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

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INTRODUCTION

Surficial mapping in the Freeport 7.5' quadrangle was conducted during 1990 and 1991 as part of the Maine Geological Survey basic geologic mapping program. The purpose of this program is to provide detailed geologic information for use by the general public, municipal, state, and federal agencies, and for fundamental background information for site-specific studies. A surficial geologic map (Weddle, 1999a) and a surficial materials map (Weddle, 1999b), both at 1:24,000 scale, have been compiled. The materials map shows the thickness and composition of surface materials at points where surface and subsurface observations were made. The geologic map shows the distribution of geological units and features that record the geological history of the quadrangle. In this report, the surficial deposits mapped in the quadrangle are described, and the glacial and postglacial history of the quadrangle is presented.

PREVIOUS WORK AND ACKNOWLEDGMENTS

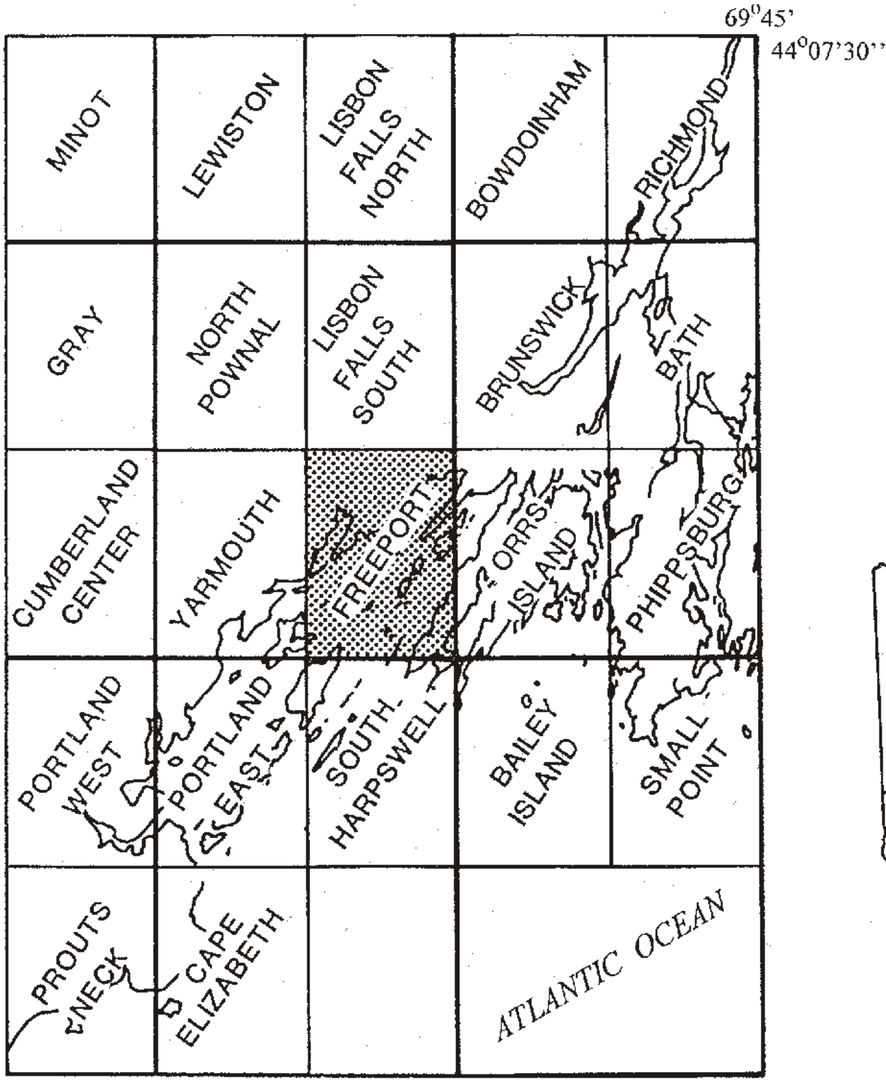
Early descriptions of the surficial deposits in the study area are found in Stone (1899), Leavitt and Perkins (1935), Donahue (1949), and Zink (1953). A regional overview of the glacial history and of glaciomarine deposits in southwestern Maine can be understood by reading Bloom (1960, 1963), Stuiver and Borns (1975), Smith (1982, 1985), Thompson (1982, 1987), Thompson and Borns (1985), Thompson et al. (1989), Smith and Hunter (1989), Retelle and Bither (1989), Kelley et al. (1992), and Weddle et al. (1993). Soils in the quadrangle have been mapped by Hedstrom (1974).

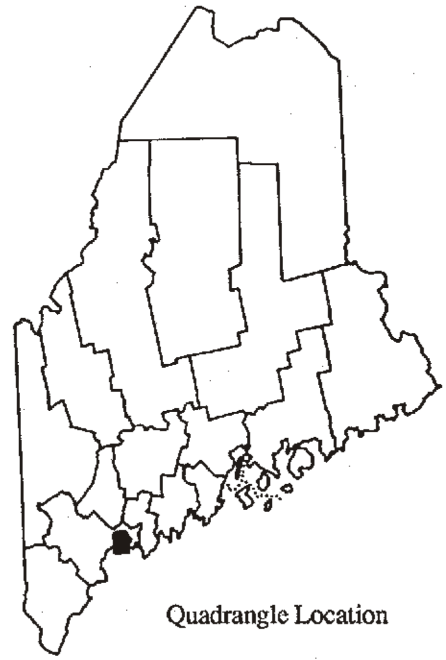
The surficial geology of the Freeport quadrangle has been mapped previously at reconnaisance level by Bloom (1960), Prescott and Thompson (1977), and Smith and Thompson (1986). Part of the surficial geology as presented in this study is taken from Prescott and Thompson (1977) as shown on Figure 1 in this report. Other modern work incorporating surficial geology in the study area includes Prescott (1967, 1968), Gerber (1979), Tepper et al. (1985), Amos and Sandford (1987), Hay (1988), Devin and Sanford (1990), and Mayer (1990). Wetlands mapping of the Freeport quadrangle is published in draft form by the U.S. Department of the Interior National Wetlands Inventory.

