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Surficial geology of the Lisbon Falls South quadrangle, Open-File 97-49
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INTRODUCTION

Surficial mapping in the Lisbon Falls South 7.5' quadrangle was conducted during 1992 and 1993 as part of the Maine Geological Survey's 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, 1997) and a surficial materials map (Weddle, 1999c), 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. This report describes the surficial deposits mapped in the quadrangle and presents the glacial and postglacial history of the quadrangle.

PREVIOUS WORK AND ACKNOWLEDGMENTS

Early descriptions of the surficial geology in the study area are found in Stone (1899) and Leavitt and Perkins (1935). A regional overview of the glacial geology of 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 and others (1989), Smith and Hunter (1989), Retelle and Bither (1989), Kelley and others (1992), and Weddle and others (1993). Soils in the quadrangle were mapped by McEwen (1970) and Hedstrom (1974).

The surficial geology of the Lisbon Falls South quadrangle was mapped previously at reconnaissance level by Bloom (1960) and Smith and Thompson (1986). Other modern work incorporating surficial geology in the study area includes Prescott (1967, 1968), Attig (1975), Gerber (1979), Tepper and others (1985), and Bither (1989). Weddle (1999a,b) mapped the adjacent Freeport 7.5' quadrangle. Wetlands mapping of the quadrangle is published in draft form by the U.S. Department of the Interior National Wetlands Inventory.

Sources of materials information in the quadrangle include boring logs along Interstate 95 and other roads courtesy of the Maine Department of Transportation (MDOT), and MDOT unpublished materials inventory maps which describe many abandoned gravel pits that provided construction material for Interstate 95 (source Wilbur Tidd, MDOT). Water supply investigations subsurface data for the Brunswick-Topsham Water District was provided by David Brooks and Brad Caswell of Caswell, Eichler, and Hill, Inc. Other subsurface data was provided by David Lane, Town of Brunswick Department of Public Works (Hydrogeological and Geotechnical Assessment, Brunswick Landfill Expansion, R. G. Gerber, Inc., 1990). The Maine Geological Survey's (MGS) bedrock well database inventory also provided depth to bedrock information. (Note: the location of wells in the MGS well inventory is based on tax lot map locations and not necessarily on field observations.) Numerous gravel pit operators and private landowners are allowed permission to access their property. Discussions in the field with Cheryl Marvinney and Michael Retelle helped with mapping interpretations. Gwyneth Jones provided information on several fossil localites in the quadrangle. All radiocarbon dates reported in this text are uncorrected for the ^{14}C marine "reservoir" effect (Mangerud and Gullicksen, 1975). Thanks are extended to Carol Hildreth and Woody Thompson who reviewed this report and maps, and to Marc Loiselle who digitally produced Figure 3.

LOCATION, TOPOGRAPHY, AND DRAINAGE

The Lisbon Falls South 7.5' quadrangle is located just inland from the Maine coast between 43°52'30" and 44°00'00" N

