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Robert G. Marvinney, State Geologist

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Cumberland and Sagadahoc Counties, Maine*

Author: *Thomas K. Weddle*

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Surficial Geology of the Brunswick 7.5' Quadrangle, Cumberland and Sagadahoc Counties, Maine

Thomas K. Weddle
Maine Geological Survey
22 State House Station
Augusta, Maine 04333

INTRODUCTION

Surficial mapping in the Brunswick 7.5' quadrangle was conducted during 2000 as part of the Maine Geological Survey's basic geologic mapping program, funded in part by the U.S. Geological Survey STATEMAP 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, 2001) and a surficial materials map (Locke and Weddle, 2001), 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), Weddle and others (1993), and Weddle and Retelle (1995). Soils in the quadrangle were mapped by McEwen (1970) and Hedstrom (1974).

The surficial geology of the Brunswick quadrangle was mapped previously at reconnaissance level by Bloom (1960) and Smith (1977). Other modern work incorporating surficial geology in the study area includes Prescott (1979, 1980), Tepper and others (1985), and Crider (1998). Wetlands mapping of the

quadrangle is published by the U.S. Department of the Interior National Wetlands Inventory.

Sources of materials information in the quadrangle are numerous. Geotechnical data are recorded from construction sites, boring logs along U.S. Interstate-95, the Brunswick-Topsham Bypass, road and bridge borings courtesy of the Maine Department of Transportation (MDOT), and the Brunswick Naval Air Station Superfund site. MDOT unpublished materials inventory maps describe many abandoned gravel pits that provided construction material for Interstate 95. 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 allowed permission to access their property.

LOCATION, TOPOGRAPHY, AND DRAINAGE

The Brunswick 7.5' quadrangle is located just inland from the Maine coast between 43°62'30" and 44°00' N latitude, and 69°32'30" and 70°00' W longitude (Figure 1). It comprises parts of Cumberland and Sagadahoc Counties, and parts of the communities of Bowdoin, Bowdoinham, Durham, Topsham, and West Bath. Elevations within the quadrangle range from modern sea level at the coast at the New Meadows River, Merrymeeting Bay, and the Androscoggin River, to over 360 feet above sea level (asl) in the northwestern corner of the quadrangle at Tate Hill, with gentle relief throughout most of the area.

The major drainage in the quadrangle is by the Androscoggin River and its tributaries, the Cathance River, and the Muddy River, which all drain to Merrymeeting Bay, a large, tidally-influenced fresh-water embayment marking the confluence of the Androscoggin River and Kennebec River. In the southeast-

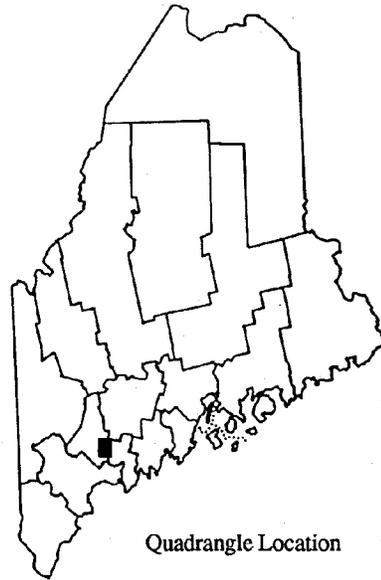
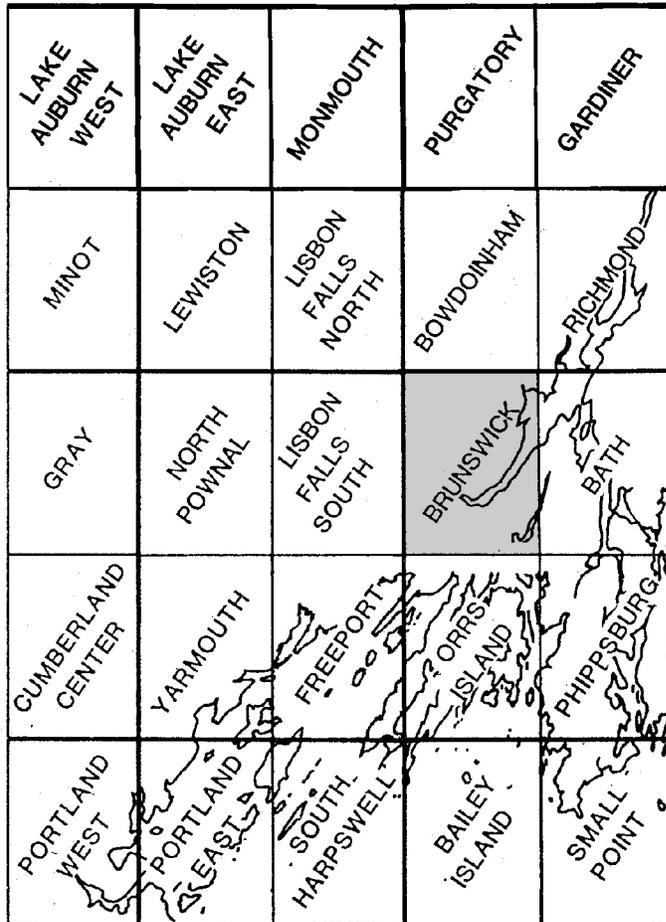


