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Surficial Geology of the Gray 7.5-minute Quadrangle, Androscoggin and Cumberland Counties, Maine

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INTRODUCTION

Surficial mapping in the Gray 7.5' quadrangle was conducted during 1994 and 1995 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 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 (1985a), 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 Gray quadrangle was mapped previously at reconnaissance level by Bloom (1960) and Thompson (1976). Other modern work incorporating surficial geology in the study area includes Prescott (1979, 1980), and Tepper and others (1985). 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 the Maine Turnpike and Interstate-95, other road and bridge borings courtesy of the Maine Turnpike Authority and the Maine Department of Transportation (MDOT), and MDOT unpublished materials inventory maps which describe many abandoned gravel pits that provided construction material for Interstate 95. Subsurface data from water supply studies for the Gray Water District was provided by John Sevee of Sevee and Maher, Inc., and from studies for Portland Sand and Gravel, Inc., East Gray gravel pit, by Kathy Bither of the Jacques Whitford Company. Other subsurface data was provided by Rebecca Hewett of the Maine Department of Environmental Protection for data from the McKin Superfund site. 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 map lot locations and not necessarily on field observations.) Numerous gravel pit operators and private landowners gave permission to access their property.

LOCATION, TOPOGRAPHY, AND DRAINAGE

The Gray 7.5' quadrangle is located just inland from the Maine coast between 43°52'30" and 44°00'00" N latitude, and 70°15' and 70°22'30" W longitude (Figure 1). It comprises parts of Androscoggin and Cumberland Counties, and parts of the communities of Auburn, Gray, New Gloucester, North Yarmouth, and Poland. Elevations within the quadrangle range from about 100 feet above sea level (asl) in the Royal River valley to over 550 feet asl in the northwestern corner of the quadrangle. The quadrangle has moderate relief, with maximum relief of 477 feet between the Royal River in the southeast and the high-

