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Surficial Geology of the Cape Elizabeth 7.5-minute Quadrangle, Cumberland and York Counties, Maine

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INTRODUCTION

Surficial mapping in the Cape Elizabeth 7.5 minute quadrangle was conducted during the summer of 1987 as part of the COGEOMAP program of the Maine Geological Survey and the United States Geological Survey. The purpose of this cooperative program is to provide detailed surficial geological information for the Coastal Lowlands geomorphic province, an area undergoing rapid urban growth due to its proximity to Portland, Maine, and its popularity as a residential area for commuters working in the Boston metropolitan area. For each quadrangle mapped as part of this program, two 1:24,000 maps are prepared: a surficial materials map (Clinch and Thompson, 1999a) which shows the thickness, composition and interpreted origin of surficial materials at points where surface and subsurface observations were made, and a surficial geologic map (Clinch and Thompson, 1999b) showing the distribution of geologic units and (where possible) features that record the Quaternary geologic history of the quadrangle.

In this report, the surficial deposits mapped in the Cape Elizabeth quadrangle are described in detail, and the glacial and postglacial history of the quadrangle is presented. An appendix is also included, which describes the surficial materials detected in subsurface test borings made as part of site investigations for sewers and highways in Cape Elizabeth.

PREVIOUS WORK

Surficial deposits in the Cape Elizabeth quadrangle were mapped by Thompson (1976) based on reconnaissance mapping and examination of active gravel pits, and by Smith (1980), who relied chiefly on air photo interpretation. These data were used to prepare the Surficial Geologic Map of Maine (Thompson and Borns, 1985a).

Information concerning the composition and origin of glacial and postglacial deposits in the region is given in Bloom, (1960, 1963), Smith (1982, 1984, 1985), Stuiver and Borns (1975), Thompson (1982), Thompson and Borns (1985b), and Belknap and others (1987). Five quadrangles south and west of the Cape Elizabeth quadrangle have been mapped as part of the COGEOMAP program, including the Dover East (Smith, 1999a,b), Portsmouth (Smith, 1999g,h), York Harbor (Clinch and O'Toole, 1999a,b), York Beach (O'Toole and Clinch, 1999c,d) and Kittery quadrangles (O'Toole and Clinch, 1999a,b). In addition, Neil (1999) and Smith (1977, 1999c-f,i,j) have mapped the four 7.5 minute quadrangles comprising the Kennebunk 15-minute quadrangle, and detailed mapping for the COGEOMAP program is being conducted in the other nearby quadrangles shown in Figure 1. Information obtained from these detailed maps was useful in interpreting the deposits and stratigraphic relationships observed during this mapping.

The elevation of glacial-marine deltas and other marine limit indicators were measured and reported by Thompson and others (1989), and the upper limit of the postglacial marine transgression was interpreted from these data. While no data were available from the Cape Elizabeth quadrangle, a marine limit elevation of 240 to 260 feet is estimated from data in nearby areas. This reconstruction indicates that the entire Cape Elizabeth quadrangle was flooded during glacial retreat, and that all of the ice-marginal deposits within the quadrangle were formed in a submarine environment at or beneath a calving glacier margin.