Figure 1. Location map showing the Brunswick 7.5' quadrangle.

ern corner of the quadrangle, drainage is into the New Meadows River, a drowned marine-coastal embayment.

BEDROCK GEOLOGY

Bedrock in the quadrangle has been recently mapped as part of a 1:100,000-scale compilation by Hussey and Marvinney (2000), and previously at a scale of 1:62,500 by Hussey (1981). Most of the quadrangle is underlain by feldspathic granofels, gneiss, schist, and amphibolite. The southeastern part of the quadrangle is dominantly feldspathic granofels, with some interbedded calc-silicate granofels and amphibolite units. More information on the bedrock geology of the region can be found in Hussey (1988, 1989).

SURFICIAL GEOLOGY

Bedrock and Thin-Drift Areas

Gray areas on the map represent bedrock where it crops out. Much of the northeastern part of the quadrangle 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.

Stratified-Drift Ice-Marginal Deposits

Certain ice-marginal deposits 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. The location of these deposits 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). Subglacial or englacial drainage followed the present-day valleys and where the ice margin was slowed in its retreat, there was time to build relatively large deposits. 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). 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 (Pem) are not common in the quadrangle. More moraines are probably present in the area, but many are buried by glaciomarine deposits overlain by a younger broad sand plain. The few mapped moraines have an east/northeast-west/southwest trend (azimuth range 60° - 90°). 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. Similar to the end moraines, submarine outwash-fan (Pmf) deposits are not common in the quadrangle, but based on subsurface data may be present at depth buried by glaciomarine mud.

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. A good exposure representing both the ice-proximal and ice-distal/basinal nature of the Presumpscot Formation was found at a roadcut on the Brunswick-Topsham Bypass (photo location 1 on the surficial geologic map).

A sandy facies of the Presumpscot Formation found overlying the fine-grained facies has been described (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 Brunswick 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, 1977, 1999; Hildreth, 1999; Hunter, 1999) is not used in the Brunswick 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 of fluvial origin and unconformably overlying the Presumpscot Formation has been mapped as sandy Presumpscot Formation (Weddle, 1987; Smith, 1977). In the Brunswick 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, Marine Regressive Delta, 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 do not necessarily have a shoreline morphology. Thick nearshore deposits (Pmn) shown on the map are found flanking the slopes of hillsides, and in broad low areas in the western part of the quadrangle. Also, nearshore deposits often are associated with thin-drift areas.

A unique feature in this quadrangle is the flat topography in Brunswick and Topsham between 100 feet to about 30 feet asl.

This feature is the Brunswick sand plain (Pmdr), and represents a delta built by ice-distal streams discharging from the Androscoggin River valley into the regressive sea. Shallow exposures on the surface of the sand plain reveal trough cross-bedded sand and gravel, characteristic of braided-stream deposits. Beneath the fluvial surface deposits, test-boring data from the Brunswick Naval Air Station and Maine Department of Transportation records, as well as other deep borings, record a coarsening-up sequence reflecting the seaward progradation of the Brunswick sand plain (Weddle and Dearborn, 2001). The significance of the sand plain will be discussed in the Glacial and Postglacial History section of this report.