Sources of striation data and outcrop locations for the islands found in the quadrangle include unpublished data from A.M. Hussey II (Bowdoin College) and unpublished Maine Geological Survey data (Marita Bryant, Bates College).

Sources of subsurface information include boring logs from the Maine Department of Transportation along I-95 and the bridge crossing Mill Stream at Mast Landing. Review of reports on file at R. G. Gerber, Inc. to supplement surficial and subsurface data was generously allowed by Robert Gerber, including the Town of Freeport Bedrock Aquifer Study, R. G. Gerber, Inc., 1986; Ground Water Resource Analysis, Harpswell, R. G. Gerber and J. R. Rand, 1982; and Geotechnical Investigation, West Harpswell Elementary School, R. G. Gerber, Inc., 1988. Other sources include L. L. Bean, Inc., warehouse expansion studies, Freeport; geotechnical data from Thomas Schwarm (Groundwater Technology) at the military fuel tank storage site in Harpswell; data from the Freeport Sewer District, courtesy of Ralph Oulton (ABB Environmental Services, Inc.); and test pit locations on Mere Point (Donald Newberg, Kimball/Chase Co., Inc., Bath, Maine). Vicki Lowe (Bartol Public Library, Freeport, and Freeport Historical Society) and Joan Hoppe (Brunswick) provided information on the location of abandoned granite quarries and brickyards.

Selected records from the Maine Geological Survey bedrock well database inventory provided depth to bedrock information. The location of wells in the MGS well inventory is based on tax lot map locations and not necessarily on field observation. Drafts of this report were critiqued and improved by John Gosse, Don Newberg, and Woodrow Thompson.





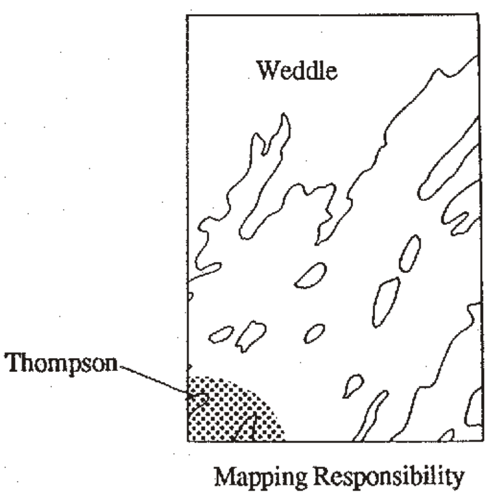


Figure 1. Location map showing the Freeport 7.5' quadrangle. Inset map shows area mapped by W. B. Thompson.

LOCATION, TOPOGRAPHY, AND DRAINAGE

The Freeport 7.5' quadrangle is located on the coast of Maine in eastern Cumberland County between 43°45'00" and 43°52'30" N latitude and 70°00'00" and 70°07'30" W longitude (Fig. 1). It includes part of each of the communities of Freeport, Harpswell, Brunswick, Cumberland, and Yarmouth. Elevations within the quadrangle range from sea level to approximately 260 feet (78 m) above sea level (asl) at Hedgehog Mountain in the northwest corner of the quadrangle. Most of the quadrangle has low to moderate relief, however, the maximum relief of approximately 220 feet (66 m) occurs between sea level and a hill west of the Cushing Briggs section of Freeport.

Approximately 60% of the quadrangle is covered by Casco Bay, part of the Atlantic Ocean, and there are numerous islands present, the largest of which include Birch Island, Upper and Lower Goose Island, Bustins Island, Moshier Island, Whaleboat Island, and portions of Littlejohn and Great Chebeague Islands. Several long peninsulas are prominent, including Wolf Neck, Flying Point Neck, Merepoint Neck, and Harpswell Neck. The peninsulas form the land perimeter of coastal estuaries including the Harraseeket River, Maquoit Bay, and Middle Bay. There is a strong northeast-southwest trend to the topography in the study area, which reflects the control of landforms by bedrock strike in the region.

Most of the mainland is drained in the western part of the quadrangle by tributaries to the Harraseeket River estuary, including Frost Gully, Allen Range Brook, Mill Stream, and Kelsey Brook. Merrill Brook drains the northwestern corner of the quadrangle and is tributary to the Cousins River in the adjacent Yarmouth quadrangle. The central part of the quadrangle is drained by the Little River, and the eastern portion is drained by Bunganuc Stream and its tributaries.

BEDROCK GEOLOGY

The bedrock geology of the Freeport quadrangle has been mapped by Hussey (1981, 1985). The bedrock units are dominated by interbedded gneiss and granofels, schist, and amphibolite. The formations mapped in the quadrangle include the Casco Bay Group in the southeastern part of the quadrangle, the Falmouth-Brunswick sequence in the central part of the quadrangle, and in the northwestern part the Hutchins Corner Formation (formerly the Vassalboro Formation; Osberg, 1989). These units are cut by numerous pegmatites and, in places, by diabase dikes, the latter found, for example, at the east end of Bunganuc Point and on the east side of Wolf Neck Point in the state park. The structure of the bedrock is strongly controlled by northeast-southwest trending folds and faults. More detailed information regarding the bedrock geology of the region can be found in Hussey (1988, 1989).

SURFICIAL GEOLOGY

Bedrock and Thin-Drift Areas

Bedrock has been mapped along the shoreline and on the mainland where it crops out. It is shown on the mainland as a solid symbol or on small islands with the notation rk (rock). Much of the area is mapped as thin drift (Ptdu) where surficial material over bedrock is less than 10 feet (3 m) thick. Individual outcrops in these areas are not always indicated on the map. The surficial deposits most often found in thin-drift areas are till, marine deposits, glaciomarine deposits, or nearshore deposits.