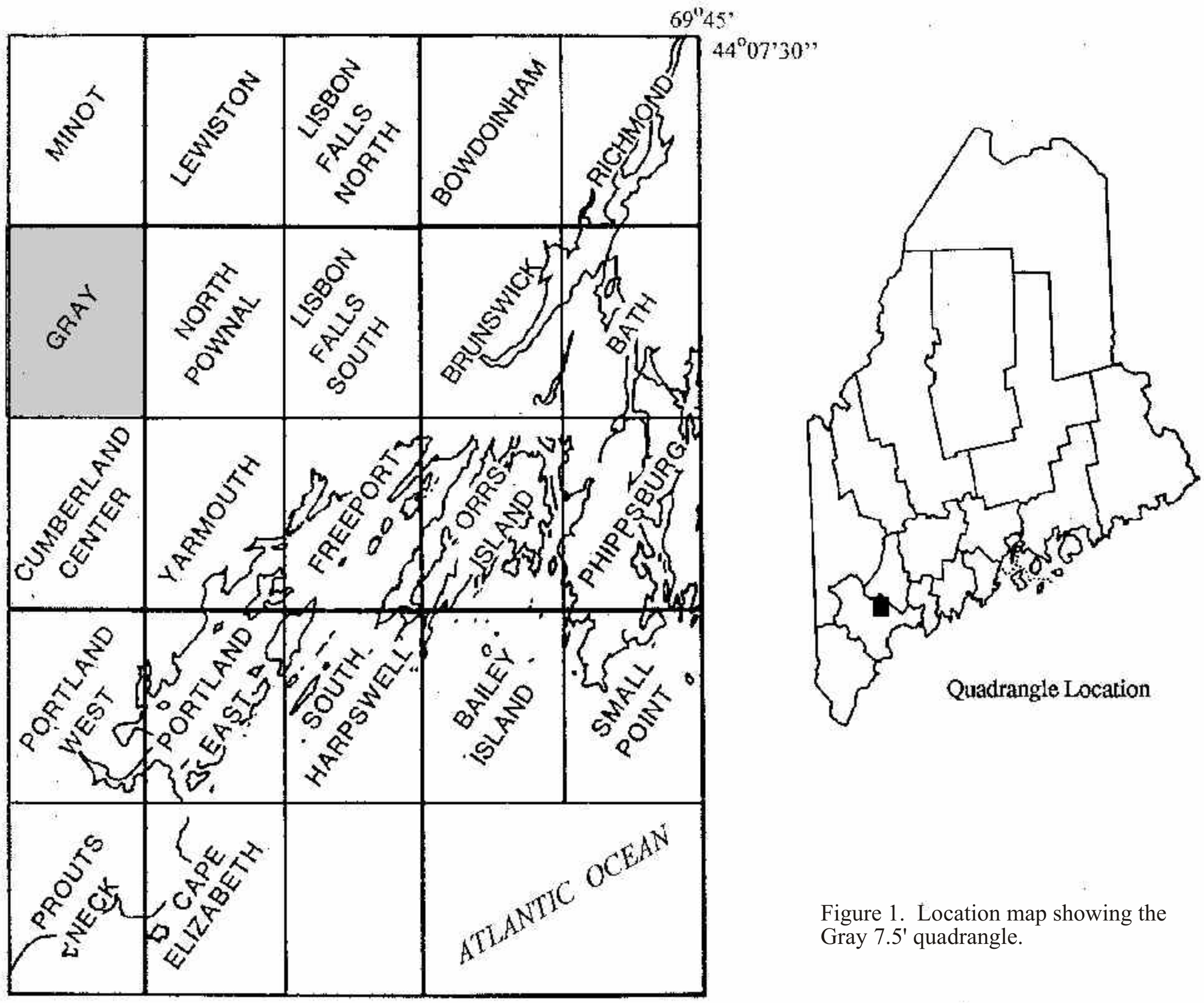

Figure 1. Location map showing the Gray 7.5' quadrangle.

land west of the Shaker Village at Sabbathday Pond in the northwest.

The major drainage in the quadrangle is the Royal River and its tributaries. The river flows from the northwest corner and out of the quadrangle but re-enters it in the northeast, flowing due south in the eastern half of the quadrangle. Drainage in the center of the quadrangle is by tributaries to Collyer Brook, which joins the Royal River at Gray Station. Drainage in the southwest corner of the quadrangle is by headwaters of the Pleasant River, a tributary to the Presumpscot River, which is the next major drainage system southwest of the Royal River.

BEDROCK GEOLOGY

Creasy and Robinson (1997) mapped the bedrock geology of the Gray quadrangle. Bedrock in the quadrangle is chiefly comprised of granitoids of the Carboniferous to Permian age Sebago pluton. Three varieties of granite are recognized, with medium- to coarse-grained textures dominant, although pegmatite is abundant. Metamorphic rocks of probable Silurian or Ordovician age are present in the southeastern and northeastern parts of the quadrangle. However, all are intruded by granite or occur as inclusions in granite and as a component of migmatites. Northeast-southwest trending Mesozoic age mafic dikes are uncommon, but in places cut the older rocks in the quadrangle. Dominant structural features in the quadrangle include northeast-southwest trending joints, and foliation that may represent a northeast-trending, broad antiformal fold in the older rocks. More information on the bedrock geology of the region can be found in Hussey (1988, 1989).

SURFICIAL GEOLOGY

Bedrock and Thin-Drift Areas

Gray dots 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 in an excavation on a streamlined hill along Woodman Road and a gravel pit along Meadow Lane in the northeast part of the quadrangle, and are often found in temporary roadway excavations in upland areas.

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. 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.