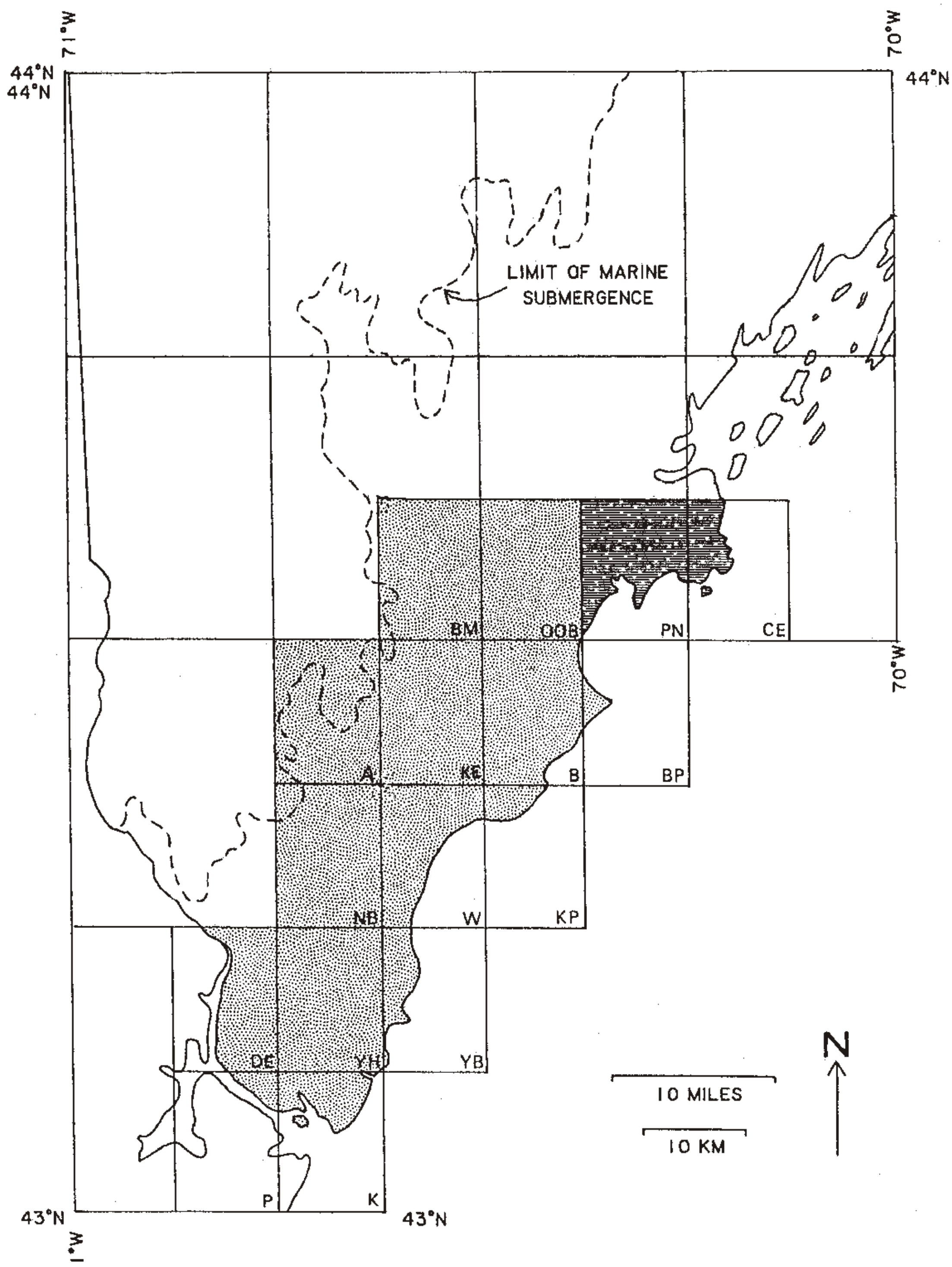

Figure 1. Location map showing the Prouts Neck and Cape Elizabeth quadrangles (lined pattern). Other quadrangles mapped in detail through 1987 are shown in the dot pattern. Quadrangle names are as follows: A - Alfred, BM - Bar Mills, B - Biddeford, BP - Biddeford Pool, CE - Cape Elizabeth, DE - Dover East, KE - Kennebunk, KP - Kennebunkport, K - Kittery, NB - North Berwick, OOB - Old Orchard Beach, P - Portsmouth, PN - Prouts Neck, W - Wells, YB - York Beach, YH - York Harbor.

LOCATION AND TOPOGRAPHY

The Cape Elizabeth 7.5' quadrangle extends from 43° 30'N to 43°37'30"N and from 70°07'30"W to 70°15'W, and covers an area of 54 square miles, of which approximately 80% is covered by the ocean. The quadrangle is located on the coast of Maine in Cumberland County. This area is immediately south of Portland, the largest city in Maine, and is the site of rapid development.

Elevations within the study area range from sea level to a maximum elevation of 133 feet above sea level. The maximum local relief is approximately 100 feet at several sites along the seacoast. While there are only limited amounts of local relief, many slopes in the quadrangle are quite steep.

Most of the quadrangle is drained by tributaries of the Spurwink River. The lower reaches of this river have been drowned during Holocene marine transgression and are now estuaries occupied by salt marshes. The remainder of the quadrangle is drained by Alewife Brook, Trout Brook, and other small, unnamed creeks.

BEDROCK GEOLOGY

The distribution of bedrock units in the Cape Elizabeth and neighboring Prouts Neck quadrangles was mapped by Hussey (1985). Bedrock exposed within the region includes a variety of metamorphic lithologies of the Casco Bay Group. The formations of the Casco Bay Group, and gross lithologies of each unit are (Hussey and others, 1986):

Macworth Formation - (uppermost unit) fine-grained, slightly calcareous and feldspathic, thinly laminated gray granofels, with sporadic thin beds of metafelsite tuff and coarse granule beds.

Jewell Formation - rusty and non-rusty weathering, gray phyllites with minor greenish gray chlorite phyllite.

Spurwink Metalimestone - thin, ribbon bedded, gray impure marble and quartz-biotite-plagioclase granofels.

Scarboro Formation - rusty and non-rusty weathering, gray phyllites with minor greenish-gray chlorite phyllite, lithologically identical to the Jewell Formation.

Diamond Island Formation - rusty weathering graphite-quartz-muscovite phyllite with tissue-thin quartz laminae parallel to foliation.

Spring Point Formation - a varied sequence of mafic metavolcanic, metasedimentary and felsic metavolcanic rocks, metamorphosed from chlorite grade (chlorite-spessartitic garnet phyllite) to garnet grade (biotite-actinolite-plagioclase gneiss).

Cape Elizabeth Formation - thin-bedded quartz-plagioclase-biotite phyllite, schist, or gneiss, metamorphosed from chlorite to K-feldspar - sillimanite grade, with interbeds of metapelite, rusty phyllite and schist.

Cushing Formation - (lowest unit) felsic to intermediate metavolcanics and medasedimentary rocks, with lesser mafic metavolcanics, calc-silicate granofels, marble and sulfidic schist.

The Casco Bay Group is dated as Precambrian to Ordovician(?) in age. These units have undergone one major deformation, which produced north-northeast trending upright folds with gentle plunges. Evidence for an earlier stage of deformation is locally observed in the Cape Elizabeth Formation, but has not been observed in the other units. Bedding, differential weathering along more easily erodible lithologies, and structural features all impart a strong northeast to southwest trending grain to the topography, clearly visible in the bedrock ridges in the quadrangle and in projecting bedrock points along the shoreline.

INVESTIGATION PROCEDURE

Most of the Cape Elizabeth quadrangle is underlain by bedrock, with only a thin (less than 10 feet) veneer of Quaternary deposits. Exposure of surficial deposits within the Cape Elizabeth quadrangle is poor and has deteriorated since earlier mapping by Thompson (unpub. field notes, 1976). The best exposures were located in active and inactive gravel pits north of Great Pond and adjacent to the Spurwink River, but these pits have been graded and covered by housing developments. No excavated pits exist south of Great Pond, as the majority of the land is closed to development, either as land which is part of the Land Bank (the Sprague Corporation properties) or as part of Crescent Beach and Two Lights State Parks.

In addition, wave activity during the Pleistocene marine recession has reworked sediments exposed on hillcrests and slopes and produced a blanket of sand and gravel several feet thick over virtually all areas not covered by Presumpscot Formation clays or Holocene deposits. This sand and gravel blanket completely masks the presence of underlying units in shallow shovel excavations, auger holes and even some shallow foundation excavations. This wave activity has also smoothed the topography of many of the Pleistocene deposits to such an extent that deposit morphology cannot be used reliably to infer the distribution of glacial deposits or interpret the recessional history of the glaciers that occupied this area.