Till

Till (Pt) is found at some surface localities and is reported in subsurface test borings. It is commonly a compact, gray to olive gray, pebbly, silty, sandy, poorly sorted deposit (diamicton). It is found overlying bedrock in locations along the coast, and a good example occurs at Ash Point Cove in the southeast corner of the quadrangle. A large erratic boulder greater than 4000 ft^3 (>1200 m^3), probably associated with till deposition, is found on Harpswell Neck approximately 1000 ft (300 m) north of the junction of Ash Point Cove Road with Route 123 (D.W. Newberg, pers. commun., 1992). Good exposures of the compact diamicton also are found along the west shore of Harpswell Neck south of the U.S. Naval Reserve tank farm. A loose, olive gray, pebbly sandy diamicton is present in places, for example, at the south end of Bartol Island in the Harraseeket River estuary and at an exposure in the cove south of Whites Point on Harpswell Neck. Loose, gray, silty sandy diamicton associated with subaqueous outwash is found in glacial submarine fan deposits (described below) in the gravel pit adjacent to Lane Cemetery along Pleasant Hill Road in Freeport.

Stratified-Drift Ice-Marginal Deposits

Certain ice-marginal deposits below the marine limit in Maine have been termed stratified end moraines because of their geomorphologic and sedimentologic character (Ashley et al., 1991). They are linearly lobate ridges, comprised of ice-tunnel deposits (eskers), submarine fans, deltas, and associated ice-proximal diamicton deposits, and may contain deformation structures due to ice-marginal push or overriding. Not all the above features are present in the Freeport quadrangle; however, those present are subdivided for discussion into submarine outwash fans and end moraines. The end moraines are most likely complexes of submarine fans comprised of subaqueous outwash, or they may be “washboard” or DeGeer moraines (Sugden and John, 1988; Lundqvist, 1981), but because of lack of exposure are here only termed end moraines. These ice-front deposits are generally parallel to the former margin of the retreating ice sheet (Ashley et al., 1991) and therefore can be used to trace ice marginal positions during deglaciation.

End Moraines. End moraines (Pem) have not been widely recognized in the Freeport quadrangle. Some are mapped in the northwest corner of the quadrangle in Merrill Brook valley, Frost Gully, and east of Winston Hill, as well as on Flying Point Neck near Brickyard Cove and at Goose Point in the center of the quadrangle. These moraines are small, usually occurring in clusters, not more than 10-20 feet (3 - 6 m) high, 100 feet (30 m) wide, and 1000 feet (300 m) in length. Surface auger holes expose sandy diamicton in the moraine. In general, the moraines have a northeast-southwest trend (azimuth range 60^o - 70^o) and are commonly associated with submarine fan deposits. North of Frost Gully along Route 125 in the Lisbon Falls South quadrangle, several end moraines and associated fans are exposed in a series of abandoned and active gravel pits. The internal structure of these moraines was not exposed anywhere in the Freeport quadrangle. However, Retelle and Bither (1989) have described in detail a moraine in Topsham (Brunswick quadrangle), about 8 miles northeast of Freeport. Many end moraines in the Freeport region are probably hidden by overlying glaciomarine deposits.

The hummocky, morainic topography is sometimes pronounced by gullying due to stream erosion, especially where the moraines are mantled by glaciomarine mud, for example, the Merrill Brook moraines in the Freeport quadrangle. However, positive identification of the moraines is not always accomplished. The trend of the topography in the Little River valley due south of Flying Point Cemetery is similar to the trend of the moraines in the quadrangle. Exposures at the head of gullies in this area and at cut banks on the Little River expose only Presumpscot Formation and no morainic deposits. The gullies have steep walls and flat, wide floors, and the land surfaces between the gullies are flat and all at the same elevation. Although the topography may be due to buried moraines draped by the Presumpscot Formation, there is no evidence that strongly supports this, and thus this topography is interpreted to be erosional and is not mapped as moraine.

Submarine Outwash Fans. Submarine outwash-fan deposits (Pmf) are not well preserved in the study area because of removal and slumping of sand and gravel in excavation pits. Several exhausted pits are present on the map, which by virtue of remnant material and map morphology are interpreted as submarine fans. These include the fans between Winston Hill and the Cushing Briggs section of Freeport, the fan south of Hedgehog Mountain, and the fan adjacent to Lane Cemetery on Pleasant Hill. North of the Pleasant Hill fan, several inactive gravel pits are present in the adjacent Lisbon Falls South quadrangle along Mill Stream valley. Based on subsurface data along this valley, Gerber (1979) reports a discontinuous esker system buried by thick glaciomarine mud. An esker system is a series of sinuous ridges comprised of coarse-grained fluvial material transported and deposited in the ice-tunnel system which deposited fans and associated fine-grained materials at the ice margin. As with the end moraines and esker system, smaller fans may be present in the Freeport quadrangle, but are covered by later glaciomarine deposits and were undetected.

A natural cut along Mill Stream at the abandoned mill site in the Maine Audubon Society Mast Landing Sanctuary exposes distal deposits of either two small stacked fans, or two separate stacked lobes of a single fan (Pmfml). Here, interbedded stratified sand, silt, and clay overlie sandy diamicton which rests on striated bedrock (striae 170^o). The younger fan deposits include 8 feet (2 m) of interbedded silt, clay, and fine sand with dropstones (beds 1 - 3 in (2 - 7 cm) thick). The underlying older fan deposits include 1 foot (30 cm) of medium-to fine-grained massive sand, faintly bedded at its base, over 3 feet (1 m) of interbedded coarse to medium sand, fine sand, silt, and clay with dropstones (beds 0.25 - 1ft (7 - 30 cm) thick). Average bedding orientation of the fan deposits is $285^o/9^o$SW. The underlying sandy diamicton is about 3 feet (1 m) thick and contains striated clasts, of which several large clasts have a preferred 347^o trend, consistent with the striations on the underlying bedrock. In association with these features, the lack of graded beds or sedimentary structures in the unit, and its massive character with respect to overall grain-size distribution based on visual observations, the diamicton is interpreted as a subglacial deposit (lodgement till). At the top of the diamicton, a discontinuous pebble lag is present, preserved as pods of crudely stratified pebble gravel between the diamicton and the overlying stratified units. Large clasts, protruding from the top of the diamicton, are draped by the basal layers of the overlying stratified deposits. The upper part of the diamicton and the pebble lag may be materials reworked from the diamicton and deposited by meltwater. The ice margin retreated north of the site prior to the deposition of the overlying fan sediments.

