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Surficial Geology Handbook for Southern Maine

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for
SOUTHERN MAINE

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Cover photograph:

The landslide of January 25, 1973, at Rockland, Maine. Large blocks of clay were tilted by slump movement. Photo by Arthur M. Hussey II.

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Thanks to the Maine Geological Survey and State Geologist Robert Marvinney for supporting this update of the Surficial Geology Handbook that was first published in the 1970s. Prior to his retirement, MGS publications director Robert Tucker encouraged me to undertake the task and made the job easier by providing a digital version of the original text. His successor, Christian Halsted, has carried on with the project by taking my text and figures and formatting them into this publication.

Thanks also to Richard Heath and Mark Stebbins, Maine Department of Environmental Protection, for their help with information on commercial sand and gravel processing methods, and current State regulations for siting of landfills in surficial earth materials.

Discussions with many geologists over the years, along with their maps and publications, have contributed greatly to our knowledge of Maine's glacial and postglacial history, as well as related sea-level changes. I am grateful for collaborations with Harold Borns Jr., Stephen Dickson, Carol Hildreth, William Holland, Joseph Kelley, Carl Koteff, Michael Retelle, Geoffrey Smith, Thomas Weddle, and many other "Friends of the Pleistocene".

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Preface

This publication is an updated version of the *Surficial Geology Handbook for Coastal Maine*, authored by W. B. Thompson and published by the Maine Geological Survey (MGS). The first edition was prepared for the Maine State Planning Office (SPO) in 1978. This was followed in 1979 by a slightly revised second edition. The information in those original handbooks was based largely on surficial geologic mapping for the SPO's Coastal Planning Program. Mapping was carried out by the MGS from 1974 to 1977 in towns included in the Coastal Inventory.

Since that time, MGS geologists and other workers have added a tremendous amount of information to our knowledge about the surficial earth materials in Maine. Much of the information here is the direct result of the MGS surficial geologic mapping program. The MGS first carried out reconnaissance-level mapping over large parts of southern and central Maine during the 1970s. This work was funded largely by regional planning commissions in order to acquire baseline information for land-use planning, evaluation of aggregate resources, and other applications.

In the early 1980s, a grant from the U. S. Department of Energy enabled a program of reconnaissance geologic mapping throughout Maine. This effort involved MGS staff and seasonal contractors for several years, culminating in publication of the *Surficial Geologic Map of Maine* (Thompson and Borns, 1985), as well as the companion *Bedrock Geologic Map of Maine* (Osberg *et al.*, 1985). MGS then published the 6-volume *Studies in Maine Geology* series in 1989, bringing together a collection of papers describing glacial deposits and many other aspects of the state's geology.

Starting in 1986, MGS participated in the U. S. Geological Survey's nationwide Cooperative Geologic Mapping Program (COGEOMAP), which was followed by the STATEMAP program from 1993 to the present. Competitive proposals submitted annually by MGS have generated matching funds from the USGS, enabling production of detailed 7.5-minute quadrangle maps and 1:100,000 regional compilation maps. The information on these geologic maps (and the companion series of surficial materials maps) has been enhanced by subsurface data from sources including MGS significant sand and gravel aquifer maps, well drillers' records, and test-borings by the Maine Department of Transportation.

Besides the knowledge gained from mapping projects, a growing body of student thesis studies and other academic research projects has continually expanded our understanding of Maine's surficial geology. In particular, the complex stratigraphy of marine sediments deposited across southern Maine during glacial retreat is far better understood than when this handbook was originally published!

Along with the exponential growth of geologic studies in recent years, there have been many changes in how the land is used and regulated. For example, the technology of waste disposal has improved at all scales, from the design of leach fields serving one home to large urban landfills. Also, the Maine laws regulating many facets of land use have become ever more complex. It has not been possible for the author to consider all these changes, so the land-use guidelines presented here should be taken as a starting point based on fundamental geologic principles.

Some of the references from the original Surficial Geology Handbook have been retained, and many newer ones have been added. It may be difficult to locate the earlier sources that are now out of print, but a few of them continue to be included if they have useful content that is still valid. Much additional information concerning the topics discussed here can be obtained from searching internet resources. The author has cited a number of key websites with links that will take you directly to them.