Ice-contact straified drift deposts (Pgi). Sand and gravel deposited against remnant masses of glacial ice are common in the western part of the quadrangle, especially near Sabbathday Pond and Crystal Lake. This material is recognized by the coarse-grained texture of its deposits, and the irregular, hummocky topography usually associated with melting ice masses. In the Gray quadrangle, it is found near the ice-proximal zone of glaciomarine deltas, described later in this report. Exposures in the ice-contact sediments found in gravel pits at the northeast end of Sabbathday Pond and in the esker ridge just south of Crystal Lake indicate fluvial deposition in tunnels in the ice, as well as deposition adjacent to ice in local ponds into which coarse sediment was deposited subaqueously.

End Moraines (Pem). End moraines are common in the quadrangle. More moraines than shown on the map are probably present in the area, but are buried under glaciomarine deposits. In general, the moraines have an east-northeast - west-southwest trend (azimuth range 60^{o} - 90^{o}) in the Royal River valley, although west of Colley Hill in the Libby Brook valley moraines have a northwest-southeast trend. The moraines are commonly associated with submarine fan deposits. These moraines are small to moderately large, usually occur in clusters, and are not more than 10-30 feet high, 100-200 feet wide, and 1000-3000 feet in length. The curvilinear orientations of the moraines to the east and west of Colley Hill reflect the importance of the hill as a pinning position of the ice margin. During its retreat, the glacier margin was retarded by the upland, whereas in adjacent lowlands of Libby Brook, Collyer Brook, and the Royal River, the ice front retreated somewhat more rapidly.

Submarine Outwash Fans (Pmf). Submarine outwash-fan deposits are present in several areas in the quadrangle, especially in the Royal River valley and in the Libby Brook lowland between Colley Hill and Crystal Lake. The series of fans in the Royal River valley reflect the trend of a meltwater drainage system in the glacier, as do the fans in Libby Brook valley. In both cases, the fans identify positions where the ice margin remained long enough for the fans to form. Later, as the ice margin retreated to a new position to the north, distal glacial deposits from the more northerly position partially buried the ice-marginal deposits to the south. The Libby Brook valley fans are traceable along trend to other stratified drift deposits north of Sabbathday Pond and on into the adjacent Minot and Mechanic Falls quadrangles as part of an extensive esker system in western Maine (Thompson and Borns, 1985b). The Royal River valley fans are not traceable beyond the north end of the Gray quadrangle, but may be present at depth beneath glaciomarine deposits in the Danville area in the adjacent Minot quadrangle, as shown by test-boring records in Prescott (1979, 1980).

A gravel pit in the Morse Road fan (Pmfm) in the southeast corner of the quadrangle exposed ice-push deformation features in the fan deposits. Northward-dipping low-angle thrust faults offset the deposits of the fan, indicating ice-push from the north. Striations trend 175^{o} on bedrock in the base of another pit in the fan, just south of the thrust-fault exposure. These striations may be older and unrelated to ice-push deformation because the fan ridge trends 60^{o}, not perpendicular to the striation trend. However, the fan ridge is subparallel to the trend of many moraines in the region, and is supportive of an ice-push origin for these moraines.

Glaciomarine Deltas and Alluvial Fans (Pmd; Pgf). Glaciomarine deltas occupy a large area of the Gray quadrangle, most notably the Crystal Lake-Sabbathday Pond-New Gloucester delta complex in the northwest, described by Bloom (1960) as the Gray delta. The deltas in the southern part of the quadrangle include the Gray Meadow (Pmdgm), East Gray (Pmdeg), Gray village (Pmdg), and Libby Hill (Pmdlh) deltas.

The southern deltas are ice-contact deltas built to synglacial sea level in the lowlands along a retreating ice margin pinned by Colley Hill and by uplands to the east and west in the south-central part of the quadrangle. The East Gray delta is the site of a large active gravel operation and one can safely view the internal composition of the delta from an overview on Mayall Road, which runs along the crest of the gravel pit. The northern portion of the pit is comprised of extremely coarse boulder-cobble gravel, which comprises the alluvial fan mapped as Pgf on the surficial map. This fan is in part a source for the delta and the coarse deposits can be traced southward at the surface of the pit to less coarse fluvial topset beds underlain by east-dipping and south-dipping foreset beds.