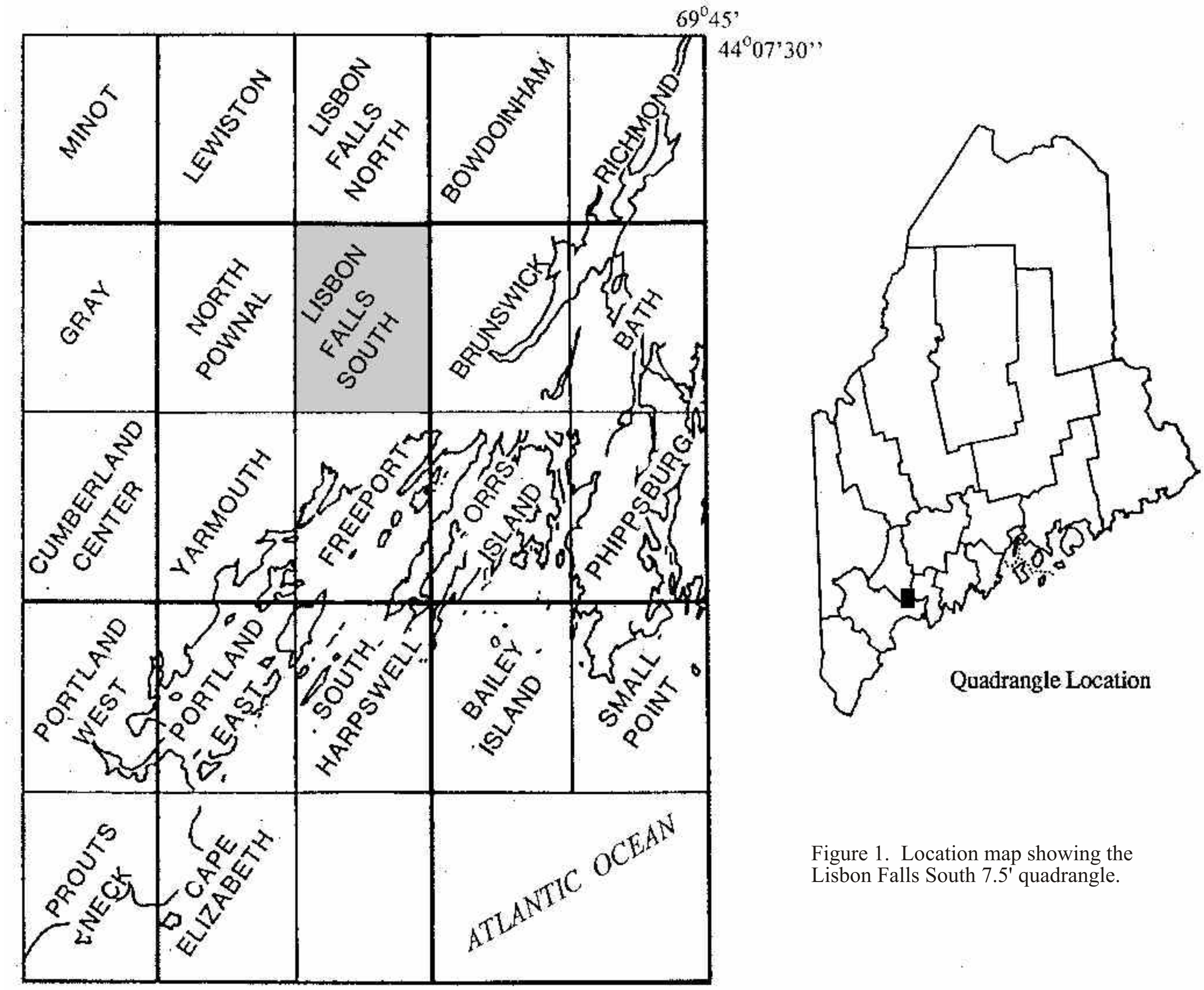

Figure 1. Location map showing the Lisbon Falls South 7.5' quadrangle.

latitude and 70°00'00" and 70°07'30" W longitude (Figure 1). It comprises parts of Androscoggin, Cumberland, and Sagadahoc Counties, and parts of the communities of Brunswick, Durham, Freeport, Lisbon, Pownal, and Topsham. Elevations within the quadrangle range from about 45 feet above sea level (asl) in the Androscoggin River valley to over 350 feet asl at Cox Pinnacle in the center of the quadrangle. Most of the quadrangle has low to moderate relief. The maximum relief of approximately 220 feet occurs between the Androscoggin River and the highlands between Pejepscot and Rocky Hill in the eastern part of the quadrangle. The southeastern quarter of the quadrangle has a prominent northeast-southwest topographic expression, reflecting bedrock structural control. The remainder of the quadrangle has a similar topographic trend, but is not as strongly pronounced as in the southeastern part of the map.

The major drainage in the northern two-thirds of the quadrangle is the Androscoggin River and its tributaries. The river flows parallel to the topographic trend in the extreme northwest corner of the map. In the adjoining Lisbon Falls North quadrangle it turns to the southeast across the topographic grain and continues to the adjoining Brunswick quadrangle to the east. Drainage in the southern third of the quadrangle is by Collins Brook, which leads to tributaries of the Royal River to the west, and by Mill Stream, Kelsey Brook, and Bunganuc Brook which lead to the Harraseeket River estuary in the adjoining Freeport quadrangle to the south.

BEDROCK GEOLOGY

Hussey (1981, 1985) mapped the bedrock geology of the Lisbon Falls South quadrangle. The bedrock in the southeastern part of the quadrangle is comprised of rocks of the Falmouth-Brunswick sequence of Ordovician or older age. The Hutchins Corner Formation (formerly the Vassalboro Formation; Osberg,

1989) comprises the bedrock in the remainder of the quadrangle. These units are separated by the Hackmatack Pond fault, the trend of which is traced along the Mill Stream valley. The structure of the bedrock is strongly controlled by northeast-southwest trending folds and faults. These units are cut by numerous pegmatites and, in places, by diabase dikes. More detailed information on the bedrock geology of the region can be found in Hussey (1988, 1989).

SURFICIAL GEOLOGY

Bedrock and Thin-Drift Areas

Solid symbols on the map represent bedrock where it crops out. Much of the area is mapped as thin drift (Ptd) where surficial material over bedrock is less than 10 feet thick. Individual outcrops in these areas are not always indicated on the map. The lithologies of the surficial deposits most often found in thin-drift areas may be till, marine deposits, glaciomarine deposits, or nearshore deposits.

Till

Till (Pt) is found at some surface localities and reported in subsurface test borings. It is commonly a loose to compact, gray to olive gray, pebbly, silty, sandy, poorly sorted deposit (diamicton) often found overlying bedrock. Exposures of sandy diamicton are present along Durham Road 0.25 miles east of the intersection with Lunt Road. Gray, silty sandy diamicton associated with subaqueous outwash is found in glacial submarine fan deposits in several gravel pits including the Seymour pit in Freeport (on Curtis Road in the Wardtown section of Freeport, 0.5 miles west of Collins Cemetery), the Labbe pit in Brunswick (0.3 miles east of Jones Cemetery, off Lisbon Falls Road), the Hubbard pit in Topsham (0.25 miles north of Elmlawn Cemetery along Route 196), and in the Haggerty pit in Topsham (0.75 miles south of where the Little River crosses Route 196). These diamictons are associated with ice-shove structures and were deposited during minor oscillations of the ice margin as the ice overode fronting subaqueous outwash. Some of the diamicton in these exposures may be subaqueously deposited debris flows, or flowtill (Hartshorn, 1958; Brodzikowski and Van Loon, 1991). Sandy diamicton that was dumped from melting icebergs or deposited in place by debris flows can be found in the Brown pit in Brunswick (0.5 miles south of power lines on River Road).

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 and others, 1991). They are linear 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 Lisbon Falls South 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 and others, 1991), and therefore can be used to trace ice-marginal positions during deglaciation.