In all excavations, the remnant materials in the north (ice-proximal) side of the pits consist of pebbly coarse sand, with cobbles and large boulders strewn about on the pit base. In the Pleasant Hill fan, sandy diamicton is present in its north face. On the south (ice-distal) side of the pits, in general, glaciomarine mud or silty fine-grained sand overlies or is interbedded with planar-bedded sand which overlies gravelly sand. Both the Hedgehog Mountain fan (Pmfhm) and the early Winston Hill fan ($Pmfwh_1$) pits are floored by bedrock. Striae oriented 172^o are present on the bedrock floor of the early Winston Hill fan pit.

Presumpscot Formation

Glaciomarine mud (Pp) in the southern Maine region has been named the Presumpscot Formation by Bloom (1960). The silt and clay of this unit occupies most of the valleys in the study area. Subsurface data and surface exposures show that the unit directly overlies bedrock, till, fans, and end moraines, and can be interbedded with subaqueous outwash. It can be massive or layered, containing outsized clasts, and in places is fossiliferous. It has a blue-gray color unweathered, and an olive gray color when weathered. Fracture surfaces in the weathered Presumpscot Formation commonly are stained by iron-manganese oxides. The

Presumpscot Formation was deposited by glaciofluvial activity discharging material into the glacial sea. Based on associated fossil assemblages, it is considered a late Pleistocene cold-water *marine* unit (Bloom, 1960). It can be stratigraphically related to ice-marginal deposits, hence in its oldest stratigraphic position, it is also *glaciomarine* in origin. However, upsection at some point it becomes exclusively marine when it is no longer directly linked with glacial ice in contact with the ocean.

An extensive exposure of stratified glaciomarine mud is found at the bluff west of Bunganuc Point in Brunswick and has been described by Zink (1953), Amos and Sandford (1987), and Hay (1988). Belknap et al. (1989) and Belknap and Shipp (1991) describe the Bunganuc section as an example of draped glaciomarine mud partly deposited under an ice shelf near the ice-grounding line. In this report, the Bunganuc bluff is interpreted as a time-transgressive section, representing different depositional environments over time, and is described later in the text.

A sandy facies of the Presumpscot Formation found overlying the fine-grained facies has been described for southwestern Maine (Smith, 1982, 1985; Thompson, 1982, 1987). The contact between the facies is reported to be sharp or gradational, and the origin of the sandy facies appears to be associated with shoaling during the regression of the sea. It also has been described as a gradation facies between the clay and the deltaic/fan facies (Koteff, 1991), although this interpretation places it stratigraphically below the regressive deposits.

Interbedded sand and clayey silt in the Freeport quadrangle overlying massive Presumpscot Formation mud are present at Bunganuc bluff, as well as at locations in adjacent quadrangles and in test-boring reports in the area. However, the informal term sandy Presumpscot Formation as used by others as a mappable unit (e.g., Smith, 1988; Hildreth, 1999a,b; Hunter, 1999a,b) is not used in the Freeport quadrangle. This unit has been associated by these workers with marine regressive deposits, stratigraphically above the massive mud of the Presumpscot Formation (*sensu stricto*). In some instances, massive sand probably of fluvial origin and unconformably overlying the Presumpscot Formation has been mapped as sandy Presumpscot Formation (Smith, 1977; Smith and Thompson, 1986). In the Freeport quadrangle, the term nearshore deposit (Pmn) is used for shallow water or wave-reworked deposits associated with marine transgression and regression (see below). Distal sand related to subaqueous glaciomarine fan or delta deposition and interbedded with the Presumpscot Formation is considered part of the Presumpscot Formation and is mapped as such (Pp).

The Presumpscot Formation in the quadrangle has variable thickness, and can be greater than 70 feet (21 m) thick in places (Devin and Sandford, 1990). Water well records show thickness of overburden as much as 243 feet (74 m) at a well on Lower Mast Landing Road in Freeport, although the record does not indicate if the total thickness is glaciomarine mud.

In the Freeport quadrangle, molds of fossil shells have been reported from the Presumpscot Formation by Bloom (1960) from a gravel pit 0.8 miles (1.3 km) north of Freeport Village on the east side of Route 1. The pit is no longer exposed, and no fossils were found at the site.

Nearshore and Shoreline Deposits

Subsequent to the deposition of the Presumpscot Formation, existing units were reworked by the marine regression, and nearshore deposits (Pmn) were laid down. Water depth and relative sea level in the region were controlled by glacio-isostatic rebound and eustatic sea level changes, and during the late Pleistocene in this area, isostatic conditions were prevalent (Stuiver and Borns, 1975; Belknap et al., 1987; Kelley et al., 1992). These deposits are found in many locations, as a thin to thick veneer of sediments ranging in grain size from coarse gravels to massive mud; however, most are not shown on the map because they are not thick enough to obscure the underlying units. These deposits are the result of wave activity in late Pleistocene nearshore or shallow-marine environments (subtidal, lagoonal, and beach environments; cf. Retelle and Bither, 1989), and compositionally reflect the underlying parent material. However, they are not associated with a definite shoreline morphology. Thick nearshore deposits (Pmn) shown on the map are found near Burr Cemetery and South Freeport Cemetery. Nearshore deposits also are often associated with thin-drift areas. The unit described previously as sandy Presumpscot Formation, representing shallowing conditons during marine regression, is included in this description of nearshore deposits. It was probably deposited after the glacier was well out of the area.