Crossen (1984) studied several of the deltas in the Gray quadrangle, measuring topset/foreset elevation contacts and foreset bedding in the East Gray (289 ft asl) and Libby Hill (302 ft asl) deltas. The East Gray delta topset/foreset contact is lower than the Libby Hill contact and may be due to ice-contact collapse resulting in a lower contact elevation in the portion of the East Gray delta where the measurement was made. Precise surface elevations near the outer edge of the East Gray delta at the McKin Superfund site and estimation of topset-bed thickness from photos of the site excavation enable a topset/foreset contact to be interpreted at 295 ft asl. However, this elevation, too, is at a lower elevation than the Libby Hill delta, and hence must be considered a minimum value for relative sea level when the East Gray delta formed.

Crossen (1984) interpreted the East Gray delta to have formed when a large ice block became detached from the ice-margin in the lee of a bedrock ridge. The ridge subsequently pinned the ice margin on its stoss side and meltwater streams passed through low areas in the ridge and deposited the delta on the lee side (Crossen, 1984; Thompson and others, 1989). This interpretation is modified here to include a delta complex formed by a northward-retreating ice-margin, with sequential positions through time. The positions are based on topographic expression including ice-contact slopes, collapsed and kettled topography, grain-size charateristics of the deltaic deposits, as well as meltwater channels on the hillsides and on the surface of the deltas. The sources of the delta complex include the meltwater system represented by the fans in the Royal River valley and the Libby Brook fans. An excellent example of an ice-contact slope representing an ice-marginal position is the East Gray delta slope north of Mayall Road.

The East Gray delta is the site of one of the largest and deepest kettle holes in Maine (Leavitt and Perkins, 1935; photograph on page 98 of that report). Much of the kettle has been mined away by the gravel operation, but it still can be seen on the Gray topographic map. Also, the delta is the site of the McKin Superfund site, one of the earliest identified locations of this designation (Tolman and others, 1995). Other activities impacting land use on the deltas in the southern part of the quadrangle include a municipal landfill, municipal water supply, and gravel extraction operations.

The extensive delta complex comprised of the Crystal Lake-Sabbathday Pond-New Gloucester deltas is described by Crossen (1984) as a compound delta formed at the marine limit by a coalescing of the three deltas as they prograded seaward. The marine limit is the inland extent and highest elevation that marine waters covered the region during the time of deglaciation. This delta complex continued to accumulate sediment from glacial meltwater streams, in particular from ice in the Sabbathday Pond drainage basin in the Gray and adjacent Minot quadrangles, as evidenced by incised channels on the surface of the New Gloucester delta (Pmdng) and associated ice-contact deposits (Pgi). Also, meltwater channels incise the surface of the Sabbathday Pond delta (Pmdsp), and an apparent topset/foreset contact at 283 ft asl at the southern end of the delta on the site of the Dry Mills Fish Hatchery and Game Preserve (now Maine Wildlife Park, Gray), well below topset/foreset contacts and the surface elevations of deltas to the south, infers delta progradation to a regressive sea level.

Presumpscot Formation

Glaciomarine mud (Pp) in southern Maine 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, or 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 sediment 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 is found at the Penny Road fan (Pmfp) near the east-central border of the quadrangle. Fossil shells of *Portlandia arctica* have been found in this exposure, and were analysed for a radiocarbon age. The analysis provided an estimate of 10,060 ± 90 yr B.P. (AA-10163), but the ratio of the $^{13}C/^{12}C$ value of the shell (-18.8 $^{o}/_{oo}$) is well outside the normal range of characteristic values of $^{13}C/^{12}C$ in marine shells (range +3 to -2 $^{o}/_{oo}$), hence the age is not valid, possibly due to reprecipitated carbonate on the shell. At other locations in the region, similar shells found at similar elevation have provided reliable age estimates ranging between approximately 14,000 and 12,500 radiocarbon yr B.P. However, note that all radiocarbon ages reported in this text are uncorrected for the ^{14}C marine "reservoir" effect (Mangerud and Gullicksen, 1975; Arnold, 1995).