Pleistocene alluvium deposits (Pa) are found as terraces along the Androscoggin River valley at elevations above the modern flood plain, notably well expressed between Jordan Avenue and Route 24 in Brunswick. Where exposed they consist of trough cross-bedded sand and gravel, characteristic of braided-stream deposits (Weddle, 1997). At a site near the head of Thomas Bay, fluvial deposits overlie bioturbated, sandy near-shore deposits. The fluvial deposits are incised into the eastern edge of the sand plain and were deposited when relative sea-level had fallen just below the higher surface elevation of the sand plain.

Eolian deposits are common in the area, and blanket the region. However, they are not thick enough in most areas to mask the underlying units. In several locations in the southwestern part of the quadrangle, eolian deposits are mapped where they are large sand dunes (Pe). The topographic contours on the 7.5-minute base of the quadrangle do not reflect the geomorphic expression of the dunes. However, the old Bath 15-minute topographic quadrangle does show the dune fields, and is represented in Figure 2.

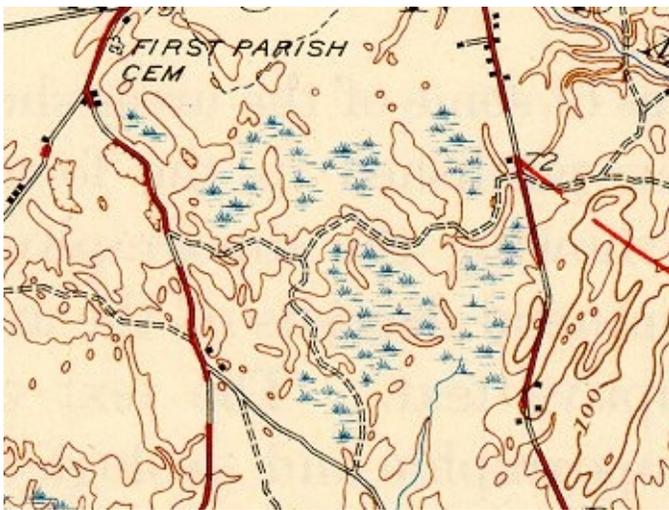


Figure 2. Part of the Bath 15-minute topographic quadrangle (1947). The trails shown by dashed lines traverse the central area on the map along the crests of eolian sand dunes, Brunswick.

Holocene Deposits

The Holocene deposits have been mapped as fresh water wetlands (Hw) and stream alluvium (Ha). Extensive channelling in Holocene deposits in the low-lying area of the Muddy River is represented on Figure 3.

GLACIAL AND POSTGLACIAL HISTORY

Quaternary Geology

The glacial deposits in the Brunswick 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. The most common trend varies within 10° of 180° . However, in a few places a less common southeasterly trend is found, with a range from 140° to 165° , and one site where a 125° striation set was found. In two places where cross-cutting striations are present, the southerly set is oldest at one site whereas the southeasterly set is oldest at the other site. Similar relative ages of cross-cutting striations are found in adjacent quadrangles where multiple-striation localities are found, however, the southeast-trending striations are more commonly older than the south- and southwest-trending striations (Weddle, 1997; 1999; Weddle and others, 1999; Maine Geological Survey, unpublished data). A good example of a streamlined hill in the Brunswick quadrangle is Tate Hill in the northwest corner.

Ice recession from the Gulf of Maine probably began sometime around 17,000 yr B.P. (Smith, 1985; Smith and Hunter, 1989). Radiocarbon dates in the immediate area provide minimum dates for the deglaciation of the region (Stuiver and Borns, 1975; Smith, 1985). A previously reported age of $14,045 \pm 95$ yr B.P. (Weddle, 1999) from a *Portlandia arctica* shell in glaciomarine deposits in Freeport was reanalysed because its $\delta^{13}\text{C}$ value (-9.1 o/oo) is well beyond the suggested mean $\delta^{13}\text{C}$ value for marine carbonate (0 ± 2 o/oo; CALIB 4.0 Manual, Table 1; <http://www.radiocarbon.org/>). A new age estimate on another *Portlandia* from the same deposits is $13,000 \pm 55$ yr B.P. (OS-18899; $\delta^{13}\text{C}$ -1.15 o/oo). However, an age analysis on *Mytilus edulis* shells found in mud overlain by near-shore deposits in Phippsburg ($13,600 \pm 380$ yr B.P., GX-21931; Weddle and Retelle, 1998; Retelle and Weddle, 2001) provides a minimal date for deglaciation in the Casco Bay region. Deglaciation probably occurred several hundred years earlier, most likely closer to 14,000 radiocarbon years B.P.