Deposits with shoreline morphology (beach, spit, or tombolo, for example) are designated by the map unit Pms (Pleistocene marine shoreline). On Harpswell Neck in the southeastern part of the quadrangle, an excavation adjacent to the military tank farm exposed 8 feet (2.5 m) of cross-bedded coarse gravelly sand overlying a thin deposit of glaciomarine mud and silty sandy diamicton. The exposure is in a curvilinear ridge which has a shallowly-dipping southwest face and a steeper-dipping northeast face. Here the crest of the ridge trends 295^{o} - 300^{o}, and unidirectional cross-bedding in the deposit dips gently to the southwest (205^{o} trend, near perpendicular to the crest of the ridge), as slightly convex-up planar and tangential cross-beds in tabular sets. Shell fragments found in mud on the diamicton surface below the pebbly sand were radiocarbon dated and provided an uncorrected age of 12,850 $\pm$ 45 yr BP (*Zirphaea crispata;* OS-2348, WHOI).

Slightly farther south on Harpswell Neck, slumped and overgrown abandoned gravel pits are found in another series of curvilinear ridges oriented subparallel to the ridge adjacent to the tank farm. These pits contain pebbly sand similar to the deposit adjacent to the tank farm. The crests of the ridges trend from 295^{o} to 350^{o}, are found at elevations between about 80 to 100 feet (24 - 30 m) asl, and are interpreted as Pleistocene shoreline deposits (Pms) because of their morphology and orientation to the open ocean. Where the deposits are exposed, the size-

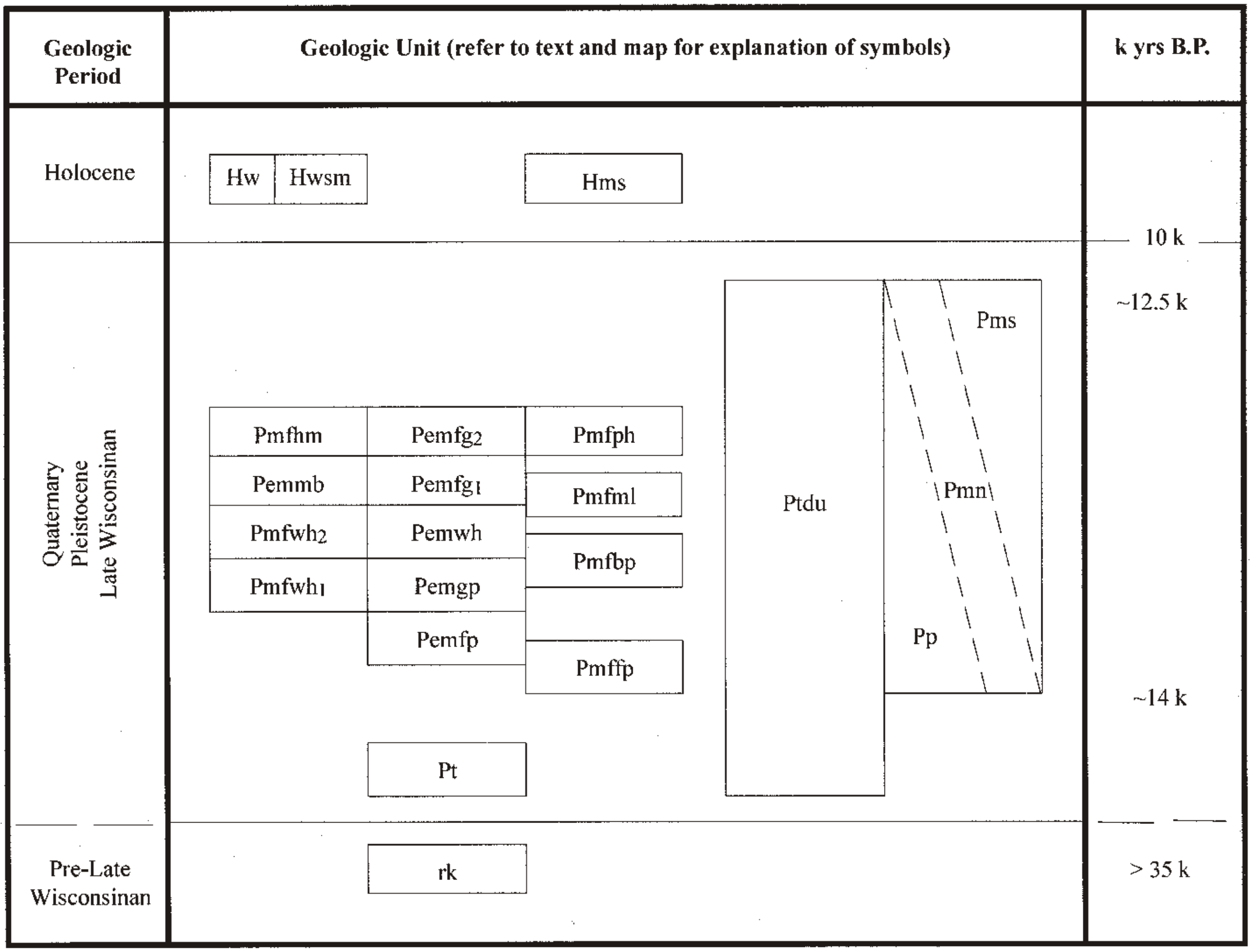


Figure 2. Schematic chart showing correlation of geologic units in the Freeport 7.5' quadrangle. End moraine (Pem) and marine fan (Pmf) units are read from left to right and bottom to top, corresponding to west to east and south to north, respectively, on the surficial geology map. Age estimates are in uncorrected radiocarbon years (Stone and Borns, 1986; unpub. data in Weddle et al., 1993). Time scale not linear; time constraints on units uncertain.

sorting within layers, open-work texture, and sedimentary structures such as tabular-bedding sets oriented shoreward in the deposits indicate nearshore processes formed the ridges. The lack of interbedded oscillatory ripple structures in the deposits is interpreted as a result of a high-energy environment, also reflected in the coarseness of the sediment in the ridges.