End Moraines. End moraines (Pem) are common in the quadrangle. More moraines are probably present in the area, but may be buried by overlying glaciomarine deposits. In general, the moraines have a northeast-southwest trend (azimuth range 60^{o} - 90^{o}), although some have a northwest-southeast trend (for example, the moraines east of the Little River and along Ward Road in the northeast part of the quadrangle). The moraines are commonly associated with submarine fan deposits. These moraines are small to moderately large, usually occurring in clusters, not more than 10-30 feet high, 100-200 feet wide, and 1000-3000 feet in length. A laterally continuous moraine is well represented topographically just north of Cox Pinnacle in the center of the quadrangle. The lobate-shaped moraine can be traced for about four miles across the map and approximates the ice-marginal position at the time it was deposited. It records that the ice margin was pinned to the bedrock upland as an ice salient, whereas along the flanks of the hill and into the adjacent valleys on either side, the ice margin had a re-entrant form. This moraine is exposed in the Labbe pit to the east and is comprised of till and deformed subaqueous outwash deposits. A small exposure shows sandy diamicton in a pit along Quaker Meeting House Road (0.25 mile west of South Durham village). Along the moraine, large boulders are present, and where it crosses under the power lines north of Cox Pinnacle it is comprised only of large boulders. The matrix of the moraine at this site was probably winnowed away during falling sea level.

Other moraines and moraine complexes are present between Wardtown and the North Freeport Cemetery. These are associated with submarine fan deposits and record several ice-marginal positions. Striations and structural features in the deposits in this area correspond well to the orientation of the moraines and ice-flow direction (Weddle and others, 1993). Striations on bedrock trend about due south and northward-dipping thrusts in the morainal deposits trend east-west. The exposure in the Haggerty pit represents another good example of the deposits at an ice-margin grounding line. Here the subaqueous outwash of a small fan has been overidden by the ice, which deposited till and thrust and folded the sediments (average trend of 5 thrusts, 59^{o} strike / 21^{o} NW dip; one fold axial plane, 40^{o} strike / 18^{o} SE dip). The internal structure and composition of similar features elsewhere in Maine has been described in detail by Smith and Hunter 1989), Retelle and Bither (1989), and Ashley and others (1991).

Submarine Outwash Fans. Submarine outwash-fan deposits (Pmf) are present in several areas in the quadrangle, especially in the Androscoggin River valley between Lisbon Falls and Rocky Hill in Brunswick, and along Route 125 in Freeport. There are small ice-tunnel (esker) deposits associated with some of these fans. However, they are not very well represented topographically on the map, hence are not maped separately from the fans. Esker represent the coarse-grained fluvial material transported and deposited in an ice-tunnel as part of the meltwater draginage system in the glacier.

North of the Pleasant Hill fan on the adjacent Freeport quadrangle, several inactive gravel pits in the Lisbon Falls South quadrangle along Mill Stream valley record subaqueous outwash fan deposits. Based on subsurface data along this valley, Gerber (1979) reports a discontinuous esker system buried by thick glaciomarine mud. Although there is no surface expression of the esker system, it most likely was deposited as part of the fans and along with the associated fine-grained materials at the ice margin. More recent studies for the Brunswick-Topsham Water District in the Rocky Hill area report similar materials at depth (personal communication, Caswell, Eichler, and Hill, Inc., 1993). As with the end moraines, smaller fans may be present in the quadrangle, but are covered by later glaciomarine deposits and were undetected.

A series of gravel pits along the Androscoggin River and north of Elmlawn Cemetery in Topsham record an instructive sequence of submarine fan deposits. At the Maine Department of Transportation (MDOT) pit adjacent to Elmlawn Cemetery, an exposure of proximal to distal fan deposits is present. The distal fan deposits at the southern end of the pit are overlain by massive glaciomarine mud, which is in turn overlain by a marine shoreline deposit. In the northern end of the pit, cobbly coarse-grained sand deposited near the ice margin is exposed. It also is overlain by massive mud. Bloom (1960) reports a varied shell assemblage from this pit including *Hiatella, Macoma, Musculus, Mya, Mytilus, Nuculana, Serripes, Natica, Neptunea,* and *Balanus*. Pelecypod molds were observed in massive mud under the nearshore deposits in the south end of the pit. However, no other fossils were found in this exposure in this study.

In the Whorff and Hubbard pits, immediately to the north of the MDOT pit, another fan sequence is found. The Whorff pit is a cross-section of the proximal component of the fan exposed in the MDOT pit. The core of the tunnel deposit (esker) was well exposed in 1994, displaying a very coarse, massive to crudely bedded boulder gravel, with ice-contact collapse structures (normal faults) and slumped beds along its flanks. The triangular cross-sectional shape of the exposed tunnel deposit is mantled by subaqueous outwash associated with the MDOT fan, deposited as the ice margin retreated northward and the locus of deposition of the tunnel feeder and fan migrated laterally. The Hubbard pit exposure details mid- to distal fan sediments deposited after the ice had retreated from the MDOT pit to a more northerly ice-marginal position. The fine-grained deposits in the Hubbard pit lap onto the coarse-grained ice-marginal deposits in the MDOT pit and were subsequently deformed by the ice when it readvanced following the deposition of the Hubbard pit fan. The deformed fan deposits are overlain by massive mud and nearshore deposits, which contain fossil shells and shell fragments, including *Neptunea, Buccinum, Macoma, Mytilus,* and *Balanus*.