The scope of this guidebook now includes much of southern and central Maine, and the practical tips for homeowners and planners can be applied statewide. Many types of surficial geologic features described here can be found throughout Maine, and the majority of Maine citizens may at some point have concerns about water sources, waste disposal, geologic hazards, and other topics discussed in this handbook. It is also hoped that students, educators, and the general public will find topics of interest here.

Chapter 1 - Introduction

The purpose of this handbook is to provide Maine citizens with information about the origin, characteristics, and applications of surficial geologic deposits. Surficial deposits are the unconsolidated earth materials that overlie bedrock. They cover a large percentage of the state and include the sediments deposited by wind, water, and glacial ice. Glacial deposits are by far the most abundant surficial materials in Maine. Ice sheets of continental proportions deposited a blanket of till, sand and gravel, marine silt and clay, and glacial-lake sediments. During and following the disappearance of the last glacier, windblown sand was deposited in some areas, and alluvium began to accumulate along streams. Wetland, lake, ocean shore, and talus deposits have also formed in postglacial time.

Consideration of surficial deposits is an important part of land-use planning. The properties of these materials affect their value as aquifers, landfill or sewage disposal sites, construction sites, and sources of gravel and other natural resources. In some cases, one is confronted with choosing the best of several possible uses of a surficial deposit. In other instances, there may be natural hazards that render a deposit unsuitable for most purposes. This report is intended to familiarize Maine citizens with surficial materials and give them some of the information needed to make sound land-use decisions. However, it is not intended to be a substitute for the detailed on-site investigations that may be necessary for specific projects.

Extensive lowland areas of southern Maine were submerged by the sea in late-glacial time, so the surficial geology of those areas differs in major respects from that of the interior uplands. Modern ocean-shore and lake-bottom deposits are excluded from the present study because they are subjects of marine and lacustrine geology, respectively. Soils are likewise omitted, although they are generally developed on surficial deposits. The reader is referred to the county soil reports by the Natural Resources Conservation Service (formerly the Soil Conservation Service), U. S. Department of Agriculture, for information about Maine's soils and their parent materials.

The metric system is still unfamiliar to many people, so measurements in this report are in English units such as feet and miles. Elevations are also given in feet because this is the unit of measurement on most of the U.S. Geological Survey's topographic maps. Ages of geologic events and features are expressed approximately in years. Many of these ages are based on radiocarbon dating of marine and terrestrial organic materials. However, the radiocarbon results have been corrected to account for a variety of factors in order to convert them to actual years.

Chapter 2 - Origin of Surficial Materials

This chapter provides a brief history of the glacial and postglacial geologic processes that created the surficial deposits in Maine. The different types of deposits will be described individually in greater detail in Chapter 3.

History of Glaciation in Maine

The blanket of surficial sediments that covers Maine was left in large part by glacial ice that formerly extended across all of New England. The glaciers that invaded Maine were vast continental ice sheets, in contrast to the much smaller alpine glaciers that once existed on a few of the state's highest mountains. Some sedimentary materials were deposited directly from the ice. Others were washed into the ocean, deposited in meltwater streams that flowed off the ice, or settled in lakes. The ice sheets that spread across Maine also modified the preexisting topography. Many hills were smoothed and elongated in the direction of ice movement, and valleys were partly filled with glacial deposits.

There is a great difference in age between the bedrock in Maine and the overlying surficial deposits. The rock formations are Precambrian to Mesozoic – from more than 650 million to about 100 million years old (Loiselle, 2002; Marvinney, 2005). Maine's surficial materials are no older than one or two million years. In fact, nearly all of them are probably younger than 100,000 years.

Glaciation has certainly affected the terrain, but the broad topographic features in preglacial time probably resembled what is seen today. The landscape had similar relief, though the mountains must have been higher than their present elevations. Maine had experienced millions of years of weathering, so mountain regions lacked the high cliffs, cirques, and other rugged features that were sculpted later by glacial ice. The preglacial drainage system was probably well integrated, without the many lakes and wetlands that glacial erosion and deposition have created. The surficial deposits that existed in preglacial time resembled the materials that now exist south of the glacial limit in the United States. A thick mantle (regolith) of alluvium, soil, and decomposed rock overlay the solid bedrock.