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 varied from approximately 230 feet asl to 270 feet asl in the southeast to northwest corners of the quadrangle, respectively (Thompson and others, 1989). The marine shoreline deposit on the north side of Tate Hill approximates this

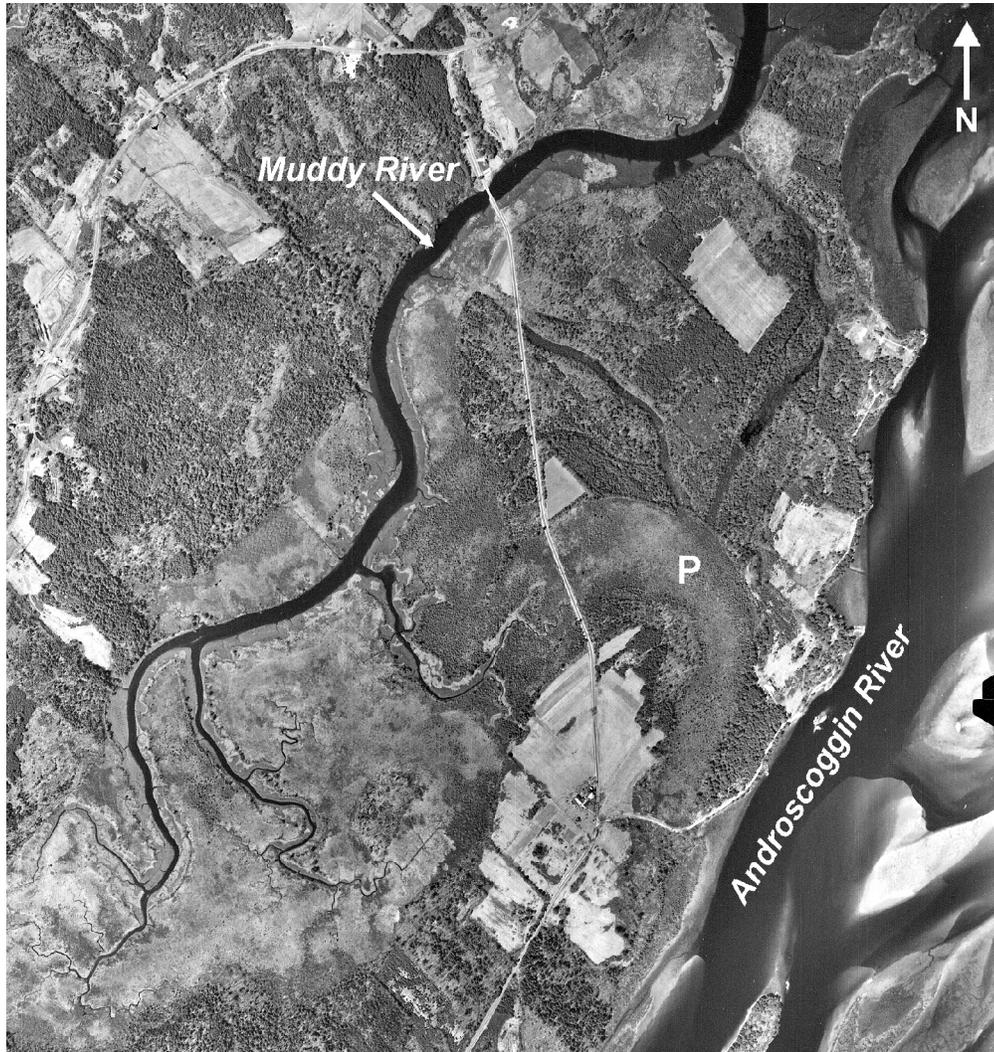


Figure 3. Abandoned meander channels in Holocene deposits, Topsham. The larger paleochannel (P) cuts two smaller paleochannels, which dissect a terraced upland. The Muddy River is tidally influenced and occupies an old course of the Androscoggin River. It is an example of antecedent drainage being drowned by rising sea level (Adkins, 2000).

high synglacial sea-level stand. As the ice margin passed through the Brunswick quadrangle, all the present-day land below about 270 feet was completely submerged. The areas above 270 feet in the quadrangle were islands and those areas just below that elevation were shoals. The tidal range in the Gulf of Maine during this time was less than a meter (Scott and Greenburg, 1983).