Just north of the Hubbard pit, a third pit exposes yet another fan deposit delineating a third ice-marginal position along this part of the river valley. The location of tunnel deposits (eskers), glaciomarine fans, and deltas is controlled by glaciology and glacial hydrology as well as topography (Gustavson and Boothroyd, 1987; Ashley and others, 1991; Crossen, 1991; Warren and Ashley, 1994). The presence of the number of deposits and volume of material in this part of the Androscoggin River valley is a result of constriction of the ice sheet in the valley. The valley is narrow here and the ice was pinned to the bedrock highlands on either side. Sub- or englacial drainage followed the present-day valley and where the ice margin was slowed in its retreat, the fans had time to build relatively large deposits.

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-manganeseoxides. 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. A good exposure representing both the ice-proximal and ice-distal/basinal nature of the Presumsumpscot Formation is found in the previously described MDOT pit in Topsham.

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 gradational 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 overlying massive Presumpscot Formation mud is present in the Lisbon Falls South quadrangle , 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., Weddle, 1987; Smith, 1999a,b; Hildreth, 1999a,b; Hunter, 1999a,b) is not used in the Lisbon Falls South 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 (Weddle, 1987; Smith, 1977; Smith and Thompson, 1986). In the Lisbon Falls South 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 which is interbedded with the Presumpscot Formation is considered part of the Presumpscot Formation and is mapped as such (Pp).

Nearshore and Shoreline Deposits and Pleistocene Alluvium

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 was 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 and others, 1987; Kelley and others, 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 of 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).

Good examples of nearshore and marine shoreline deposits (Pmn, Pms) can be found in most of the large gravel pits in the quadrangle. The deposits in the pits commonly have a coarse basal lag deposit overlying the Presumpscot Formation, although they occur over distal and proximal fan sediments as well. This relationship is especially well exposed in the MDOT pit in Topsham. Another good example is found at a small pit east of Littlefield Cemetery in Durham (0.3 mi south of bridge crossing Androscoggin River from Lisbon Falls). Here interbedded pebbly sand and fine- to medium-grained sand in broad shallow channels overlies fine-grained sandy distal fan deposits. There is a pebble lag deposit at the base of the nearshore deposit which contains mudclasts, presumably of Presumpscot Formation, along with coarse-grained sand and pebble gravel.

Coarse sand associated with a marine shoreline is found at Lunt Memorial Cemetery in the center of the quadrangle. Koteff and others (1993) have proposed that late glacial sea level was unaffected by uplift until the ice margin had receded well into Maine, and that many landforms including the tops of ice-contact deltas have been wave-reworked by the transgressive late-glacial sea. The landform at Lunt Memorial Cemetery is a shoreline reworked from adjacent till and is found at about 290 feet asl, very close to the marine limit as determined for the area by Thompson and others (1989). It was most likely formed at synglacial sea level or a very early regressive sea level during Late Wisconsinan time.

The northwest quarter of the quadrangle is a relatively flat, low-lying region with little relief except in the Androscoggin River valley and its tributaries. This area is mantled by medium- to fine-grained sand overlying the Presumpscot Formation or till. The sand is associated with marine regression and is reworked nearshore material which mantles the low-lying areas. In the adjacent North Pownal and Yarmouth quadrangles, this low region continues to the south and southwest to the present day coast and is the area where the regressive sea would have remained longest during the regression, and where nearshore reworking would have been focused for the longest time. A landform in this low area in the Lisbon Falls South quadrangle, approximately 0.5 miles northeast of Gerrish Cemetery in Durham, exposes southwest-dipping beds of silt and rippled medium sand. The landform, a Pleistocene spit, has a NW-SE trend, perpendicular to the trend of the low area, and was built between a till upland lying to the north and drumlins to the southeast.

Pleistocene alluvium (Pa) deposits are fluvial trough-crossbedded gravelly sands formed in a braided-stream environment in the postglacial Androscoggin River valley. These deposits form the Brunswick sand plain, a small part of which is found in the extreme southeast corner of the quadrangle (Weddle, 1999a,b; Weddle and Retelle, 1995; Androscoggin sand plain of Leavitt and Perkins, 1935). Small areas of Pleistocene alluvium also are found along the Androscoggin River as higher terraces than the modern floodplain. These units are of Pleistocene age because their elevation requires them to be deposited prior to the lowstand of the marine regression at about 11,000 to 10,500 yr B.P. (Barnhardt and others, 1995).

Pleistocene Eolian and Holocene Deposits

Eolian deposits (Pe) are common in the area, particularly in the northwestern and southeastern portions of the quadrangle.

However, they are not shown extensively on the map because they are not thick enough in most areas to mask the underlying units. Holocene deposits have been mapped as fresh water wetlands (Hw) and stream alluvium (Ha).

GLACIAL AND POSTGLACIAL HISTORY

Quaternary Geology

The glacial deposits in the Lisbon Falls South quadrangle were derived from the last ice sheet which covered Maine, the late Wisconsinan age Laurentide Ice Sheet, which reached its maximum in New England about 25,000 yr B.P. (Stone, 1995). Glacial striations and streamlined hill orientations reflect ice flow through the quadrangle and vary within 10^{o} - 15^{o} of 180^{o}. Striations which trend west of 180^{o} are found in the southeast corner of the map, principally in the area with the strong NE-SW topographic trend. In the adjacent Freeport quadrangle to the south, similar striations are found along the coast where the same strong topographic trend is represented by the peninsulas in Casco Bay (Weddle, 1999a,b). Striations east of 180^{o} are present throughout the quadrangle and are the most common of the measured striations. Although there are several locations where multiple striations are present, there is just one site in the Lisbon Falls South quadrangle where relative age could be determined. In a pit where glacial abrasion features are excellently preserved, approximately 0.5 miles southeast of the North Freeport Cemetery, 170^{o} striations are cut by 182^{o} striations. In the adjacent Freeport quadrangle, the same relative age relation as well as the opposite relative age relation can be found at several different multiple striation sites. No consistent trend has been found to determine the youngest set in either quadrangle.