Glaciers covered Maine at least twice and probably several times during the Pleistocene Epoch, or "Ice Age." This interval of time began about 2,500,000 years ago. The Pleistocene is defined as having ended at approximately 12,000 yr BP (years before present), when the climate became warmer during the onset of the Holocene Epoch. The last glacier had retreated into Canada by this time (Thompson, 2005). The Holocene Epoch encompasses all of postglacial time, right up to the present day.

During the onset of each glaciation, annual snow accumulation in eastern Canada exceeded the amount that melted in the warm months. The continued buildup of snow was accompanied by its compaction and conversion to glacial ice. The glacier attained a great thickness and spread outward in all directions from its source area (which was the vicinity of Hudson Bay during the most recent glaciation). The weight of the ice caused the glacier to deform and flow like a slow-moving river. It eventually entered Maine and advanced south to southeastward across the state.

During the climate warming that followed each glaciation, the ice sheet waned as melting exceeded ice accumulation. The position of the ice margin then retreated generally back toward its source. This cycle of advance and retreat was probably repeated on a statewide scale during each episode of glaciation. The most recent glacier that covered Maine, in what is called "late Wisconsinan" time, was the Laurentide Ice Sheet.

The Pleistocene glaciers removed great quantities of regolith. However, scattered remnants of disintegrated bedrock (rottenstone) still exist in Maine. They represent weathering that occurred during preglacial and/or interglacial times. Each glacier that covered the state presumably left deposits of till, sand and gravel, and other materials that it had eroded and transported. It is also reasonable to assume that rivers, lakes, and wetlands formed their characteristic deposits during the interglacial stages, but the Laurentide Ice Sheet scraped off or left a sediment cover on most older materials. The oldest glacial deposits that one can now see in Maine are tills left by the previous ice sheet of probable Illinoian age. The history and pervasive effects of the most recent continental glaciation are discussed in the following sections.

Late Wisconsinan Glaciation

The most recent glaciation of Maine began about 35,000 years ago as the Laurentide Ice Sheet expanded from Quebec (Borns and others, 2007). It flowed toward the south to southeast, past the present coastline and out onto the continental shelf. The maximum thickness of the ice is uncertain, but it covered the highest mountains in Maine. Boulders of different composition than the local bedrock occur near the summit of Mt. Katahdin (Davis, 1976; Rankin and Caldwell, 2010). They probably were deposited by the late Wisconsinan ice when it overrode the area.

Indicators of Ice-flow Directions

Several lines of evidence indicate the directions of glacial ice movement. Many ice-scoured ledges exhibit parallel scratches (striations) and broader furrows called grooves that were made by stones as they were dragged along at the base of the glacier (**Figure 2.1**). Striations are parallel to the direction of ice flow and sometimes occur in multiple sets that reveal changes in flow direction (**Figure 2.2**). This information not only sheds light on the glacial history of an area; it can also help determine sources of glacial sediments containing traces of economically important minerals (a technique called "drift prospecting").

Figure 2.1a. Glacial grooves on granite ledge in Warren. View looking south-southeast. Two flow directions are recorded here, with the earlier southeast-trending grooves overprinted by a younger south-southeast-trending set.

Figure 2.1b. Side view of ledge in Fig. 2.1a, showing smooth profile of the rock surface caused by glacial ice flowing across it from right to left.

Figure 2.2. Two sets of striations on glacially smoothed bedrock surface at Sullivan Falls in Hancock. The blue pen points in direction of earlier ice flow (140°), indicated by striations preserved on a sheltered lee surface. The red pencil points in direction of latest flow (112°).

Glacial striations and grooves are often seen on rock surfaces that have been freshly exposed at construction sites or by erosion of the sediment cover along the ocean shore. Smooth, glacially polished surfaces are the best places to find them, especially when the ledges are wet. Despite having been created thousands of years ago, striations on the more erodible rock types can be obliterated by just a few decades of weathering after being exposed. They last much longer on quartz veins, even on mountain tops where ledges have been subjected to intense weathering for millennia.