Finally, the majority of elevated locations have been developed, including virtually all sites underlain by submarine fans or end moraines. The sites which have not been modified by culture are usually those flats underlain by Presumpscot Formation silty clays or by wetlands, which are less suitable sites for residential development.

These three factors severely limit the amount of field exposure of glacial and glaciofluvial deposits. Therefore, field work was largely limited to observation of the few active gravel pits, and mapping of the location of exposed bedrock outcrops and the distribution of Presumpscot Formation marine sediments, Pleistocene alluvium, and Holocene wetlands and beach deposits. The remaining areas were assumed to be either Wisconsinan till, end moraines, or submarine fan deposits, but the true composition and distribution of these deposits could not be accurately determined.

The surficial geologic map was prepared by plotting all contacts mapped in the field and adding the point data obtained from field observations, unpublished field notes by Thompson, and sewer and road borings. This data was supplemented by contacts inferred from analysis of stereo photographs, which were chiefly useful in refining the limits of units first detected from the field data. A number of presumed ice marginal deposits were also inferred from the air photos, including probable DeGeer moraines located north of the Spurwink River.

Due to the large number of mappable ice-marginal deposits present within the neighboring Prouts Neck quadrangle (Clinch and Thompson, 1999c,d) and the correlations between these ice margins that can be supported, the ice-marginal deposits were mapped as morphosequences (Koteff, 1974; Koteff and Pessl, 1981). Submarine fans and end moraines in both quadrangles were given unique geographic names. Since correlations were often made from deposit to deposit by reasonable reconstruction of the ice margin parallel to better constrained ice margins, and not because the deposits are continuous, the same name was not used along any single ice margin, so that the correlation can be changed should new information require such a change. The correlations made between mapped deposits are indicated by the dashed ice margin lines on the map, and by the correlation chart shown in Figure 3. Finally, two marine fan deposits located in the quadrangles north of the mapped area were also included.

Wetland boundaries for this quadrangle were mapped in part by Cornelia Cameron, U. S. Geological Survey. Additional information concerning the distribution of wetlands deposits was provided by inspection of the National Wetlands Inventory Map of the Cape Elizabeth quadrangle, prepared by the Office of Biological Services, U. S. Fish and Wildlife Service, Department of the Interior. Unit contacts were modified from this mapping by field observations and by air photo analysis.

SURFICIAL DEPOSITS

The composition and distribution of the mapped units is listed below. The descriptions are based primarily on field observations, supplemented where necessary with the test boring data.

Bedrock

Bedrock (mapped as rk) has been mapped solely along the modern shoreline, where it is exposed either in cliffs 20 to 40 feet high, or as wave-cut marine terraces at the base of these cliffs, which are emergent at low tide. Minor outcrops are present near the crests of many of the bedrock ridges covered by thin drift, and these are shown by a pattern on the surficial geologic map.

Thin Drift Areas

Most hillslopes at elevations greater than 20 feet are underlain by less than ten feet of surficial material over bedrock, shown by the horizontally ruled pattern superimposed over Pt (Pleistocene till). These areas were mapped in the field on the basis of the abundance of bedrock outcrops, supplemented by test boring data, but the chief criterion used to determine the limits of this unit was whether or not the underlying bedrock structure was visible on the air photos. The dominant surficial lithology within these areas is till, with lesser amounts of Presumpscot Formation clays and marine nearshore sand deposits. Till exposures are most common on ridge crests and consist of diamictons with a silty-sand matrix. These diamictons are cobbly to bouldery, often with a cobble to boulder lag at the land surface, indicative of winnowing by wave activity during marine recession. Thin layers of Presumpscot Formation marine silty clays overlie the till in hollows and depressions. On steeper slopes, both the till and the Presumpscot Formation are overlain by thin (2-5 ft) sands and gravels, interpreted as nearshore deposits formed during marine recession when the till matrix was eroded by wave activity. Small bedrock outcrops and larger areas of numerous small outcrops are present near the crest of many ridges and hills. These are indicated by solid black areas.

Wisconsinan Till

Few mappable till units were detected in the Cape Elizabeth quadrangle. Thin till occurs in much of the area mapped as thin drift, but wave activity during the marine recession has extensively reworked these tills, so that no definitive origin can be interpreted. Till is also present in the proximal faces of the end moraines, discussed below.

End Moraines

End moraines have been mapped in numerous locations throughout the quadrangle, chiefly on the basis of air photo analysis. Uncorrelated end moraines have been mapped as Pem, while those that can be correlated to other nearby ice marginal deposits are assigned a local geographic name, and a five letter designation consisting of a single-letter age designator (P, for Pleistocene), “em” for end moraine, and a two-letter location designator (eg. gp for Great Pond). Typically, these moraines are located between bedrock knobs.

A group of end moraines was mapped immediately north of the Spurwink River, and west of the community of Pond Cove, the Pond Cove end moraines (Pempc). These end moraines are small, with heights of no more than 10-15 feet, widths of approximately 100 feet, and exposed lengths of approximately 1000 feet. In a gravel pit exposure on a moraine ridge immediately north of the Spurwink River (now graded and developed), 10 feet of clast-rich lodgment till interfingers with and overlies washed sand and gravel. These units are in turn overlain by Presumpscot Formation silty clay. Smith (1982), Smith and others (1979), and Jong (1980) have described the internal structure of similar moraines in coastal areas of Maine and have noted that most exposed moraines consist of interbedded pebble to cobble gravels and fine to coarse sand, intensely deformed by ice-push, although till moraines were also observed. These moraines are usually overlain by Presumpscot Formation clays and nearshore sands. In the Cape Elizabeth quadrangle, all moraines were mapped on the basis of morphology, and the composition of the overlying sediments that partially masked the moraines was ignored.

Two larger end moraines were mapped, chiefly on the basis of the deposit morphology. The Great Pond end moraine is a ridge located northwest of Great Pond and is the site of Fowler Road. No exposures are now present on this end moraine, but till was observed in building foundations by Thompson (unpub. field notes, 1976). The Richards Pond end moraine forms the ridge separating Great Pond from Richards Pond. Again, no exposures are present in this moraine, but till was observed in spoil piles adjacent to newly constructed houses on the northern (ice-proximal) side of the ridge. Surface sediments on this moraine consist of reworked nearshore sands adjacent to thin drift exposures and raised beach sediments along the crest of the ridge. Consequently, this unit was mapped using a “sandwich” designation, Pms-Pmn/Pemrp.