Ice recession from the Gulf of Maine probably began sometime around 17,000 yr B.P. and the ice had reached the Freeport area by about 13,000 yr B.P. (Smith, 1985; Smith and Hunter, 1989). Radiocarbon dates in the immediate area provide minimum dates for the deglaciation of the region. The oldest published date (12,560 160 yr B.P.), 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, an unpublished date on *Portlandia arctica* found in mud overlying ice-contact subaqueous outwash from the Seymour gravel pit in Freeport (14,045 95; AA10164; Weddle and others, 1993) provides an older minimal date for deglaciation in the area.

During the retreat of the glacier, the ocean was in contact with the ice margin. Pleistocene sea level at the time of deglaciation in the study area was approximately 280-300 feet above modern sea level (Thompson and others, 1989). The shoreline deposit (Pms) at Lunt Memorial Cemetery represents this high synglacial sea-level stand. As the ice margin passed through the Lisbon Falls South quadrangle, all the present-day land below about 300 feet asl was completely submerged. The tidal range in the Gulf of Maine during this time was less than a meter (Scott and Greenburg, 1983). The areas above 300 feet asl near Cox Pinnacle and Bald Rock were islands and those areas just below that elevation were shoals.

The distribution and orientation of ice-marginal submarine deposits also reflects the flow of ice indicated by the striation direction data. The moraines and glaciomarine fans occur along a trend near perpendicular to the striation directions and indicate that the glacier withdrew from the coastal zone as a near east-west trending, progressively retreating, active ice sheet grounded in a glaciomarine environment. 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.

As the ice retreated, it was pinned on bedrock highlands and was grounded in the intervening low areas as evidenced by shape and location of the moraines and 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 and others, 1991). With reasonable correlation, these deposits can be used to reconstruct the orientation and relative position of the ice margin in time during deglaciation. These landforms reflect the shape of the ice margin during deglaciation, which appears to have been slightly lobate down valley. A good example of the down valley lobate shape of the ice margin in the Lisbon Falls South quadrangle is recorded by the Cox Pinnacle moraine.

Below the marine limit, the valleys are considered to be the sites of calving embayments (Hughes and others, 1985) where the ice margin is assumed to be concave upvalley. However, the Cox Pinnacle moraine suggests the down valley lobe shape of the ice margin reported elsewhere in southern New England may be present in the valleys below the marine limit in Maine where calving embayments may have likely occurred. The grounded marine-based ice margin probably was not strongly influenced enough by the relatively shallow ocean in the valleys to produce high calving rates. Lowell and Borns (1994) have discussed the relationships between water depth and calving embayment for the Penobscot River Valley in south-central Maine.

The oldest ice-margin positions identified are the series of moraines and submarine fan deposits in the southeastern corner of the quadrangle between Pleasant Hill (Pmfpl) on the west and the moraines to the east between Pleasant Hill Road and Growstown (Pembs). These deposits are correlated with a series of moraines and fans in the adjacent Freeport quadrangle to the south (Weddle, 1999a,b).

The next ice-marginal position that is well defined by end moraine morphology is the Cox Pinnacle moraine (Pemcp), found in the center of the quadrangle. For southwestern Maine, it is an uncommonly large and laterally continuous moraine, traceable in the quadrangle for more than 3 miles, with more than 20 feet of surface relief in places. Its eastern end is comprised of submarine fan deposits found both east and west of the An-

