He plans on attending the University of Wisconsin at Madison in the fall to begin studying for a MS in Quaternary geology under Dave Mickelson, a former student of Hal Borns.
Figure 47. My Dad in Whitney Corners South Section Cuatro. *Photo by Richard A. Becker.*

Figure 81. The author in Whitney Corners North near the thrust fault. *Photo by Dennis R. Becker.*