Glacial striations and grooves typically do not indicate the absolute direction of flow, but they limit it to two possibilities such as northwest-to-southeast or southeast-to-northwest. Definite flow directions can be determined where there are certain kinds of erosion marks such as crag-and-tail (**Figure 2.3**). On a larger scale, the ice eroded bedrock knobs into distinctive shapes that are elongated parallel to ice flow and have steeper downglacier (usually south) sides. Such features are called roches moutonnées (**Figure 2.4**).

Figure 2.3. Crag-and-tail markings on shoreline outcrop, Roque Island in Jonesport. Glacial scouring of the outcrop surface left tapering "tails" on the sheltered sides of hard nodules in the rock (the "crags"). These features show that the ice flowed from right to left as seen in the photo.

Figure 2.4. Roche moutonnée near summit of Mount Zircon, Peru. Weathered glacial grooves on the more gently sloping northwest surface of the outcrop indicate ice flow toward the southeast.

Crag-and tail marks, roches moutonnées, and the distribution of glacially transported stones (erratics) collectively indicate that the ice sheet advanced generally from northwest to southeast over most of the state, and not the opposite direction.

Maine’s bedrock hills and mountains commonly show asymmetric profiles. Glacial abrasion and sediment deposition tended to produce smooth and gentle north slopes, while blocks of rock were pulled loose from the south sides of hills, often leaving steep cliffs (**Figure 2.5**). Many hills were streamlined in the direction of ice flow. A few of them (drumlins) are composed of till, but most have till draping bedrock cores.

Figure 2.5. View looking west at Chandler Hill in Bethel. The steep cliff on the south face of the hill resulted from glacial plucking of bedrock.

In some areas, ice movement formed long narrow ridges and furrows on the surface of till deposits. The ridges are similar to drumlins but usually have a greater length/width ratio and many are less than 20 ft high. They may grade into larger streamlined hills and are commonly associated with them. Till deposits with this grooved surface are called "fluted ground moraine" (**Figure 2.6**). The distinction between fluted till ridges and drumlins is somewhat arbitrary, and it has yet to be determined whether different subglacial processes created this spectrum of landforms.

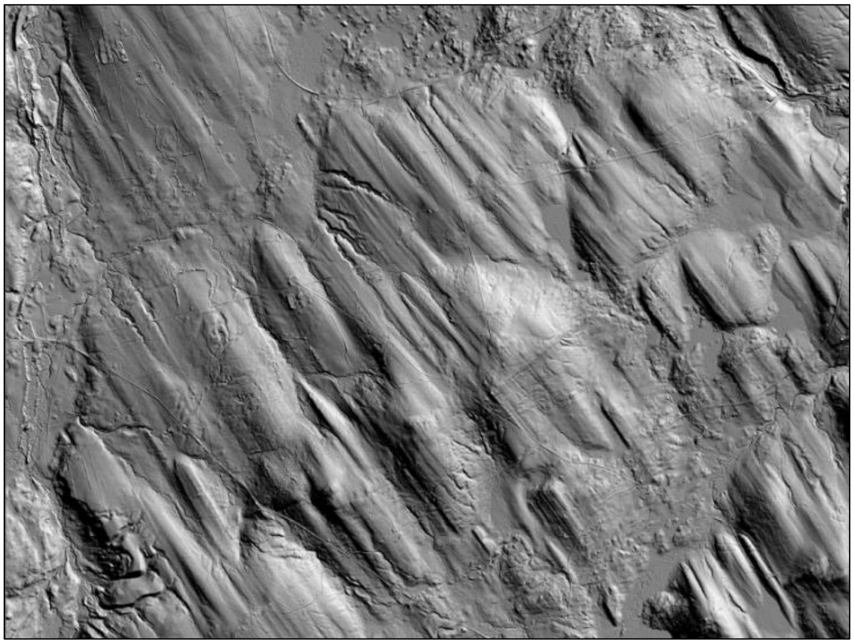


Figure 2.6. Lidar image showing glacially streamlined southeast-trending ridges (fluted ground moraine) superimposed on larger hills in Knox and Brooks. Field of view is about 4.3 miles wide.