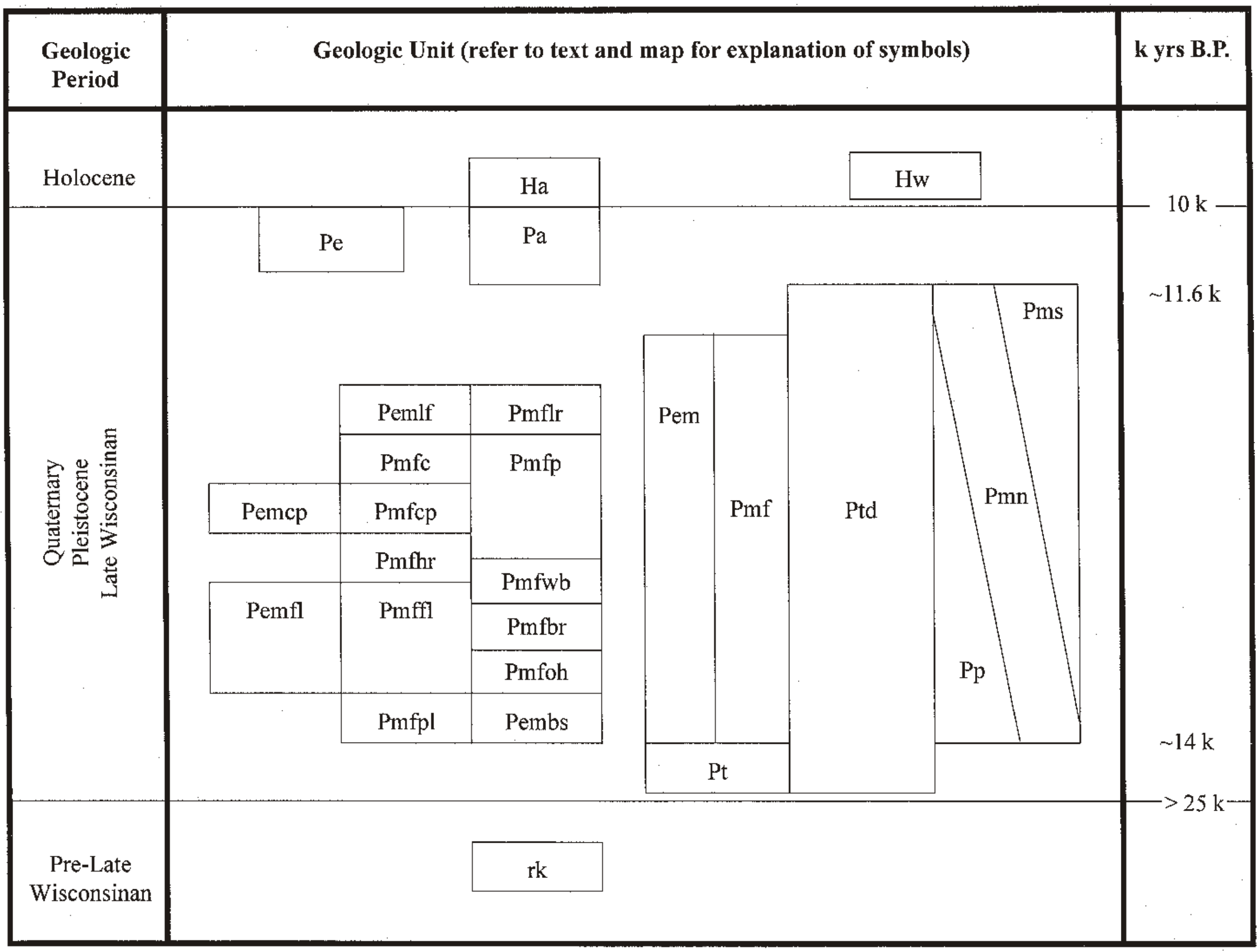

Figure 2. Schematic chart showing correlation of geologic units in the Lisbon Falls South 7.5' quadrangle. End moraine (Pem) and marine fan (Pmf) units are read from left to right and bottom to top, corresponding to west to east and south to north, respectively, on the surficial geology map. Age estimates are in uncorrected radiocarbon years (Stone and Borns, 1986; Weddle, 1994, and unpublished data). Time scale not linear; time constraints on units uncertain.

droscoggin River (Pmfcp, Pmfp) and it may be correlated with submarine fans to the west in the adjacent North Pownal quadrangle (Weddle and others, 1993).

Although there are numerous smaller moraines and several fans between the two major ice-marginal positions identified in the Lisbon Falls South quadrangle, as well as to the north of the Cox Pinnacle moraine, no other units are shown correlated as inferred ice-marginal positions because of the widespread distribution of the moraines. However, the orientation and form of these deposits corresponds to the shape of the two inferred positions described above and identifies the sites of uncorrelated ice-marginal or near ice-marginal positions. Moreover, the location of these fans and moraines between and north of the two inferred positions gives them a relative stratigraphic age in context with the two inferred positions. In particular, between these two positions, the Florida Lake deposits (Pemfl, Pmffl), the Oak Hill and Hillside fans (Pmfoh, Pmfh), the Bald Rock, Whites Beach, and Hacker Road fans (Pmfbr, Pmfwb, Pmfhr), and the first Pejepscot fan ($Pmfp_1$) are found along a relatively wide zone which trends subparallel to the configuration of the two inferred posiions. Similarly, to the north of the Cox Pinnacle moraine, the moraines and fans associated with the Little River, Lisbon Falls, and Crossman Corner deposits (Pmflr, Pemlf, Pmfc) mark the retreat of the ice margin even though these units are not correlated along an inferred position. The orientation of the ice margin as represented by the moraines described above changes from an ENE-WSW trend to a WNW-ESE trend in the Little River valley, apparently locally controlled by the topography of the Little River valley and higher areas found to the north on the adjacent Lisbon Falls North 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 are found at several locations in the quadrangle, and some of these have yielded radiocarbon age-dates (Bloom, 1960; Attig, 1975; Stuiver and Borns, 1975; Smith, 1985; Weddle and others, 1993).

Local uplift due to isostatic rebound occurred during deglaciation and resulted in regression of the glacial sea. An uncorrected radiocarbon date of 13,300 ± 50 yr B.P. (OS-4419) on *Mytilus edulis* from nearshore deposits in a pit at approximately 200 feet (61 m) asl in the adjacent North Pownal quadrangle records the earliest date for marine regression in the state. A younger date (12,820 ± 120 yr B.P., 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). An uncorrected date of 13,315 ± 90 yr B.P. (AA10162; Weddle and others, 1993) from the same pit in Topsham on *Portlandia arctica* shells found in Presumpscot Formation mud approximately one meter below the nearshore deposits containing the intertidal fauna supports the older offlap dates.