A sandy facies of the Presumpscot Formation 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 Gray quadrangle, as well as at locations in adjacent quadrangles and in test-boring reports in the area. However, the informal term "sandy Presumpscot Formation" 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 Gray 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 the Gray 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 do not necessarily have a shoreline morphology. Thick nearshore deposits (Pmn) shown on the map are found flanking the slopes of the southern region deltas, and at the northern part of the Royal River valley in the northeast corner of the quadrangle.

Nearshore deposits often are associated with thin-drift areas, and 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), for example in a gravel pit on the thin-drift upland (Ptd) in the southeast corner of the quadrangle. This unit is found at approximately 280 ft asl, close to the marine limit, the latter being approximately 300 ft asl as indicated by the flat-topped surfaces of the deltas and surveyed topset/foreset contacts in the quadrangle. The nearshore deposit thus approximates the position of the synglacial shoreline prior to or soon after the start of rapid isostatic emergence of the region.

Pleistocene alluvium (Pa) deposits are fluvial trough cross-bedded gravelly sands formed in a braided-stream environment in the Royal River valley in the area between Sabbathday Pond and the Maine Turnpike. Several terrace levels in the valley have incised the New Gloucester glaciomarine delta deposits (Pmdng). These streams were probably glacial meltwater streams derived from ice in the Sabbathday Pond basin in the adjacent Minot quadrangle to the north. A gravel pit in these deposits exposed a kettle-hole whose surface was in the lowest terrace. The kettle-hole was where a buried ice-block had melted, and the exposure showed collapse structures in the underlying glacial deposits. These deposits were subsequently overlain by stream terrace alluvium, which similarly was collapsed, indicating the ice-block was still present when the alluvium was deposited. The incised surface of the glaciomarine delta represents streams graded to a relative falling sea level. Test-boring data at lower elevations along the Maine Turnpike to the north of the incised delta record thick sand over glaciomarine mud. The sand most likely represents redisributed sand from the incised delta (Weddle and Retelle, 1995).

Holocene Deposits.

Eolian deposits are common in the area. However, they are not shown 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 Gray 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 generally vary within 10^{o} - 15^{o} of 180^{o}. Good examples of streamlined hills are found in the north-central part of the quadrangle in New Gloucester. One striation trends 140^{o} and is found on a highland near the Pineland Hospital in the southeast corner of the quadrangle. In the adjacent North

Pownal quadrangle to the east (Marvinney, 1999a,b) and Raymond quadrangle to the west (Retelle,1997a,b), several upland striations trending near 140° are present. Although no relative age relationship of striations has been observed in the Gray quadrangle, in other nearby quadrangles where multiple-striation localities are found, southeast-trending striations are more commonly older than the south- and southwest-trending striations (Weddle, 1999a,b; 1997a; Maine Geological Survey, unpublished data).

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 ± 95 yr B.P. (Weddle, 1999a,b) from a *Portlandia arctica* shell in glaciomarine deposits in Freeport was reanalysed because its $^{13}C/^{12}C$ value (-9.1 $^{o}/_{oo}$) is well beyond the suggested mean $^{13}C/^{12}C$ 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 ± 55 yr B.P. (OS-18899; $^{13}C/^{12}C$ -1.15 $^{o}/_{oo}$). However, an age analysis on *Mytilus edulis* shells found in mud overlain by nearshore deposits in Phippsburg (13,600 ± 380 yr B.P. [GX-21931; Weddle and Retelle, 1998]) 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 was approximately 300 feet above modern sea level (Thompson and others, 1989). The shoreline deposit (Pms) south of the Pineland Hospital represents this high synglacial sea-level stand, as do the delta surfaces in the quadrangle. As the ice margin passed through the Gray quadrangle, all the present-day land below about 300 feet asl was completely submerged. The areas above 300 feet asl 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 submarine and deltaic deposits also reflects the flow of ice indicated by the striation direction data. The moraines and glaciomarine deposits occur along a trend nearly perpendicular to the striation directions and indicate that the glacier withdrew from the modern coastal zone and progressively retreated inland as a nearly 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 2.

