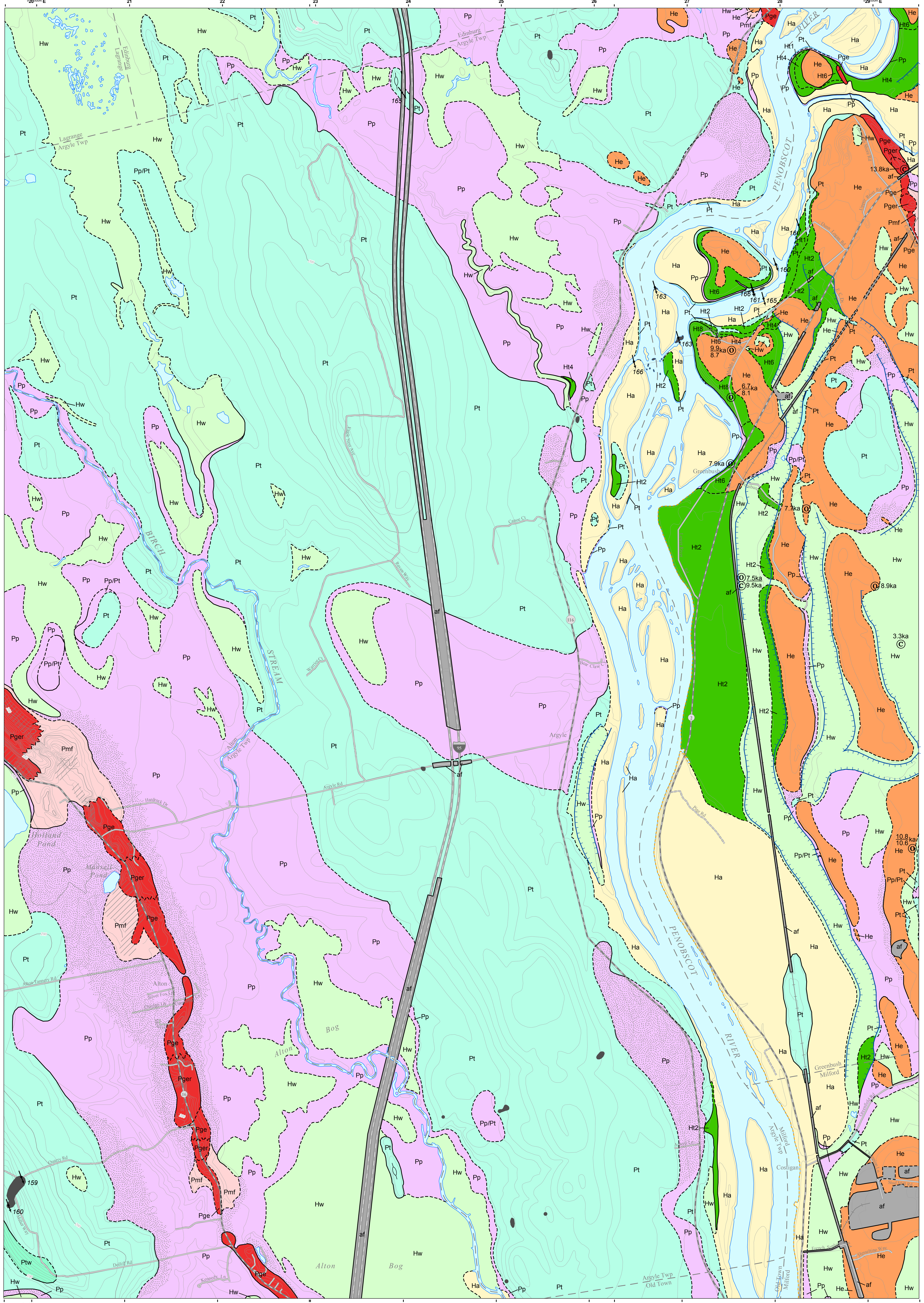
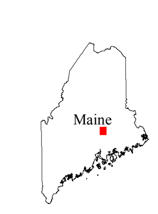
Surficial Geology



SOURCES OF MAP INFORMATION

Surficial geologic mapping of the Greenbush quadrangle was conducted by Roger LeB. Hooke, Elisabet Metcalfe, and Robin Wiesner during the 2005 and 2006 field seasons. Funding for this work was provided by the U.S. Geological Survey EDMAP program and the Maine Geological Survey, Department of Conservation.



SCALE 1:24,000

CONTOUR INTERVAL 10 FEET

Approximate Mean Declination, 2015 16.5° W (not to scale)

Base map features from Maine Office of GIS - 1:24,000 USGS contour lines, E911 roads, 1:24,000 National Hydrography Dataset, USGS GNIS placenames and 1:24,000 political boundaries. Map projection Universal Transverse Mercator, North American Datum, 1927.