Figure 2.7. View looking east at fluted till ridge (center left to right) on north side of Route 156, east of Beans Corner in Jay. Ice flow was from left to right (south-southeast).

Glacial Processes

It is difficult to determine the amount of erosion by the late Wisconsinan glacier, but it was probably on the order of tens of feet of bedrock in coastal Maine. The exact amount varied from place to place according to local topography and the structure, composition, and coherence of the rock. Nearly all of the preglacially weathered rock was removed by the end of late Wisconsinan time.

In some areas, the glacial scouring of valleys combined with streamlining of hills to create a prominent linear topography indicative of ice flow, as shown in **Figures 2.6** and **2.7**. Elsewhere the structure of the bedrock has a prominent grain that controls the topography, notably in the long northeast-trending rock ridges between Casco Bay and Penobscot Bay. As the glacier moved over hills, it tended to shape them as noted above. Certain rock types such as granite were often plucked by the glacier as large blocks that now form boulder fields strewn across the countryside in the direction the ice carried them.

Part of the rock debris that the glacier had incorporated was deposited (laid down) directly from the ice as a discontinuous layer of till (**Figure 2.8**). Till is a heterogeneous mixture of sand, silt, clay, and stones. Some of it (lodgement till) was deposited at the bottom of the ice sheet when the glacier was still active. Accretion of lodgement till to thicknesses of over 100 ft has occurred in places (though some of this till likely predates the most recent glaciation). The rock knobs often seen at the south ends of glacially streamlined hills appear to have been nuclei for till accumulation.

Figure 2.8. Stony till in the Waldoboro Moraine, south of Feylers Corner in Waldoboro.

Another type of till – often called ablation till – accumulated as loose coarse-grained debris that melted out from higher up in the glacier or slumped off the surface of the ice. There have been many attempts worldwide to provide detailed classification schemes for varieties of till. It is rarely easy to identify those varieties in the limited exposures that we see in the field, so in this handbook we only distinguish lodgement and ablation tills. These two general classes differ in ways that affect their ease of excavation and suitability for certain land uses.

Warming of the climate caused the Laurentide Ice Sheet to withdraw from the Maine coast about 15,000 years ago. Events and sedimentary deposits associated with its recession across the state are said to be of "late-glacial" age. This retreat – called deglaciation – was marked by concurrent thinning of the ice sheet and recession of its margin. The ice margin retreated to the northwest at rates that typically were in the range of 150-500 ft/yr. However, the internal forward flow of the ice continued even as the extent of the glacier diminished. The flow acted like a conveyor belt, carrying ice and pulverized rock debris to the terminus of the glacier.

During its recession, the glacier periodically advanced enough to temporarily offset the retreat of the ice margin. The position of the margin then remained constant or moved forward a short distance, and glacial sediments accumulated in ridges along the edge of the ice sheet. These ridges are called end moraines, or simply "moraines" (**Figure 2.9**). The variable size, composition, and origin of these deposits are discussed below and in the next chapter.

Figure 2.9. Aerial view of bouldery moraine ridges, south of Grays Corner in Sedgwick. These moraines are younger toward the lower left part of the photo. Photo by Joseph T. Kelley.

Marine Submergence of Southern Maine and Formation of the Coastal Moraine Belt

The weight of the Laurentide Ice Sheet depressed the Earth's crust in Maine by about 240 m (787 ft) (Stuiver and Borns, 1975). Even though worldwide sea level was lower in late-glacial time than at present because more water still existed as glacial ice, this depression caused a marine submergence of lowlands in southern Maine as the Laurentide Ice Sheet retreated. In some valleys the sea even extended far into central Maine – to the Bingham area in the upper Kennebec Valley and East Millinocket in the Penobscot Valley (**Figure 2.10**; Thompson and Borns, 1985).