The distribution and orientation of ice-marginal glaciomarine and moraine deposits also reflects the flow of ice indicated by the striation direction data. The moraines and glaciomarine deposits occur along a trend near perpendicular to the striation directions and indicate that the glacier withdrew from the modern coastal zone and progressively retreated inland as a near east-west trending, 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 4.

As the ice retreated, it was pinned on bedrock highlands and was grounded in the intervening low areas as evidenced by the 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.

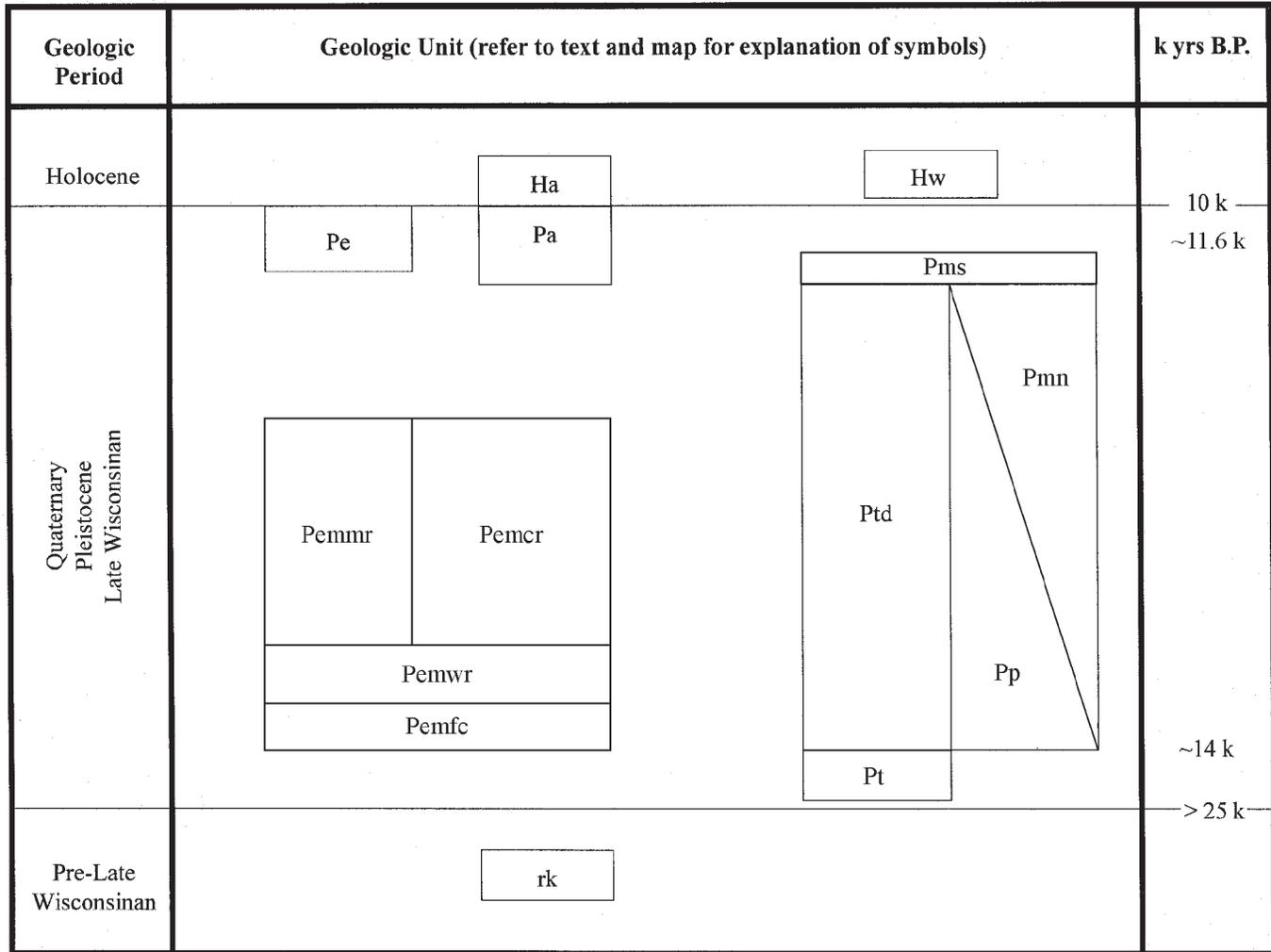


Figure 4. Schematic chart showing correlation of geologic units in the Brunswick 7.5' quadrangle. End moraine (Pem) and marine fan (Pmf) units are read from left to right and bottom to top, corresponding to west to east and south to north, respectively, on the surficial geology map. Age estimates are in uncorrected radiocarbon years.

tion, which appears to have been slightly lobate down valley. There are few of these deposits mapped in the Brunswick quadrangle, in part because much of the older deposits are masked by the Presumpscot Formation (Pp), younger nearshore deposits (Pmn), and the Brunswick sand plain (Pmdr, discussed below). However, the few moraines in the Brunswick quadrangle can be reasonably correlated with ice-marginal features in adjacent quadrangles (Lisbon Falls South and Freeport quadrangles, Weddle, 1997, 1999).

The oldest ice-marginal position in the Brunswick quadrangle is represented by the First Church moraine (Pemfp) and adjacent unnamed moraines in the southeast corner. These deposits may be associated with moraines along the same trend in the Freeport quadrangle (Frost Gully 1 and Merrill Brook end moraines). The next recognizable ice-margin deposit is in the southwest corner of the quadrangle, the Woodside Road end-moraine complex (Pemwr). This group of moraines is correlated