In the adjacent Brunswick quadrangle to the northeast, an extensive sand plain is found between 50-100 feet (15 - 30 m) asl and represents a period when falling sea level stabilized long enough for it to form. The beach ridges on Harpswell Neck are found in this elevation range and are inferred to have formed at this time as well. The ridge at about 60 feet (18 m) asl on Route 123 that connects West Harpswell with South Harpswell is pebbly sand similar to that in the higher elevation ridges. This lower ridge may have formed somewhat later than the higher ridges and probably represents a tombolo which connected West and South Harpswell during that time. A water well at a home along the low point on the flank of the tombolo is reported by the owner to have penetrated 110 feet (33 m) of Presumpscot Formation before reaching bedrock.

Holocene Deposits

Holocene wetlands have been mapped as fresh water wetlands (Hw) or as salt marsh wetlands (Hwsm). Test boring logs along the salt marsh near Mast Landing in Freeport report up to 25 feet (7.5 m) of fluvial and estuarine sand and organic-bearing sand below salt marsh peat. Holocene beach deposits (Hms) and mudflats in the Freeport quadrangle are present along the modern shoreline. At Bunganuc bluffs, a small salt marsh bisects the bluffs. Erosion of the marsh has exposed logs under the marsh peat. The logs are horizontally oriented and are not tree stumps killed in growth position. They appear to be from a slump and are found in less brackish-water marsh deposits overlain by more saline-water marsh deposits (William Duffy, pers. commun., 1992).

GLACIAL AND POSTGLACIAL HISTORY

Quaternary Geology

The glacial deposits in the Freeport quadrangle were derived from the last ice sheet which covered Maine. Glacial striae and streamlined hill directions in the quadrangle vary within 10^o-15^o of 180^o. Exceptions to this are found on Harpswell Neck where at a few sites striae trending 110^o, 112^o, and 147^o occur on coastline bedrock exposures. On the eastern shore of Basin Cove on Harpswell Neck, the 112^o trend is the youngest of a multiple striation reading. The glacial origin of this trend is suspect because of the lack of many other localities where this trend is found. Because the east-oriented striations are found only immediately along the coast, they could be due to scratching from debris frozen in the base of nearshore sea ice, or by mooring lines. At the Basin Cove location, which is at a boat launch, the striae are short and discontinuous, however, at the other sites they are long and continuous.

The striae which trend east of 180^o are more commonly found on the mainland, whereas the striae west of 180^o are more commonly found on the peninsulas and the islands in the quadrangle. At the Basin Cove multiple striation site, striae trending 170^o are older than striae trending 196^o, which in turn are cut by 112^o striae. On the north end of Harpswell Harbor, a large 186^o trending groove contains 170^o trending striae. Southwest-trending striae are reported to be cut by southeast-trending striae on the east shore of Staples Cove (R. G. Gerber, pers. commun., 1991).

The southwest-oriented striae found along the the peninsulas and islands in Casco Bay reflect the strong topographic control on the Late Wisconsinan ice by the northeast trend of the bedrock structure in the area. For example, Hussey (1981, 1985) maps the trend of the Flying Point fault along Maquoit Bay just east of Bunganuc bluff. Marine seismic surveys by Kelley et al. (1987) in the bays east of the bluff show that depth to bedrock in the bay troughs is over 200 feet (90 m) deep in places. These data suggest that ice preferentially flowed along the northeast-trending troughs, in which less resistant, brittle-faulted rock is found. At some localities, the southwest-oriented striae are younger than the dominant southeast set. However, this relationship has not been seen consistently enough to warrant regional merit, and in places in the area the reverse age-sense of cross-cutting striae has been noted.

There are few exposed ice-marginal glacial deposits in the Freeport quadrangle, however, their distribution and orientation on the mainland reflects the flow of ice indicated by the striation direction data. The moraines and glaciomarine fans occur along a trend nearly perpendicular to the striation directions and indicate that the glacier withdrew from the coastal zone as a nearly east-west trending, progressively retreating, active ice sheet, with its margin grounded in a glaciomarine environment.

Ice recession from the Gulf of Maine probably began sometime around 17,000 yr B.P. and had retreated to near the Freeport area by about 13,000 yr B.P. (Smith, 1985; Smith and Hunter, 1989). Uncorrected radiocarbon dates in the immediate area provide minimum dates for the deglaciation of the region. The oldest published date (12,560 $\pm$ 160 yr B.P.; Y-2212) on shells from a gravel pit in Lisbon Falls indicates that the Freeport quadrangle was deglaciated prior to this time (Stuiver and Borns, 1975; Smith, 1985). However, a date from the adjacent Lisbon Falls quadrangle (14,045 $\pm$ 95; AA10164; Weddle et al., 1993) provides an older minimal date for initiation of deglaciation in the area.

During the retreat of the glacier from the Freeport region, the ocean was in contact with the ice margin. Pleistocene sea level at the time of deglaciation in the study area was approximately 280-290 feet (85 m) above modern sea level (Thompson et al., 1989). As the ice margin passed through the Freeport quadrangle, all the present-day land was completely submerged. However, the ice was pinned on bedrock highlands and was grounded in the intervening low areas as indicated by the moraines and inferred ice marginal positions. At the ice marginal positions, end moraines and fans comprised of subaqueous outwash represent deposition by ice-tunnel or stream discharge, or by ice-push at the margin (Ashley et al., 1991). Two mapped ice-margins based on reasonable correlations of surficial deposits and subsurface data are shown in the northwest corner of the quadrangle, and two groups of ice-marginal deposits infer the ice-margin position in the center of the quadrangle. The deposits are regularly younger from south to north, reflecting the systematic retreat of the ice in the quadrangle. The correlations and approximate age of the deposits are schematically represented on Figure 2.