The use of industry, firm, or local government names on this map is for location purposes only and does not impute responsibility for any present or potential effects on the natural resources.

Note: The first letter of each map unit indicates the general age of the unit:
H = Holocene (postglacial deposit; formed during the last 11,700 years).
Q = Quaternary (deposit of uncertain age usually late-glacial and/or postglacial).
P = Pleistocene (deposit formed during glacial to late-glacial time, prior to 11,700 yr B.P. [years before present]).

Ha — **Modern flood plain** - Floodplains are those areas that, on average, are flooded once every couple of years. Higher surfaces are terraces. Records from a gaging station at West Enfield suggest that the gage height of the mean annual flood, that with a recurrence interval of 2.33 years, is 4.6 m. Thus, surfaces that would be flooded at this gage height are mapped as floodplain. Floodplains in the Greenbush Quadrangle are typically underlain by moderate to dark yellowish brown, unstratified, mature, rather poorly sorted, very-fine sand and silt. Coarser sands or small-pebble gravels may occur at depth, but some of these are Late Quaternary or early Holocene in age.

Hw — **Holocene wetlands** - Dark gray or black organic muck. Boundaries are largely taken from the U.S. Geological Survey 1:24,000-scale Greenbush topographic map. Contacts between **Pp** and **Hw** in Alton Bog are largely after Cameron and others, 1984.

He — **Eolian deposits** - Poorly to moderately sorted, moderate yellowish brown, medium sand. Dune stratification was observed in exposures in sand pits (Figure 1). Dune forms are diagnostic, but some sand in topographically relatively featureless areas are also mapped as eolian sand. Some of these could be nearshore Pp or abandoned braidplains (terraces - Htx).

Htx — **River terraces** - Medium to coarse sand or larger material, up to pebble gravel underlying topographic terraces. Well stratified in good exposures. Formed during a period of river aggradation between ~9 and ~6 ka and later incised. The digit at the end of the symbol is the approximate height in meters above the modern floodplain.

Pmf — **Submarine fan** - Medium sand to pebble gravel deposited downflow from an esker head (**Pger**). Fans are inferred to have formed in the sea where esker-building glacier meltwater flows, having left their gravel load in an esker head as they emerged from a subglacial tunnel, deposited finer material in a submarine fan. The fan may drape a continuation of the esker.

Pge — **Esker gravels** - Ridges of pebble or small-cobble gravel, commonly draped by fine sand (nearshore **Pp**).

Pger — **Esker head** - These are areas where, when traced southward, an esker rises gradually and then drops off sharply or (in some quadrangles) merges with a delta. Downflow (southward) the esker gravels typically interfinger with and eventually transition to sand in submarine fans. Some are also draped by fine sand (nearshore **Pp**).

Pp — **Presumpscot Formation** - Moderately-sorted silt, clayey silt, or silty clay, commonly light gray (ca N6 or N7), but may be light olive gray (5Y 5/2) to pale yellowish brown (10Y 6/2) where oxidized. Commonly stiff or compact.

Pp — **Nearshore facies of the Presumpscot Formation** - Poorly-sorted silt to very fine sand, commonly oxidized to moderate yellowish brown (10YR 5/4). Inferred to have been deposited in a marine environment with slightly higher energy than that of the silt or clayey silt facies. Commonly found between Presumpscot Formation (**Pp**) and higher ground.

Pt — **Glacial till** - Poorly sorted silty fine- to medium sand with granules and small pebbles in soil probe samples, and pebbles, cobbles, and boulders in road cuts. Scattered cobbles and boulders commonly protrude from the ground surface.

Ptw — **Water-washed till** - This is the inferred origin of a gravel deposit in the southwestern corner of the quadrangle in the lee of a bedrock hill. Beds display a pseudo-anticlinal structure, inferred to have been formed in a subglacial cavity (Figure 7).

Bedrock outcrops - Size of exposures is typically exaggerated for clarity.

af — **Artificial fill** - Areas of fill emplaced by humans. Shown only where sufficiently extensive to map.

Contact - Boundary between map units. Dashed where approximately located. Sawtooth where gradational or interfingering.

Glacial striation locality - Symbol shows trend of glacial ice-flow inferred from striations on bedrock. Dot marks point of observation. Number is azimuth (in degrees) of flow direction.

Glacially streamlined hill - Symbol shows long axis of hill or ridge inferred to have been shaped by flow of glacial ice. Axis is parallel to former ice-flow direction.

Gravel pit.

Stream channel (paleochannel bank) - Bank of abandoned stream channel associated with stream terraces.

Optically stimulated luminescence age on sand dune. Ages are in thousands of years before present. When dates are shown as 9.9/8.7 the upper date is from a sample that was stratigraphically higher than the lower one.