with deposits that mark a strong ice-marginal position identified in the Freeport and Lisbon Falls South quadrangles, delineated by the Bunganuc Stream moraine, Pleasant Hill fans, Frost Gully 2 moraines, and Hedgehog Mountain fan in these quadrangles. The Cathance River moraines (Pemcr1) are the next youngest series of moraines found to the north, and the younger group (Pemcr2) are correlated with the adjacent Meadow Road moraines (Pemmr) in the Brunswick quadrangle. These two sets of moraines are broadly correlated with the large Cox Pinnacle moraine and fans and Pejepscof fans in the Lisbon Falls South quadrangle. Radiocarbon age analyses from deposits stratigraphically above the Meadow Road moraines and the Pejepscof fans yield approximate ages of 13,300 and 13,200 yr B.P., respectively, and are minimum ages for the ice margin associated with these deposits (Retelle and Weddle, 2001). The last ice-marginal deposit in the Brunswick quadrangle is the Bradley Pond fan (Pmfbp), which can be correlated with the Little River

fan and Lisbon Falls moraines in the Lisbon Falls South 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. Marine fossils in the Presumpscot Formation are found at several locations in the quadrangle, and some of these have yielded radiocarbon age-dates. Specifically, photo-locality sites 1, 2, and 5 represented on the map and described on the map sidebar provide estimates of time of deglaciation (as mentioned above) and onset of emergence of the land from the sea after deglaciation.

At site 1, fragments and whole pieces of marine organisms including mussels, clams, whelks, and barnacle plates still attached to bedrock are found. Along with the barnacle fragments found on the rock outcrop at the road cut, hard remains of worms and algae are present, as are remains of bryozoans, invertebrates that live in colonies in hard incrustations similar to coral. The barnacle plates from the rock outcrop yielded a radiocarbon age of 12,780 yr B.P., and *Mya arenaria* shells from part way up the section yielded an age of 12,760 yr B.P.

Site 2 is a well documented location (Retelle and Bither, 1989), where the 13,300 yr B.P. age from the Presumpscot Formation overlying the above-mentioned Meadow Road moraines was reported, as well as a 12,800 yr B.P. age from an in-situ mussel and barnacle assemblage found in nearshore deposits over the Presumpscot Formation (Retelle and Weddle, 2001).