The oldest positions identified are the series of moraines and submarine fan deposits on Flying Point and Flying Point Neck (Pemfp, Pmffp). Exposures along the coast show these deposits to be sandy diamicton and sand overlain by the Presumpscot Formation. On the Flying Point peninsula east of Brickyard Cove, an abandoned pit in a moraine contains sandy diamicton over striated bedrock. Along the northeast shore of Flying Point, pebbly sand and medium- to fine-grained sand over striated bedrock are exposed at the wave-cut base of slopes. These sandy units are interpreted as subaqeuous stratified drift associated with the moraine.

The next inland position of the ice margin is represented by the small Goose Point moraine (Pemgp) and the Winston Hill fans and end moraine ($Pmfwh_{1,2}$, Pemwh). These positions are inferred by surface morphology and sediment texture in poor exposures in abandoned pits. The Goose Point moraine and the Winston Hill deposits are not correlated along an ice-marginal position on the surficial geology map, however, because they are found at nearly the same latitude, they probably were formed at nearly the same time during deglaciation and are tentatively correlated (Figure 2).

A small, very poorly exposed section of sandy diamicton under subaqueous outwash (Pmfbp) at the west end of Bunganuc Point may mark a nearby ice margin. Most of the section is overlain by the Presumpscot Formation, and there is no surface expression of an ice-marginal deposit here. The timing of the deposition of this subaqueous outwash as noted on Figure 2 is questionable, but it is probably younger than the Goose Point and Winston Hill deposits.

The moraines (Pemmb) in Merrill Brook valley are correlated with the moraine just south of the railroad embankment over Frost Gully ($Pemfg_1$) northeast of Freeport center and reflect the next ice-marginal position. These moraines may correspond to buried fan deposits in Mill Stream valley identified by Gerber (1979) as a discontinuous esker system. The discontinuous nature of the esker system most likely reflects the sequential retreat of the ice margin. Coarse-grained deposits in boring records mark the position of fans and associated esker feeders at the ice margin. They are separated by fine-grained glaciomarine deposits along the valley trend, which represent more distal deposits between consecutive ice margins. The tentative positions of the ice margins associated with these deposits cannot be verified by surface morphology because they are buried by thick Presumpscot Formation. However, the Merrill Brook - Frost Gulley margin is tentatively continued eastward to Mill Stream, based on the thick subaqueous outwash sand units encountered in borings along Mill Stream and by the distal fan deposits at the old mill site at Mast Landing (Pmfml). The Mast Landing deposits are probably somewhat older than the Merrill Brook - Frost Gully deposits.

The next ice-marginal position can be traced from the fan just south of Hedgehog Mountain (Pmfhm), through a series of moraines and an abandoned gravel pit in Frost Gully ($Pemfg_2$) north of Route 1, to the Pleasant Hill fan (Pmfph). The Pleasant Hill fan is the largest of a series of fans exposed in gravel pits in Mill Stream valley which continues to the northeast in the adjacent Lisbon Falls South quadrangle. These pits are poorly exposed due to slumping and overgrowth, however, they mark ice-marginal positions in that quadrangle.

The Presumpscot Formation (Pp) was deposited coeval with the ice-marginal deposits. These sediments settled out both near and beyond the margin of the ice, and can be found interfingering with the fan sediments or as a blanket draping older deposits. Fossils in the Presumpscot Formation were found only at the Harpswell Neck site in the Freeport quadrangle. However, shell fragments have been reported by a homeowner in wash from a water well boring along Upper Mast Landing Road which penetrated 120 feet (36 m) of overburden.

Local uplift due to isostatic rebound occurred during deglaciation and resulted in regression of the glacial sea. An uncorrected radiocarbon date of 12,820 $\pm$ 120 (SI-7017) on in-situ intertidal fauna is reported by Retelle and Bither (1989) from nearshore deposits at an elevation of 152 feet (46 m) asl in a gravel pit in Topsham (Brunswick 7.5-minute quadrangle). This date appears anomalously old for the marine regression in this region when compared to other dates (Smith, 1985). However, an uncorrected date from the same pit on *Portlandia arctica* shells found stratigraphically below the intertidal fauna sets minimal deglaciation at the site at 13,315 $\pm$ 90 yr B.P. (AA10162; Weddle et al., 1993), and the date from the Harpswell Neck site (12,850 $\pm$ 45 yr B.P.) supports the older offlap date.

During this relative fall of sea level, nearshore and shoreline deposits were formed. At times during the regression, sea level was stable long enough for sand plains to form, such as the plain in Brunswick which occurs at about 100 - 50 feet (30 - 15 m) asl. Pleistocene beach ridges on Harpswell Neck are found within this elevation range. When the 150 - 50 feet (46 - 15 m) elevation range is plotted against time on a local relative sea level curve for Maine (Kelley et al., 1992), the age of features which represent shoreline deposits found in this elevation range is between 11,900 - 11,500 yr B.P. The timing of the regression suggested by the sea level curve is significantly younger than the uncorrected radiocarbon dates on the shells from the Topsham pit, which infer the time of formation of the nearshore deposits to be closer to 13,000 yr B.P. rather than 12,000 yr B.P.

As noted previously, the bluff located west of Bunganuc Point at the outer extremity of the Brunswick sand plain has been described by Belknap et al. (1989) and Belknap and Shipp (1991) as draped glaciomarine mud deposited near the ice-grounding position. However, the exposures along the bluff suggest a time-transgressive history for the origin of the more than 70 foot (21 m) thick section reported at the site (Devin and Sandford, 1990). At the west end of the section, pegmatitic bedrock with southeast-oriented striae is overlain by sandy diamicton and sand, which is poorly exposed. Material above this is obscured by slump and overgrowth. Eastward, near the top of the section is 6 to 8 feet (2 - 2.5 m) of fine-grained sand containing clay rip-up clasts. The clasts are found in erosional channels cut into underlying stratified sand, silt, and clay with syndepositional slump structures. Draping or warping of beds in the lower part of the section at the western end is present and may reflect a shallow bedrock surface. In another channel farther east along the top of the bluff, stratified sand and silt beds are displaced by normal faults which do not penetrate into the underlying deposits.