Calibrated radiocarbon date.

SOURCES OF RELATED INFORMATION

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Greenbush Quadrangle, Maine

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SURFICIAL GEOLOGIC HISTORY

During the advance of the Laurentide Ice Sheet in the late Wisconsin, the bedrock in the Greenbush quadrangle (low- to medium-grade metasedimentary rocks of the Siluro-Ordovician Vassalboro Formation (Osberg *et al*., 1985)) was scoured by the ice and then largely covered by till. During deglaciation, water draining along the bed melted tunnels upward into the ice. Coarse gravels were deposited in these tunnels. When the ice melted, the gravels were left as ridges, now called eskers (**Pge**). One such esker cuts across the southwest corner, and another across the far northeastern corner of the quadrangle. When the eskers were forming the land was still depressed below sea level by the weight of the ice and the glacier ended in the sea. Measurements of the marine limit in nearby areas (Thompson and others, 1989) suggest that only the top of the esker on the western edge of the quadrangle is likely to have been above sea level. There is a subhorizontal bench at 90 m on this esker ~250 m west of the quadrangle boundary; this appears to be ~10 m too low to be related to the marine limit, but could be correlative with prominent wave-cut benches in two deltas in downeast Maine that are a similar distance below the marine limit, and with other benches 4 - 6 m below the marine limit cut into deltas north of Medway.

Wherever the ice margin remained in one location for a period of years during retreat, the esker-forming water melted large portals in the ice margin. The water velocity decreased as it expanded from the tunnel into these portals. This deceleration led to deposition of coarse-grained "esker heads" (**Pger**) in the portals and of finer grained submarine fans (**Pmf**) (Figure 1) downflow from the portals. Further retreat commonly left a drape of sand over the esker (Figure 2). Farther from the ice front, silt and clay settled out of the water, forming a layer of marine mud over the till – the Presumpscot Formation. Along the Penobscot River, Presumpscot clay is locally greater than 7 m thick, and because it is weak and plastic, it has a tendency to slowly collapse into the river (Figure 3), sometimes taking roads or houses with it.

During a minor readvance, small clam shells (*Hyatella arctica*) were dragged up onto the esker head in the northeast corner of the quadrangle. A pod of clam shells (*Hyatella arctica*) on top of this esker head *appears* to have been dragged into place during a minor readvance of the ice. A ^{14}C date on these shells places the ice margin here 13,780±50 years ago (11,920±50 ^{14}C years ago after making a 600-year reservoir correction). This date is likely too young, however, as other dates (Borns and others, 2004), place the margin already 65 km further north 1300 years earlier. On the basis of the latter and other dates reported by Borns and others, the ice margin was probably retreating across the Greenbush quadrangle about 15,300 years ago.

By about 14,000 years ago the ice margin had retreated to northern Maine, but the Greenbush quadrangle was still largely under water and marine muds were still slowly accumulating. Comparison with a relative sea level curve compiled by Barnhardt and others (1995) suggests that the quadrangle probably emerged above sea level about 13,000 years ago. As the land emerged, wave action and then rainfall eroded the Presumpscot from most of the higher areas. As the sea retreated, the Penobscot River spread coarse sand and gravel along its lengthening course. Gravel, likely from this time period, can be observed beneath the modern floodplain in many places.

The lowest stand of sea level, ~60 m below present sea level, occurred about 12,000 years ago (Barnhardt and others, 1995), but bedrock outcrops south of the quadrangle limited any effect this had on the river in the Greenbush quadrangle.

Between ~12,000 and ~9,000 years ago, flow in the Penobscot River decreased as the last ice in the headwaters melted, the climate became drier (Webb et al. 1993), and rebound of the land shifted the drainage of Moosehead Lake from the West Branch of the Penobscot River to the Kennebec River (Balco et al. 1998; Kelley et al., 2011). The drier climate persisted to ~7,000 years ago.

During the dry spell, sand, likely blown in by the prevailing westerly winds, accumulated in eolian dunes (Figures 4 and 5). The most extensive dunes lie east of the Penobscot River, suggesting that the river was a source of sand. However, a few kilometers north of the quadrangle other dunes lie west of the river, implying a more westerly source. The sand delivered to the Penobscot valley exceeded the river's ability to move it and, although a lot was carried down to Penobscot Bay where it formed a delta that is now submerged (by a further rise in sea level) off Castine (Belknap *et al*., 2005), a lot was also deposited in the valley. This resulted in aggradation of the river bed and formation of a braidplain ~6 m above the modern floodplain (Figure 6). After ~6,000 years ago the climate became wetter, former sediment sources became stabilized by vegetation so the sediment supply decreased, and the river began to cut down, leaving the braidplain as a terrace (**Ht6**) in the northeastern quarter of the quadrangle. This terrace is informally named the Sugar terrace as it is well developed on Sugar Island. In places the braidplain sediments in it are as much as 8 m thick. Pauses in the downcutting left local strath terraces. In the Greenbush quadrangle these are typically 1 to ~4 m above the modern floodplain.