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, which appears to have been slightly lobate down valley.

The ice-marginal positions inferred on the map are found in the lowlands of the Royal River and Libby Brook. These two areas are separated by central highlands and bordered by highlands to the east and west. The oldest ice-margin positions identified are associated with the deltas formed along a retreating ice margin pinned by Colley Hill and by uplands to its east and west in the south-central part of the quadrangle. Subsurface test-boring data from the McKin Superfund site describes coarse-grained deposits at depth in the Royal River valley (unpublished reports, Maine Department of Environmental Protection; personal communication, Janet Stone, U.S. Geological Survey). These deposits most likely represent glaciomarine fan deposits formed at about the same time as the East Gray delta.

The most southern delta, the Gray Meadow delta, may have formed when the ice margin was at the most southerly position shown in the East Gray area. It is unclear where the ice margin for the Gray Meadow delta was located because the surface of the delta has been reworked and strongly incised by younger fluvial deposits and no ice-contact deposits were observed in exposures in the Gray Meadow delta. It may be that it formed when the ice margin was at the next northerly position, shown along the southern end of the great kettlehole in the East Gray delta. However, because of the extensive coarse-grained material in the subsurface found in the Royal River valley to the east, the Gray Meadow delta is thought to have formed at a slightly earlier time than the main body of the East Gray delta.

As described previously, the East Gray delta was formed as the ice margin was pinned along Colley Hill and constructed by multiple meltwater sources, including a glacial meltwater drainage system in the Royal River valley represented by the submarine outwash fans in the valley, and from a source best represented by the extensive channels in the coarse glaciofluvial fan sediment on the east side of Colley Hill, as well as the alluvial gravel itself. Dip direction in uncollapsed foreset beds in the delta have an average southwesterly trend of 204°. However, meltwater channels on the surface of the delta trend easterly, and photographs of excavations of the McKin site show foreset beds with apparent eastward dip.

The Gray village delta on the west side of Colley Hill formed at about the same time as the East Gray delta. Meltwater channels on the west side of the hill mark ice-marginal positions. The channels on the hill extend onto the surface of the delta, reflecting the approximate positions of the ice margin as it retreated northward. Similarly, the Libby Hill delta on the east side of Libby Hill formed as the ice margin in the Libby Brook valley retreated, its positions marked by kettleholes on the surface of the delta. Although the ice margins shown on the map in the