Submarine Outwash Fans

Submarine outwash fans have been mapped at two sites in the Cape Elizabeth quadrangle. As they are associated with the two large end moraines, they were given the same geographic names as the end moraines, and are differentiated from the end moraines as “mf”, for marine fan, instead of “em”, for end moraine. No exposures are now present in these marine fans, but based on the exposures and subsurface data obtained in the neighboring Prouts Neck quadrangle, these fans are composite units and include not only sand and gravel, but also significant amounts of till at the proximal margin of the fan, thick layers of Presumpscot Formation silty clay interbedded with and overlying the submarine fan sand and gravel, and a surface blanket of nearshore deposits reworked from the underlying materials by wave activity during marine regression.

Idealized cross sections of a typical large end moraine and submarine fan are shown in Figure 2. The composition and structure of the submarine fans is similar to that of the larger end moraines. Till occurs only in the proximal parts of these features, and the bulk of the sediment is composed of sand and gravel. The distinction between the features is probably arbitrary and was made here primarily on the basis of the form of the outcrop and subcrop pattern; linear features were called end moraines, while more elliptical to equant features were called submarine fans. In many cases, end moraines were mapped adjacent to prominent marine fans, and the boundaries between them are arbitrary.

These submarine fans are thought to be formed from fluvial debris transported in subglacial tunnels, and deposited at the ice margin at the mouth of these tunnels. Unpublished mapping by the senior author at modern marine glacier termini suggest that fans and deltas the size of those found in the Cape Elizabeth quadrangle can form in as short a time as a decade.

Presumpscot Formation

Thick silts and clays of the Presumpscot Formation (mapped as Pp) underlie low-relief areas north and south of the Spurwink River, along several of the minor streams and in flats atop bedrock highs. The clays disconformably overlie till and bedrock, and are interbedded with and conformably overlie end moraine and submarine fan deposits, as was previously discussed. The Presumpscot Formation consists of massive to laminated silty clays, with rare ice-rafted clasts. Unoxidized Presumpscot Formation clays have a blue-gray color and are characterized by their low bearing capacity; in some places, probes through unweathered Presumpscot Formation can penetrate the clay simply due to the weight of the hammer placed atop the probe. Weathered Presumpscot Formation is an oxidized olive gray to green color, and has a higher bearing capacity and resistance to penetration.

The Presumpscot Formation consists of silts and clays delivered to the glacier terminus by subglacial fluvial activity. Coarser sand and gravel is deposited at the mouths of these tunnels as submarine fans, while the finer silt and clay are transported farther from the ice margin, where they eventually settle out as blankets of marine clay that preferentially infill topographic lows and cover all but the steepest slopes.

Nearshore Deposits

Following deposition of the Presumpscot Formation, all surficial materials were winnowed and reworked by wave activity during marine recession. This reworking is recorded by a thin to thick blanket of reworked sand, sand and gravel, or silty sand covering virtually all hillslopes and the flats adjacent to these hillslopes, mapped and interpreted as nearshore deposits (Pmn). This layer is detected in virtually all natural exposures and test borings, as noted in the logs appended to the surficial materials map, but it was only included on the surficial geology map where it completely obscures and masks the older ice-contact deposits.

While these deposits are the result of wave activity along or near ancient shorelines, they are not mapped as beaches, because they are not associated with definite beach morphology. Beach morphology related to a Pleistocene shoreline is possibly preserved at only one site, atop the Richards Pond end moraine, where thick beach and dune sands are present atop the moraine at elevations above modern shoreline deposits.

Holocene Alluvium, Estuarine Sediments, and Wetland Deposits

Holocene wetland deposits have been mapped over much of the lowlands within the quadrangle. The largest wetlands are the salt marshes developed in the drowned estuaries along the Spurwink Rivers and its tributaries. Test borings across similar marshes in the Prouts Neck quadrangle indicate that the Presumpscot Formation silty clays exposed in the scarps fringing