During the period of aggradation, the river was apparently more extensively braided than it is today. Linear wetlands (**Hw**) east of the river are interpreted to be paleochannels dating from this time period. Coring transects across two of these wetlands at ~45°4'N show that the peat is generally less than 2.5 m thick, and is underlain by coarse sand, presumed to be fluvial in origin. Calibrated radiocarbon dates from the basal peat in the eastern and western of these paleochannels suggest that the channels were abandoned ~3,300 and ~9,500 years ago, respectively. The latter date is puzzling because the thalweg of the channel is ~5 m below the Sugar terrace, so one would expect that it would have remained active until after the river began to cut down through the Sugar braidplain, leaving it as a terrace, ~6,000 years ago. If the date and our interpretation is correct, the channel must have become blocked by dunes and by the aggrading main stem of the river.

Downcutting of the Penobscot was likely largely arrested between 5,000 and 4,000 years ago by exposure (or re-exposure) of bedrock outcrops. One such outcrop is ~2 km south of the northern edge of the quadrangle and another is ~3 km south of the southern edge. These and other bedrock thresholds further north, separate the river into stretches with low gradient between thresholds, so the river now carries a light and rather fine sediment load, and has been building its present floodplain.

During the last 9,000 years or so, wetlands (**Hw**) have formed throughout the quadrangle as lakes either drained or became filled with sediment.

Hooke et al. (in press) provides a more detailed discussion of the river history, including details of all the dates, will be submitted for publication in the near future.

Figure 1. Photograph, looking upflow, of downflow side of large esker head on eastern side of quadrangle, showing sand deposited in fan.

Figure 2. Photograph, looking downflow, of upflow side of esker head in Figure 1 showing sand drape. Gravel core is inferred to be buried under sand. Gravel is exposed in another pit to left (east).

Figure 3: Road (pavement visible on right under fence and in distance) damaged by collapse of Presumpscot Formation. Note exposure of square cement-block casing around old storm drain in center of image. (Site is at 45°5'N, 38°54'W)

Figure 4. Eolian Dune 3. This dune was last active about 11,300 years ago.

Figure 5: Eolian dune topography in vicinity of the 9.9/8.7 dates in NE quadrant of quadrangle. The dates suggest that the dune was last active about 9,900 years ago.

Figure 6. Typical braidplain sands and gravels. Exposure is in south end of Qsp2 terrace on west side of the Penobscot River, about 0.7 km north of the southern edge of the quadrangle.

Figure 7. Water washed gravels (**Ptw**) in lee of hill in southwestern corner of quadrangle.

ACCURACY OF MAPPING

Road cuts, river banks, and gravel pits provided the best exposures in the quadrangle, but were not common. Elsewhere, a soil probe was used to obtain samples from a depth of, usually, ≥0.3 meters. Occasionally a hand auger was used to get samples from as deep as 2 meters. Observation points were located by hand-held GPS; most are shown on the accompanying surficial materials map (Hooke and others, 2008); some were omitted for clarity.

Many of the map units are quite similar in appearance. Poorly sorted fine to medium sand can be found in eolian sand dunes, in the modern floodplain, and in braidplains. Thus, in the absence of other data such as topographic expression and/or the height above the Penobscot River, distinguishing among these units can be problematical. Similarly, silt can be found in the floodplain or in the Presumpscot Formation, although the latter is generally more compact.

Finally, pebble gravels, similar to gravels in modern river bars, were found beneath modern floodplain deposits in several places. In two of these, a few decimeters of mottled moderate yellowish brown silt separated the gravel from the darker, less well sorted floodplain silt. The contact between the two silts was sharp, suggesting that the lower one was Presumpscot, not floodplain. If that is the case, the gravels must predate the Presumpscot, and are presumably local ice-contact deposits similar to the grounding line moraines seen elsewhere in Maine (Ashley *et al*, 1991). Alternatively, if the yellowish brown silt is not marine, or is lacking, the gravels could be remnants of a braidplain that existed immediately prior to the initiation of river aggradation.

Thin layers of Presumpscot silt were commonly present on till, and in some instances are shown as Pp/Pt. Wetland deposits <0.5 m thick and resting on the Presumpscot Formation, are generally mapped as Hw.

These uncertainties, in combination with the locally low density of sampling points, may result in some contacts being mislocated by over 100 m. The size of some units, particularly bedrock outcrops and units exposed in river banks, has been exaggerated for clarity.