Site 5 is a series of cores taken from the New Meadows River (Oakley, 2001). As shown in the map sidebar figure, each core from west to east respectively sampled stratigraphically younger sediment, interpreted as Presumpscot Formation. The oldest units are found in core C, and radiocarbon ages from marine shells in these units from oldest to youngest are 13,280 yr B.P. and 12,460 yr B.P. The ages from shells in the units from core A were inverted, with the youngest stratigraphically below the oldest (12,230 yr B.P.; 12,280 yr B.P.). The stratigraphically highest shell age came from core B, 12,250 yr B.P. The inverted ages in core A and the age in Core B are all statistically within the standard deviation reported for each sample (Oakley, 2001), and thus do not present a problem to the overall younging upward age of the sediment in the cores. The inversion may be due to reworking of shells or sediment slumping during storm events.

Local uplift due to isostatic rebound and emergence of the land occurred during deglaciation and resulted in regression of the glacial sea. From the above discussion of the New Meadows River valley radiocarbon ages, it is clear that deposition of the Presumpscot Formation glaciomarine mud continued as the regression took place. During this relative fall of sea level, nearshore and shoreline deposits were formed. Pleistocene nearshore deposits are found along flanks of uplands, as well as over glaciomarine mud and in low-lying parts of the quadrangle, notably in the western area.

The timing of regression in the Brunswick quadrangle is reasonably well known. In the adjacent Lisbon Falls quadrangle, nearshore deposits were forming at approximately 190 ft asl about 13,200 radiocarbon yr B.P. Relative sea-level in the Brunswick quadrangle had fallen to about 150 ft by approximately 12,800 (Retelle and Weddle, 2001), thus an estimate of relative sea-level fall in the region is about 10 ft / 100 yr. The lowest elevation in the Brunswick quadrangle is at modern sea level, so based on the estimated emergence rate above, and assuming a near steady relative sea-level fall, the marine regression would have been complete in the quadrangle by around 11,300 radiocarbon yr B.P. However, evidence exists for periods of relative stillstands during the marine regression in the region, hence the above estimate of when marine regression in the quadrangle was complete is tentative (Weddle and Retelle, 1995; Retelle and Weddle, 2001).

The marine regression in Maine was not monotonic, but was likely influenced by eustatic sea-level rise, punctuated by periods of rapid increase (Adkins and others, 1998; Bard and others, 1996; Blanchon and Shaw, 1995; Fairbanks, 1989; Locker and others, 1996). The interplay between postglacial rebound and abrupt sea-level rise is seen geomorphically where prominent nearshore landforms including regressive outwash deltas, beaches, and terraces mark apparent stillstands of sea level during the marine regression (Weddle and Retelle, 1995).

The most prominent geomorphic evidence for such a stillstand in the study area is the Brunswick sand plain, an expansive, regressive coastal braid-plain delta (Weddle and Retelle, 1995; Crider, 1998; see Figure 3b on map sidebar; Retelle and Weddle, 2001). This deposit is the most areally extensive unit on the geologic map and is unusual with respect to other sand plains in Maine by virtue of its low elevation. The heads of most sand plains in Maine in the area where the late-glacial sea transgressed can be found at the local maximum marine limit. The highest surface of the Brunswick plain is at an elevation about 150 feet below the elevation of the maximum marine limit in the region, hence it did not form at the time of maximum marine submergence. More likely, this regressive sand-plain was formed by a combination of several factors: (1) increased discharge by the late-glacial Androscoggin River, (2) loss of capacity where the late-glacial Androscoggin River exited from a confined valley to an unconfined valley, (3) reworking of coarse-grained ice marginal sediments deposited during ice retreat through the lowland, and (4) 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-isostatic uplift long enough for the coastal braid-delta to form. The surface of the sand plain gently slopes from west to east, with a gradient of 15 feet/mile. The distal edge of the braid-plain delta is represented on the southwestern lower edge of the Brunswick quadrangle by the slope below 50 feet asl between Merepoint Road and Maquoit Road, and in the central part of the quadrangle in Topsham by the slope below 50 feet asl at the head of the Muddy River. As the