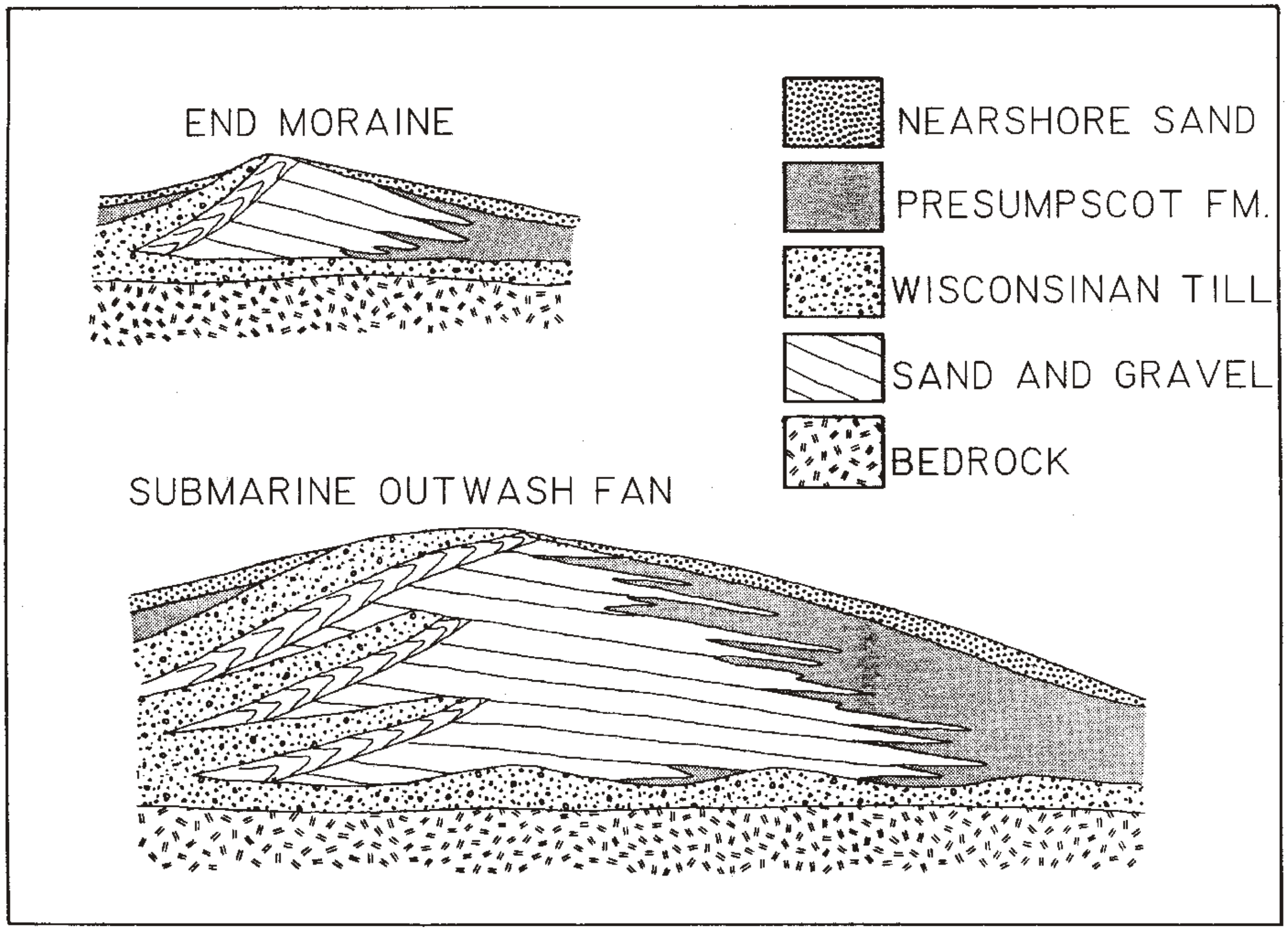

Figure 2. Idealized cross sections of the larger end moraines and submarine outwash fans in the Prouts Neck quadrangle, based on pit exposures and subsurface test boring data. This illustrates how similar the two types of deposits are.

the salt marshes were removed by fluvial erosion to a depth of at least 20 feet below sea level during a relative low stand of sea level. During the subsequent marine transgression, these rivers were drowned, the valleys were filled by estuarine sands and muds, and the salt marshes developed atop these estuarine sediments. Other wetlands mapped include the swamps and marshes surrounding Great Pond, swamps along the courses of some of the minor drainages, and a large swampy area southwest of Great Pond where a swamp is developed in thin sediments overlying bedrock.

All wetland deposits were distinguished on the basis of whether the water in these areas is brackish or salt (salt marshes, Hwsm), or fresh (all other wetlands), and by the vegetation present in these areas: grasses and sedges (salt marshes, Hwsm, and freshwater marshes, Hwfm), bushes and scrub brush (heaths, Hwh), or trees (swamps, Hws). Suffixes are used to describe the abundance of peat in the wetlands, with p designating over 5 feet of commercial quality peat (ash content less than 25%, dry basis), t designating less than 5 feet of commercial peat, or any thickness of non-commercial peat, and no subscript to designate a mineral substrate.

Holocene Beach Deposits

Modern beaches, mapped as Hms, are mapped along the modern shoreline. The largest beach mapped is Crescent Beach, developed in a protected cove between bedrock capes. Other small pocket beaches mapped along the coast are also formed in protected coves between projecting rock spurs and consist largely of cobbles and boulders.

GLACIAL AND POSTGLACIAL HISTORY

While it is almost certain that numerous glaciations have helped to shape the coastal area of Maine, there is no evidence within the Cape Elizabeth quadrangle that can be used to demonstrate these older glacial events. All deposits mapped within the quadrangle or detected in subsurface test borings were deposited during the most recent glacial advance-retreat cycle in Late Wisconsinan time, or during postglacial time.

Striation directions measured within the Cape Elizabeth and adjoining Prouts Neck quadrangle are nearly unidirectional, with ice flow directions varying between 160° and 175°. No crossing striations were noted.

Regional studies indicate that ice completely covered the Gulf of Maine during the last glacial maximum. Retreat probably began approximately 17,000 yr B. P., and the ice margin may have been near the coast of Maine at approximately 14,000 yr B. P. No radiocarbon dates have been obtained from deposits in the Prouts Neck or Cape Elizabeth quadrangles, but dates limiting the time of deglaciation are available from nearby areas. Smith (1985) describes the stratigraphic implication of two dates obtained from exposures in the Kennebunk area, from Great Hill (13,830 ± 100, QL-192) and from the Kennebunk landfill (13,200 ± 120, Y-2208), which he interprets as dating the presence of the ice margin at these sites. If these dates are correct, reconstruction of the ice margin at that time demonstrates that the Cape Elizabeth quadrangle would have been covered by ice. Four dates have been obtained from shelly horizons in the Presumpscot Formation, exposed in the Portland West quadrangle, immediately north of the Cape Elizabeth quadrangle, 12,370 ± 140 (Y-2209), 12,350 ± 140 (Y-2210), 12,040 ± 105 (SI-3926) and 11,640 ± 115 (DIC-1595) (Smith, 1985). All of these are minimum dates for the deglaciation of the region, and demonstrate that the Prouts Neck and Cape Elizabeth quadrangles were deglaciated prior to approximately 12,500 yr B. P.

During glacial retreat through the Cape Elizabeth quadrangle, the glacier retreated by calving into open ocean waters which covered the entire quadrangle. While ocean levels worldwide were considerably lower than modern sea level due to the tremendous volume of water stored as ice in the continental glaciers, in Maine the land surface was isostatically depressed so that local sea level was higher than the modern sea level. Extrapolation of shoreline elevation data from neighboring areas suggests that the Pleistocene relative sea level was approximately 240-260 feet above modern sea level (Thompson and others, 1989).