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 sand plain in the adjacent Brunswick quadrangle. Pleistocene beach ridges on Harpswell Neck are found at the same elevation range as the sand plain, and overlie nearshore deposits radiocarbon dated at 12,850 ± 45 yr B. P. (OS-2348; Weddle, 1999a,b). The northwest portion of the quadrangle is a region where nearshore deposits are found over glaciomarine mud over a considerable area. This region is the northern portion of a low area that continues to the south in the adjacent North Pownal quadrangle, and which was postulated as a former drainageway for the preglacial Androscoggin River (cf. Bither, 1989). However, geophysical investigations by Bither (1989) indicate that no south-draining preglacial channel exists in this area.

The nearshore deposits in this area are best exposed in a stream cut along Newell Brook, south of Plummer Mill. Here 10 feet (3 m) of medium- to fine-grained cross-bedded sand, with cross stratified climbing-ripple drift and mud drapes are present overlying 10 feet (3 m) of bedded silt and clay (Presumpscot Formation ?). The current direction in the sand is to the north, and the deposits probably represent a nearshore estuarine environment.

The timing of regression in the Lisbon Falls South quadrangle is inferred to have occurred between about 13,300 to 11,600 yr B.P. (Attig, 1975; Stuiver and Borns, 1975; Smith, 1985; Retelle and Bither, 1989; Weddle, 1999a,b; Weddle and Retelle, 1995; and Maine Geological Survey unpublished data). It is likely that regression was influenced by eustatic sea level rise during the period of meltwater pulse-1a (MWP-1a, Fairbanks, 1989; Blanchon and Shaw, 1995; 13,000 - 12,000 ^{14}C yr BP; -400 year low-latitude marine reservoir correction factor applied), and that a steady relative sea-level fall was not consistent during regression.

Evidence for stillstands in southwestern Maine during the marine regression is noted by Smith (1999a,b), Hildreth (1999a,b), and Clinch and Thompson (1999a,b) between elevations 217 to 20 feet asl (66 to 6 m asl). The Brunswick sand plain, a small portion of which is found in the extreme southeast corner of the Lisbon Falls South quadrangle (Pa), may have formed during the time of MWP-1a, when late or postglacial braided streams entered the regressive sea and relative sea-level may have been temporarily stable (Weddle and Retelle, 1995). Although the sand plain is only a minor landform in this quadrangle, it merits discussion because several radiocarbon age-dates in the Lisbon Falls South quadrangle have bearing on the time of its formation.

The plain surface grades from about 120 feet to 60 feet (36 m to 18 m) asl, with a surface gradient of 0.028. Shallow excavations in the surface of the plain reveal fluvial trough-cross beds of fine- to medium-grained sand, in places containing mud rip-up clasts and mud drapes, typical of a braided-stream environment. The plain morphology and sedimentology classify it as a coastal braid delta (McPherson and others, 1987; Blair and McPherson, 1994).

These braided-stream deposits unconformably overlie a coarsening-up sequence of massive and laminated mud grading upwards to interbedded silt and fine- to medium-grained sand layers, known collectively as the Presumpscot Formation (Bloom, 1960,1963). This muddy unit beneath the fluvial sand represents a transition during glaciomarine transgression from a distal glaciomarine and submarine plain environment to shallowing conditions during marine regression. Subsequent to the deposition of the massive glaciomarine mud, existing units were reworked by the marine regression and nearshore deposits were laid down. In the study area, these deposits are best exposed at eroded coastal bluffs (Weddle and others, 1993; Weddle, 1999a,b) and are reported from detailed geotechnical logs from the Superfund site at the Naval Air Station in Brunswick (Draft Final Feasibility Study, ABB Environmental Services Inc., November, 1991, Portland, Maine).

Several origins for the Brunswick sand plain may be proposed: increased discharge by the late- to postglacial Androscoggin River, deposition due to loss of capacity where the late- to postglacial Androscoggin River exited from a confined valley to an unconfined valley, and in association with the above, the plain was deposited during a period when falling relative sea-level may have stabilized as a response to a rising eustatic sea-level, balancing glacio-isotatic uplift long enough for the coastal braid delta to form. In any model, the age of the plain is minimally constrained by the elevations of radiocarbon-age dates on *Hiatella arctica* shells (13,100 ± 125 yr B.P., GX-20774; Weddle and Retelle, 1995) found beneath the outer edge of the plain (personal communication, A. M. Hussey, II, 1995), and from sites