Beneath the channels and the upper sandy portion of the bluff, dominantly muddy sediments are present, best exposed at the east end of the section. These lower deposits at Bunganuc are thin, well-stratified, and laterally continuous silt and clay beds, with silty fine sand laminations, and rare dropstones.

Southwest-oriented striae on diabase bedrock are exposed at the waterline at the east end of the bluff.

Rather than representing a single depositional environment, the complete section at Bunganuc bluff (including subsurface data) records changing environments over time. An ice-marginal component (till overlain by subaqueous outwash) is present at the western end, overlain by a thick, muddy, distal glaciomarine fan or submarine plain component (central and eastern end of section), in turn overlain by nearshore and possibly in part fluvial deposits (sandy, channeled upper section at western end), finally capped by eolian material.

By the time the Brunswick sand plain was deposited, the nearest glacial ice should have been well out of the lower Androscoggin River valley (Stone and Borns, 1986). Reconnaissance study in the adjacent Brunswick quadrangle and extensive test-boring data from the Brunswick Naval Air Station Superfund Site reveal that the fluvial deposits of the sand plain overlie fine-grained deposits (interbedded sandy silt and silty sand, over massive silt and clay) similar to that present at Bunganuc (subsurface data from Brunswick Naval Air Station Superfund Site; Draft Final Feasibility Study, ABB Environmental Services Inc., November 1991). These relations suggest the interbedded sand and silt underlying the sand plain may be associated with the deposition of the sand plain during the marine regression, analogous to the Embden Formation of Borns and Hagar (1965) and offlap units of the Leda Clay described by Gadd (1986). Detailed mapping in the Brunswick quadrangle may confirm whether the upper Bunganuc sediments are shoaling deposits laid down as the region came through wave base during isostatic rebound, or are estuarine sediments related to the postglacial Androscoggin River as it entered the sea.

As sea level reached its lowest level, the present day drainage became established. Deep erosion in the glaciomarine mud, such as the gullies found north of Bunganuc Point and Frost Gully north of Freeport also formed during this time. Many of these gullies have downcut to bedrock as at Frost Gully at the railroad crossing and Mill Stream at Mast Landing. Most of the gullies are floored by wetland deposits; however, a thin veneer of Holocene alluvium (unmapped in this quadrangle) is present along stretches in some valleys. Due to the 20-foot (6 m) contour interval on the quadrangle, the topographic expression is not well represented. Most gullies have steep sidewalls bounding a broad, flat-floored valley, in which streamflow during floods can be dramatic. Slumping and erosion of the gully sidewalls during floods is a modern process; however, most of the gully erosion probably occurred during late-glacial time prior to vegetation.

After reaching its lowest level, sea level began to rise resulting in aggradation within river channels and drowning of the channels to form estuaries such as the Harraseekett River, and Maquoit and Middle Bays. Modern salt marshes and beaches are forming in these environments at present. Similarly, fresh water marshes and soils have been forming since the exposure of the land to terrestrial conditions. The coastal evolution is also a response to the drowned coastline. Wave energy produces bouldery shores where bedrock is exposed at the coastline, mudflats where the Presumpscot Formation is dominant, and where sand supply is available, spits, tombolos, and sandy beaches are present (Kelley, 1987). Kelley et al. (1987, 1990, 1992) provide a discussion of the offshore submarine geology of the Casco Bay region including the Freeport quadrangle.

Recent mass movement features are common at the coast where landslides of the Presumpscot Formation occur, supplying sediment to adjacent mudflats (Kelley, 1987; Novak, 1987, 1990). Long-time residents of the Bunganuc area in Brunswick recount slumping as a very common occurrence, and note significant changes to the coastal bluffs there over the years. On the west shore of Wolf Neck south of the "Wolf" benchmark are several very large boulders which have spalled from the bedrock coast. The largest of these is at least 6250 ft^3 (1893 m^3) in dimension.

Archeology

The University of Southern Maine Department of Geography-Anthropology has been actively conducting prehistoric and historic archaeological investigations in the Freeport area since 1987. There are several shell midden locations along the coast in the Freeport quadrangle, part of the Casco Bay archaeological research area described in Sanger and Kellogg (1989). The middens are associated with inhabitants from the Ceramic Period (3,000 to 500 yr B.P.; pers. communs., 1992, A.E. Speiss, Maine Historic Preservation Commission; N.D. Hamilton, University of Southern Maine). However, artifacts from the Late Archaic Period (5,000 to 3,000 yr B.P.) have been found (Sanger and Kellogg, 1989). Also, a Paleoindian fluted point was found at the Desert of Maine in Freeport (Yarmouth quadrangle), reported in a survey of isolated fluted points from Maine (Spiess and Wilson, 1987).

Economic Geological History

Abandoned or exhausted sand and gravel mining and rock quarrying operations in the Freeport quadrangle attest to active prospects in the past. The only active operation is in a gravelly Pleistocene beach deposit in Harpswell adjacent to the military fuel depot, however, this deposit is not of major commercial importance. While there is active mining within Freeport town boundaries, all activities are found in the adjacent Lisbon Falls South and Yarmouth quadrangles. The largest rock quarry operation in the Freeport quadrangle was the E.B. Mallett quarry on Torrey Hill, active circa 1900 A.D. Mr. Mallett was a local benefactor to the town of Freeport and also maintained a brickyard in the downtown. Other locations of brickworks include sites at Mast Landing and Brickyard Cove in Freeport, in the Bunganuc area in Brunswick, and at Brickyard Road, Stovers Cove, Harpswell.

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