Glaciers retreat in this environment by calving, or shedding icebergs at sites where the glacier had thinned sufficiently so that it started to float. Ice margins in such an environment are the reverse of what would be expected from sites with similar topography above the marine limit. Deeper water within topographic lows promotes more rapid calving retreat, leading to an embayed ice margin at these sites. In contrast, the glacier retreats more slowly over topographic highs, resulting in local promontories of ice at these sites. Ice marginal positions in a topographic low should therefore be concave downglacier, and the trace of successive positions typically pivots about particularly high points on either side of these valleys. This pattern for ice retreat is well displayed in the Prouts Neck and Cape Elizabeth quadrangles.

A total of fourteen successive ice marginal positions could be identified by reasonable correlations of the ice marginal deposits in the Prouts Neck quadrangle, and three of these could be identified in the Cape Elizabeth quadrangle, as shown in the correlation chart (Figure 3) and by the mapped ice margins shown in Figure 4. The mapped ice margins are designated by capital letters, A to N. Only the first four ice margins (A-D) are identified in the Cape Elizabeth quadrangle.

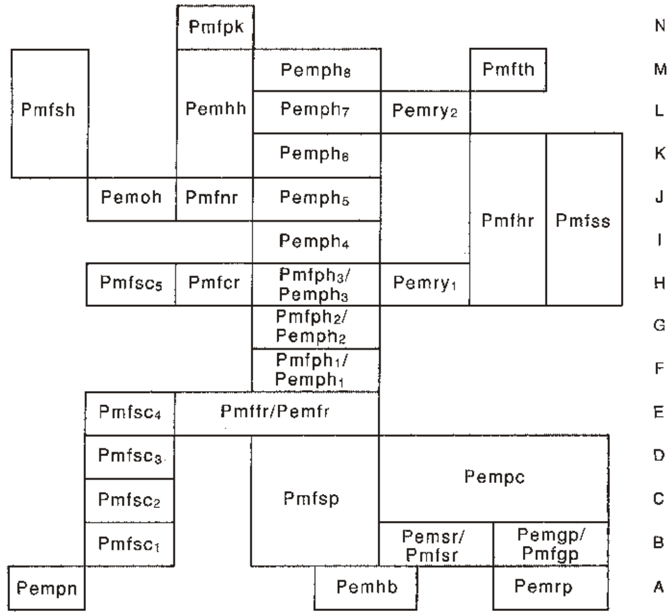

Figure 3. Correlation chart, showing which ice marginal deposits record successive retreat positions in the Prouts Neck and Cape Elizabeth quadrangles, and portions of the neighboring quadrangles. Each successive ice margin is designated by the letters A through N, which are used to label the ice margins in Figure 4.

The earliest ice margin (A) is defined by the Prouts Neck end moraine (Pempn), which underlies the unconsolidated deposits that connect Prouts Neck itself with the mainland. The ice margin is correlated with the Higgins Beach end moraine cluster (Pemhb), and tentatively correlated with the Richards Pond end moraine (Pemrp) in the Cape Elizabeth quadrangle, although this last correlation cannot be proven with certainty.

The glacier retreated rapidly up the valley of the Spurwink River and the Scarborough River and in the low now occupied by Great Pond, and less rapidly on the highlands between these lows. A second ice margin (B) is defined by the first of the Scarborough Center marine fans ($Pmfsc_1$), the Sanford Pit marine fan (Pmfsp), the Spurwink River marine fan and end moraine (Pemsr, Pmfsr), and the Great Pond end moraine and marine fan (Pemgp, Pmfgp) in the Cape Elizabeth quadrangle.The glacier remained pinned on the highlands adjacent to the Sanford Pit marine fan, while retreating in the lowlands adjacent to this highland. In the Scarborough River basin, at least two more small marine fan complexes were deposited ($Pmfsc_2$, $Pmfsc_3$), which define ice margins C and D, while a group of DeGeer moraines, the Pond Cove end moraines (Pempc), was formed north of the