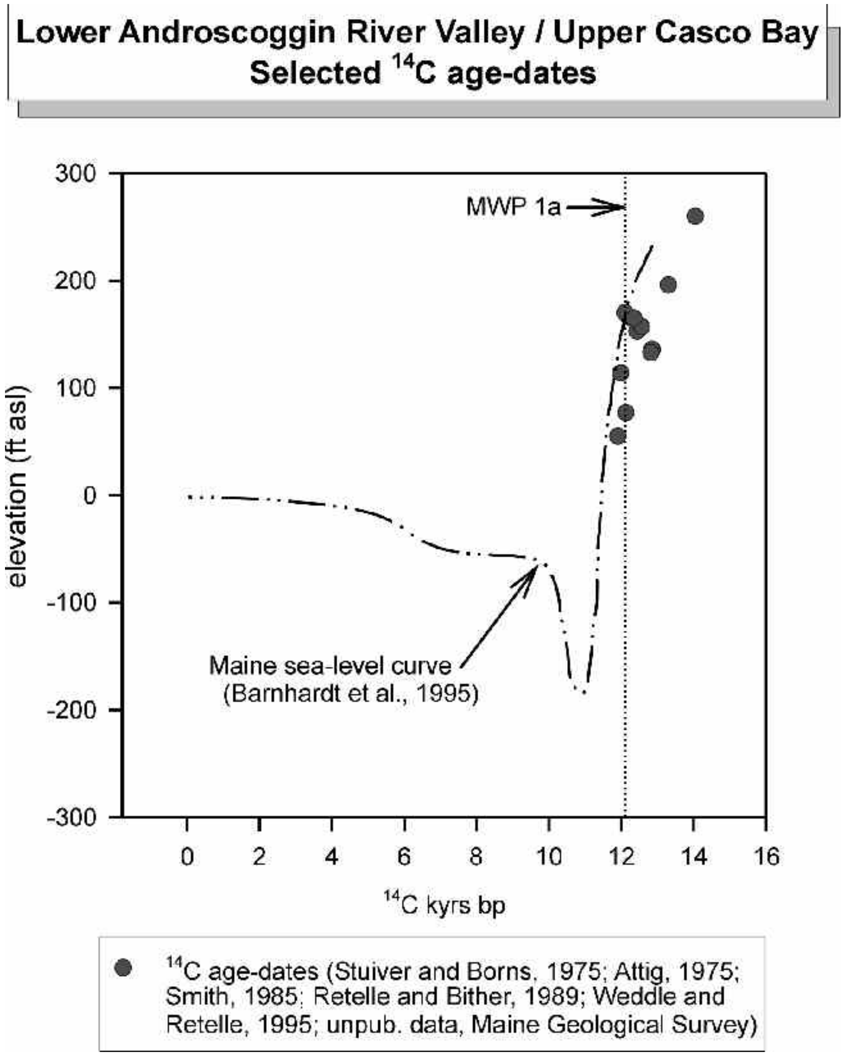

Figure 3. Maine sea-level curve (Barnhardt and others, 1995) and radiocarbon age-dates from the lower Androscoggin River valley and upper Casco Bay area. MWP-1a refers to meltwater pulse-1a (Fairbanks, 1989), a period of eustatic sea-level rise from 13,000 to 12,000 radiocarbon years BP. MWP-1a peak shown by dashed line (Fairbanks,

beneath regressive deposits in nearby Harpswell (30 m asl) and Topsham (47 m asl), which constrain the age of the plain to be as old as or slightly younger than 12,500 yr B.P. (Retelle and Bither, 1989; Weddle, 1999a,b; Weddle and Retelle, 1995).

If the Brunswick sand plain does represent a time of relative stability of sea level, there should be other evidence to support this interpretation. Shoreline deposits found at similar elevations as the sand plain are present in the adjacent Freeport quadrangle (Weddle, 1999a,b). However, elsewhere in the lower Androscoggin River valley there are few documented landforms or deposits at the same elevation as the sand plain that necessarily indicate a relative stability of sea level in the region.

The Maine relative sea-level curve (Barhardt and others, 1995) is derived from radiocarbon age-dates from a statewide database, and hence is an averaged curve. Dates on marine shells found associated with nearshore deposits in the Lisbon Falls South and adjacent quadrangles were not used in the construction of this curve (Belknap and others, 1987). Based on eight previously published dates (Attig, 1975; Stuiver and Borns, 1975; Smith, 1985; Retelle and Bither, 1987) and three recently published dates (Weddle and Retelle, 1995), a local relative sea-level curve can be constructed for the lower Androscoggin River valley and upper Casco Bay area.

Figure 3 illustrates the Maine relative sea-level curve and the local lower Androscoggin River valley and upper Casco Bay data normalized to a relative sea level of 260 ft (79 m) asl. Also shown on the figure is the peak time of MWP-1a (Fairbanks, 1989; Blanchon and Shaw, 1995). There are two points of interest on this figure: first, the dates from the lower Androscoggin River valley plot older than the Maine sea-level curve, as they should since they are older than any of the dates used in the Maine curve. The curve that can be constructed by connecting the lower Androscoggin River valley data points is similar in shape to the upper part of the statewide-average curve of Barnhardt and others (1995), and to curves constructed in other areas that have undergone glacio-isostatic adjustment (Retelle and others, 1989). Second, there is a cluster of previously published dates that plot between 12,500 and 12,000 yr B.P. around the MWP-1a position. This cluster of dates may be explained in several ways. The age-dates may be in error; however, there is no unequivocal reason to reject these dates. Alternatively, the elevations reported for the dated sites may be in error. Although many of these sites are reported from locations from 15-minute topographic quadrangles, there is no justifiable reason to disregard the dates based on incorrect reporting of location. Finally as another explanation, the age-dates are correct and may represent a rise or stability of relative falling sea-level during eustatic sea-level rise associated with MWP-1a.

This proposed terrestrial radiocarbon age-date evidence of rapid rise of sea-level in Maine is younger than that reported by Koteff and others (1993), but like their work, it relates the terrestrial evidence in Maine to oceanic studies on eustatic sea-level rise. Further field data and more radiocarbon age-dates are required to test this proposal for the time and mode of formation of the Brunswick sand plain.

As sea level reached its lowest level (Kelley and others, 1992; Barnhardt and others, 1995), present day drainage became established. Deep erosion in the glaciomarine mud, such as the gullies occupied by Pinkham Brook and Mill Stream also formed during this time. Many of these gullies have downcut to bedrock, and most of the gullies are floored by wetland deposits; however, a thin veneer of Holocene alluvium (unmapped) is present along stretches in some valleys. 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. There are no modern coastal or esturaine deposits in the Lisbon Falls South quadrangle.

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