sand plain formed it expanded from west to east, and incised its surface as relative sea-level fell, represented by a series of subtle scarps on the western side of the plain in Brunswick. Stream flow over the plain surface was directed easterly, diverted by the southern part of the plain having been deposited early in its formation. Several scarps at lower elevations between Route 24 north of the Naval Air Station and Jordan Avenue and on the opposite side of the Androscoggin River record the incision of the streams as they became more channeled in the modern course of the Androscoggin valley and toward Merrymeeting Bay. At some point, the stream occupied a channel cut through the plain in east Brunswick from the trailer park 0.75 miles north of Route 1 to Thomas Bay and the New Meadows River on the south. When relative sea-level had fallen below this elevation, the channel switched to the area occupied by Merrymeeting Bay, which today is a tidally-influenced fresh water embayment, with a dominantly sandy bottom.

In any model, the age of the plain is constrained by ages on *Hiattella arctica* shells (13,100 yr B.P.) found beneath the outer edge of the plain at Cooks Corner in Brunswick (personal communication, A. M. Hussey II, 1995); by ages about 12,800 yr B.P. at sites beneath regressive deposits in nearby Harpswell and Topsham, but at elevations just above that of the sand plain; and by the youngest New Meadows River core ages (12,230 yr B.P., Oakley, 2001). The youngest sediment of the New Meadows cores is likely the distal equivalent of the sand plain, and in context with these maximum ages, the plain formed sometime between 12,500 to 12,000 yr B.P. (Figure 11 of Retelle and Weddle, 2001).

Following the deposition of the sand plain, the climate at this time was warming, but vegetation in the area was similar to that found in tundra regions, with much open unvegetated area. Where there is a source for sand and silt, such as the Brunswick-Topsham sand plain, wind-blown deposits and dunes can form. The eolian mantle and dunes discussed previously (Figure 2) began to accumulate at this time and probably continued until vegetation stabilized the sand, between 12,000 and 10,000 radiocarbon yr B.P. (Davis and Jacobson, 1985, Jacobson and others, 1987).

As relative sea-level reached its lowest level around 10,500 well offshore of the modern coastline (Kelley and others, 1992; Barnhardt and others, 1995, 1997), present day drainage became established. Channeling in the low-lying area of the Muddy River, and deep erosion in the glaciomarine mud, such as the gullies now found on the surface of the Brunswick sand plain and along the Cathance River drainage 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 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 near the modern coast to form estuaries.

Due to the melting of the major ice sheets, worldwide rise of sea level eventually overtook the local emergence of the Maine coast, and the sea again began to transgress the exposed land (Barnhardt and others, 1995). This transgression was rapid at first, rising 120 feet in 1600 years (Barnhardt and others, 1997). After about 9,000 radiocarbon yr B.P., the transgression slowed, then increased from 7,000 to 5,500 radiocarbon yr B.P., and slowed again to the present. The transgression continues today, and since historic times, Gehrels and others (1996, 2001) report that it has increased in the last 200 years, corresponding with global climatic warming.

By the time of the second transgression, humans had begun to populate the region (Bourque, 1995, 2001). Adkins (2000) studied the archeologically rich area around Merrymeeting Bay, documenting the adaptation of the native people to a rising sea level. Early archeological sites are located just above head of tide at now-submerged waterfalls in the channels of the Androscoggin River and Muddy River. Later archeological sites are found within the tidally-influenced zone of the bay. The falls were crucial fishery sites during prehistoric and historic times. Reconstruction of the tidal migration into Merrymeeting Bay revealed that sea-level fluctuations correspond with changes in the archeological record (Adkins, 2000). Archeological sites along the Muddy River adjacent to a paleochannel now occupied by wetlands between the Muddy River and the Androscoggin River seemed unusual as habitation sites, considering that the present day Muddy River is a sluggish stream (Figure 3). Artifacts from archeological sites adjacent to the paleochannel indicate human occupation at these sites as early as 5,000 yr B.P. A radiocarbon analysis on a wood fragment from peat overlying sand and gravel in a core from the paleochannel indicates that the channel was active prior to about 2,800 radiocarbon yr B.P. As evidenced by the gravel found below the peat, a more dynamic stream occupied the paleochannel and may have been more attractive for habitation during the period of occupation than at present (Adkins, 2000).

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