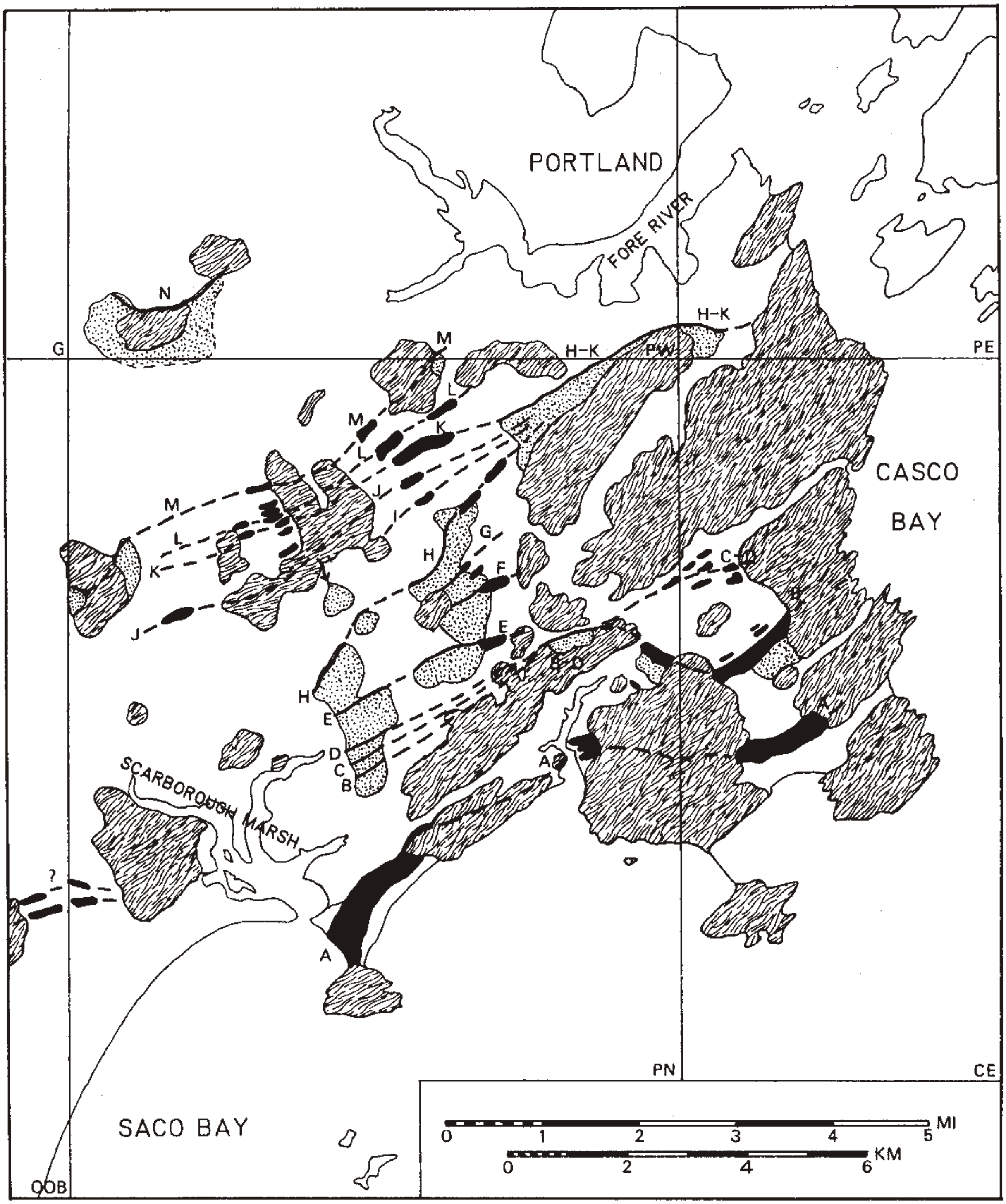

Figure 4. Sketch map of successive ice marginal positions in the Prouts Neck (PN) and Cape Elizabeth (CE) quadrangles, and portions of the Portland East (PE), Portland West (PW), and Old Orchard Beach (OOB) quadrangles. End moraines are shown in black, submarine fans are shown by the sand pattern and bedrock knobs are shown by the schist pattern.

Spurwink River. Following deposition of these units, the glacier retreated away from the coastal highlands. No younger ice marginal deposits were observed in the Cape Elizabeth quadrangle.

As the glacier occupied each of these ice-marginal positions in succession, coarse clastic debris was deposited in the immediate vicinity of the glacier margin, in the form of submarine outwash and/or till, now preserved as submarine fans and end moraines. Finer clastic debris delivered to the glacier margin in subglacial tunnels was more widely dispersed and was deposited beyond the glacier margin as the Presumpscot Formation. The pattern of glacial retreat in the area suggests that the position of the ice margin was largely or entirely controlled by local topography, with no evidence for climatically controlled readvances.

Local uplift, the result of isostatic rebound, took place during glacial retreat, causing a marine recession shortly after the glaciers left the area. Regional data reported by Belknap and others (1987) suggests that the recessional sea level reached modern sea level at approximately 11,000 yr B. P. During this recession, wave activity winnowed tills and other deposits mantling hillslopes, forming the blanket of nearshore deposits found on hillslopes and the flats adjacent to hills.

Relative sea level continued to lower, until approximately 9,000 yr B. P., as isostatic rebound continued to outpace eustatic sea level rise caused by the melting glaciers (Belknap and others, 1987). During this time interval, downcutting occurred along all of the major drainages to levels below modern sea level. Since 9,000 yr B. P., sea level has risen to its modern level, causing aggradation within the river channels, drowning of the lower portions of the channels to form estuaries now filled by salt marshes, and the formation of modern beaches.

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Appendix A: Surficial Materials of the Cape Elizabeth Quadrangle

J. Michael Clinch and Woodrow B. Thompson

Test borings were made for the Portland Water Authority in portions of the Cape Elizabeth Quadrangle, as part of sewer construction. The vast majority of test borings were probes to refusal, typically on bedrock in areas of thin drift cover. The location and probe depth of these borings were not recorded on the surficial materials map, nor are they listed here. For those few test borings where a description of the materials was provided, the thickness, composition and interpretation of the units encountered is provided below. The authors wish to thank Mr. Ian Robertson, the engineer in charge of construction of the sewer system, for providing access to the specifications and blueprints which contained the test boring logs.

APPENDIX A. SURFICIAL MATERIALS OF THE CAPE ELIZABETH QUADRANGLE.