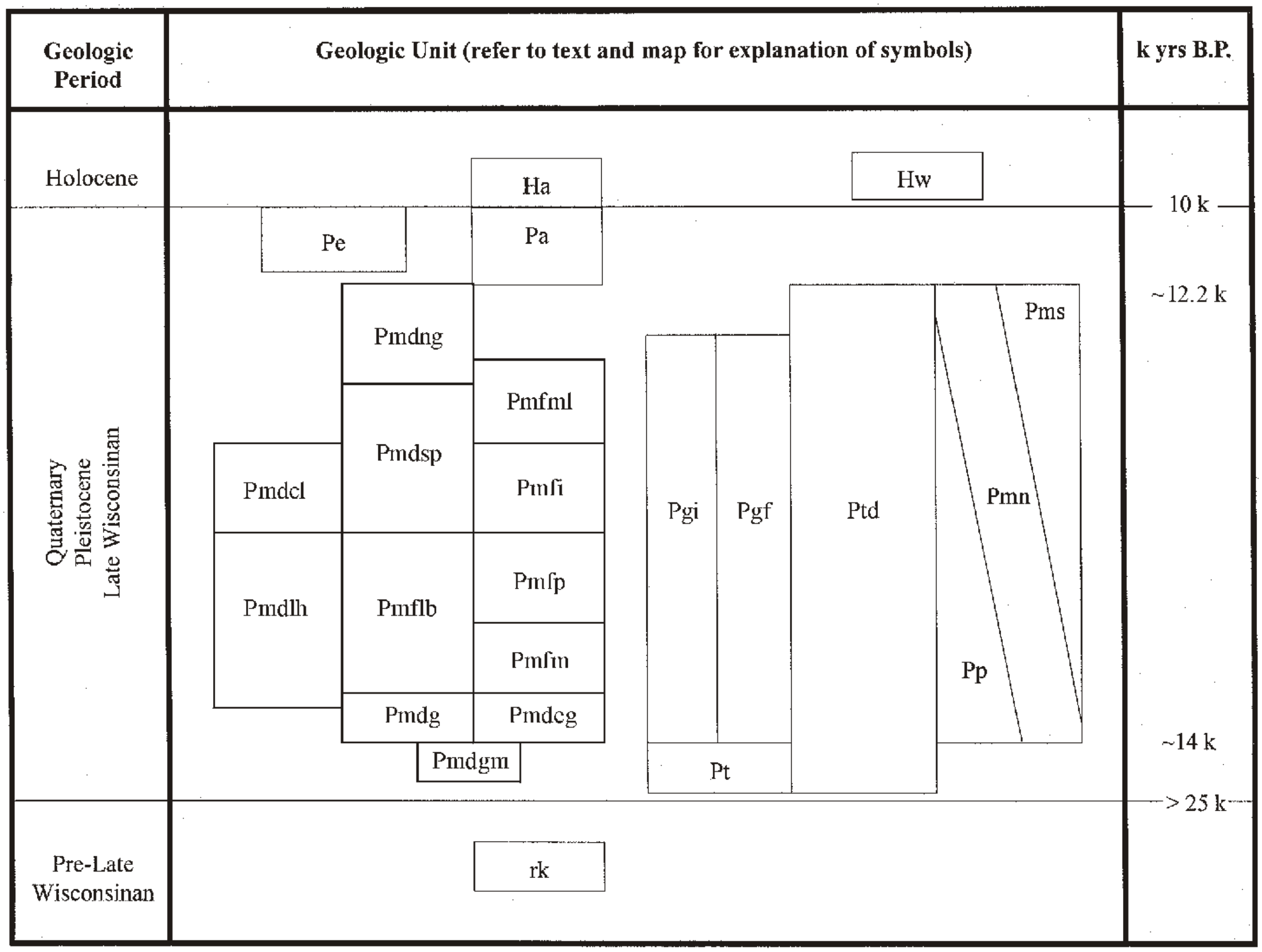

Figure 2. Schematic chart showing correlation of geologic units in the Gray 7.5' quadrangle. End moraine (Pem), delta (Pmd), and marine fan (Pmf) units are read from left to right and bottom to top, corresponding to west to east and south to north, respectively, on the surficial geology map. Age estimates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

Royal River and Libby Brook valleys are not correlated with one another, it is clear by the form of the inferred-margin lines that a slightly lobate margin was present in the lowlands. Also, the lobate margin is represented in the low area north of Colley Hill by the trend of moraines and ice-marginal positions associated with the Libby Brook submarine outwash fans and the ice-marginal positions south of Crystal Lake.

An ice-marginal position north of Crystal Lake supplied sediment to the Crystal Lake delta (Pmdcl) and the associated ice-contact deposits and glacial alluvial fan at the north end of the lake. Submarine outwash fans in the Royal River valley near Intervale, east of the streamlined hill uplands in New Gloucester, may be associated with the Crystal Lake ice margin.