Boring No.	Thickness (in feet)	Description of Subsurface Materials	Lithologic Interpretation
AB-1	6	fine sand, some silt	nearshore deposit
AB-2	4	fine sand, some silt	Wisconsinan till
		trace fine gravel	
	0.5	weathered rock	
		Refusal	
AB-3	5	fine sand and silt	Wisconsinan till
		trace fine gravel	
AB-22	10	fine to coarse sand	Wisconsinan till
		trace fine to coarse	
		gravel, trace silt	
AB-23	4	fine to coarse sand	Wisconsinan till
		little silt and fine	
		to medium gravel	
	3	fine to coarse sand	submarine outwash
		trace fine to coarse	
		gravel	
AB-28	3	silt	freshwater marsh
	2	silty sand	freshwater marsh
	2	fine to coarse sand	nearshore deposit
AB-29	3	artificial fill	
	2	fine to coarse sand	nearshore deposit
	4	silty clay	Presumpscot Formation
AB-30	1.5	silty clay	Presumpscot Formation
	1.5	silty clay	Presumpscot Formation
AB-31	8	silty clay	Presumpscot Formation
AB-32	6	clay	Presumpscot Formation
	1	gravel and clay,	Wisconsinan till
		trace sand	
AB-33	3	silty clay	Presumpscot Formation
	6	sandy clay	proximal Presumpscot
			Formation
AB-34	3	fine to coarse sand	nearshore deposit
		and silt, little	
		fine to coarse gravel	
AB-35	4.5	silt and fine to coarse	Wisconsinan till
		sand, trace fine to	
		coarse gravel and	
		occasional stones	
		Refusal	
B-1	3	fine to coarse sand	Wisconsinan till
		with gravel, some silt	
	5	fine to coarse sand	submarine outwash
		with gravel	
	3.5	fine to medium sand	submarine outwash
		Probed to 14.9 ft. - no refusal	
CB-21	3	fine to coarse sand	Wisconsinan till
		some fine to coarse	
		gravel	
	5	fine sand, some silt	Wisconsinan till
		trace fine to medium	
		gravel	
CB-22	7	silty fine to coarse sand	nearshore deposit
	3	silty fine sand	
CB-23	3	fine to coarse sand	nearshore deposit
		and gravel	
	5	fine to medium sand,	nearshore deposit
		little silt	
EF-7	3	fine silt	Holocene swamp
	5	fine sand and silt	nearshore deposit
		some clay	
EF-8	1	silt	Holocene swamp
	1.5	weathered rock	
		Refusal	
EF-8A	2	silt and some fine sand	nearshore deposit
	1	weathered rock	
		Refusal	
EF-8B	8	fine sand and silt	nearshore deposit
		some clay	
EF-9	3	silt	Presumpscot Formation
	7	silt and clay, trace	Presumpscot Formation
		fine sand	
EF-10	7.5	fine to coarse sand	nearshore deposit
	1	weathered rock	
		Refusal	
EF-11	6	silty fine to coarse sand	nearshore deposit
EF-12	7	silty fine to coarse sand	nearshore deposit
P-1	8	silty, gravelly sand	Wisconsinan till
		with cobbles	
	3	sandy silt with gravel	Wisconsinan till
P-2	6	artificial fill	
	4	sandy clayey silt	proximal Presumpscot
			Formation
P-3	4	artificial fill	
	3	clayey sandy silt	proximal Presumpscot
			Formation
	3.5	fine sand	submarine outwash
P-4	3	artificial fill	
	5	sandy silt with gravel	Wisconsinan till
		cobbles and boulders	
	0.25	weathered rock	
		Refusal	

APPENDIX A. SURFICIAL MATERIALS OF THE CAPE ELIZABETH QUADRANGLE.

Boring No.	Thickness (in feet)	Description of Subsurface Materials	Lithologic Interpretation
P-5	5	artificial fill	
	3	fine sand	nearshore deposit
P-6	2	artificial fill	
	4	sandy silt with gravel	Wisconsinan till
		Refusal	
P-7	3	artificial fill	
	6	fine to medium sand with silt	nearshore deposit
P-8	2	artificial fill	
	3	sandy silt, trace clay	nearshore deposit
	4	fine sand	nearshore deposit
P-9	3	artificial fill	
	5	fine sand	nearshore deposit
	1	sandy silt with gravel	Wisconsinan till
P-10	1	artificial fill	
	6.5	silty fine to medium sand	nearshore deposit
		Refusal	
P-10A	2	artificial fill	
	1	weathered rock	
		Refusal	
P-11	1	artificial fill	
	2	silty fine to medium sand	nearshore deposit
	1	weathered rock	
		Refusal	
P-14	4	silty, gravelly sand	Wisconsinan till
	3.5	weathered rock	
		Refusal	
PC-1	3	organic silt, trace sand	Holocene swamp
		Refusal	
SC-44	4	fine to coarse sand and gravel	Wisconsinan till
		Refusal	
SC-46	2	fine to coarse sand and gravel	nearshore deposit
	3.5	Fine sand, some silt trace fine to coarse gravel	Wisconsinan till
SC-53	3	fine to coarse gravel trace rock fragments	Wisconsinan till or nearshore deposit
		Refusal	
SC-63	4	fine sand	nearshore deposit
	3	fine to medium sand trace fine gravel	nearshore deposit
SC-67	3	fine to coarse sand and gravel	nearshore deposit
	3	fine sand and silt little clay	proximal Presumpscot Formation
SC-75	3.5	fine to coarse sand some fine to coarse gravel, trace silt	Wisconsinan till
		Refusal	
SC-77	1	fine to coarse sand	nearshore deposit
	3	weathered rock	
		Refusal	
SC-79	5	fine sand, some silt trace fine gravel	Wisconsinan till
	1	weathered rock	
		Refusal	
SC-155	7	fine to medium sand, some fine to coarse gravel, trace silt	Wisconsinan till
SC-157	5.2	fine to medium sand, some fine to coarse gravel, trace silt	Wisconsinan till
SC-159	7	fine to coarse sand and gravel, trace silt	Wisconsinan till
SC-193	1	weathered rock	
		Refusal	
SC-215	6	silty fine sand	nearshore deposit
SC-223	2	fine to coarse sand	nearshore deposit
		Refusal	
SC-225	6	fine to coarse sand	nearshore deposit
SC-227	6	fine to coarse sand	nearshore deposit
SC-229	7	fine to coarse sand	nearshore deposit
SS-20	3.5	fine to coarse sand little silt and fine to coarse gravel	Wisconsinan till
		Refusal	
SS-21	3.5	fine to coarse sand trace fine to coarse gravel	Wisconsinan till
		Refusal	
SS-23	5.5	fine to coarse sand and little fine to coarse gravel, weathered rock	Wisconsinan till
		Refusal	
SS-25	1	fine to coarse sand, trace fine to coarse gravel	Wisconsinan till
SS-27	1	fine to coarse sand trace silt	Wisconsinan till
		Refusal	
SS-30	6	fine to coarse sand some decayed rock, trace silt	Wisconsinan till
SS-32	5	fine to coarse sand little fine to medium gravel, trace silt	Wisconsinan till
SS-33	1.5	artificial fill	
	3.5	silt, little fine to coarse sand, trace fine gravel	proximal Presumpscot Formation
		Refusal	
SS-35	1.5	artificial fill	
	0.5	silt, little fine sand trace fine gravel	proximal Presumpscot Formation
		Refusal	
SS-37	2	artificial fill	
	5	silt and fine to coarse sand, decayed rock	Wisconsinan till