North of this series of margins, the next ice-marginal position is the ice-contact head of the Sabbathday Pond delta (Pmdsp), at the southern end of Sabbathday Pond. The Sabbathday Pond delta is the largest delta in the quadrangle, covering approximately 6 sq mi of land surface area. Meltwater from the ice margin in the Sabbathday Pond area continued to supply sediment to this delta for a relatively long period of time to create a delta of this size. The drainage basin of Sabbathday Pond is small, hence the meltwater source had to be present in the basin to build the delta. Although a large block of ice occupied Sabbathday Pond after the ice margin had retreated to the north, and could have been partly responsible for the meltwater, it would require much more water (via a tunnel) to deliver all the sediment of the Sabbathday Pond delta. The next delta to the north, the New Gloucester delta (Pmdng) was formed by meltwater deposits originating north of Sabbathday Pond in the adjacent Minot quadrangle, but still in the drainage basin. This delta and adjacent ice-contact deposits are deeply incised by meltwater channels in which the Royal River now flows. The meltwater channels attest to the nearby glacial source within the basin to form the deltas and the meltwater channels.

Just south of Snows Hill, a kettle pond called the Sinkhole is located on the surface of the Sabbathday Pond delta. Davis and Jacobson (1985) report a radiocarbon age estimate from a core taken from the kettle pond (12,710 ± 125; SI-4567), as well as a similar age from Poland Spring Pond, another kettle pond to the north on the adjacent Minot quadrangle (12,860 ± 325; SI-4656). Although these are bulk-sediment age analyses, they are close in age compared with other radiocarbon age analyses in the region. A marine shell from an ice-marginal glaciomarine delta in Lewiston just to the northeast provided an AMS-radiocarbon age 12,980 ± 85 yr B.P. (Weddle and Retelle, 1995). It should be noted that because of the poor accuracy, bulk sediment age analysis has been questioned (Wohlfarth, 1996), and the marine reservoir correction associated with marine shells (Mangerud and Gullickson, 1975) is unknown for the Pleistocene Gulf of Maine. The age of the kettle pond cores may be older than the true age of the start of deposition of the core material because they may contain older redeposited organic material. Also, the core may contain organic remains from aquatic plants that derive their carbon from non-atmospheric sources, hence the reported age may be inaccurate. However, these age analyses are considered provisional values, tentatively supporting a time of deglaciation of the northern part of the Gray quadrangle sometime prior to 13,000 radiocarbon yr B.P.

The Presumpscot Formation (Pp) was deposited coevally 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.

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. on *Mytilus edulis* from nearshore deposits in a pit at approximately 200 feet (61 m) asl in the adjacent North Pownal quadrangle to the east records the earliest date for marine regression in the immediate area. During this relative fall of sea level, nearshore and shoreline deposits were formed. Pleistocene nearshore deposits are found along glaciomarine delta flanks and fronts, as well as overlying glaciomarine mud over a considerable area in the quadrangle; and wave-cut terraces have been reported on the delta slopes (Crossen, 1984, 1991).

The timing of regression in the Gray quadrangle is not very well known. If as in the adjacent quadrangles, nearshore deposits were forming at approximately 200 ft asl about 13,300 radiocarbon yr B.P., and had fallen to about 150 ft by approximately 12,800 (Weddle and Retelle, 1995, 1998), an estimate of relative sea-level fall in the region can be determined and is about 8.3 ft / 100 yr (2.5 m / 100 yr). The lowest elevation in the Gray quadrangle is at approximately 90 ft, 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 12,200 radiocarbon yr B.P. However, Weddle and Retelle (1995) present evidence 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.

As relative sea-level reached its lowest level around 10,500 radiocarbon yr B.P. well offshore of the modern coastline (Kelley and others, 1992; Barnhardt and others, 1995), present day drainage became established. Deep erosion in the glaciomarine mud, such as the gullies now found in the Royal River valley 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 near the modern coast to form estuaries.

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