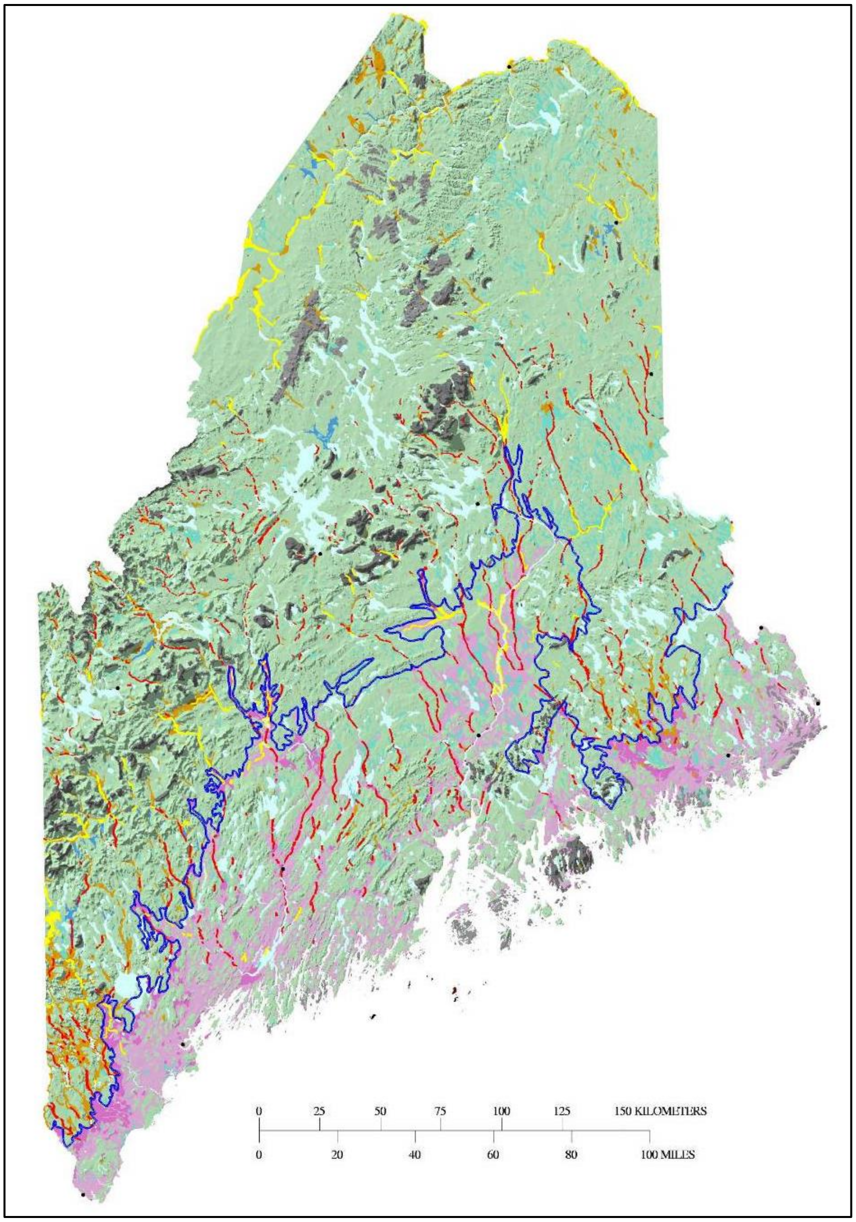


Figure 2.10. Simplified surficial geologic map of Maine, from Thompson and Borns (1985). Dark-blue line shows inland limit of late-glacial marine submergence.

The *upper marine limit* is the maximum elevation reached by the sea in any particular area. It is higher as one proceeds northwest from the modern coastline, rising from 200 ft in Berwick to about 468 ft near Bingham in the upper Kennebec River valley (Thompson *et al.*, 1989; Thompson, unpub. data). This variation resulted from combined uplift and tilt of the land as the glacier melted. The ice had been thicker to the northwest (causing greater subsidence), so there was also greater recovery in this direction.

The *inland marine limit* is the maximum inland extent of the late-glacial sea. It is shown as a sinuous line on the surficial geologic map of Maine (Thompson and Borns, 1985; Thompson, 2005). It is important to remember that not all of the area seaward of this line was submerged. There were numerous islands where the land was higher than contemporary sea level.

Moraines are most numerous in the formerly submerged areas near the coast. **Figure 2.11** shows the environment in which the moraine ridges were deposited. They formed along the base of the ice margin, where it was grounded in contact with shallow marine waters. Meltwater issued under pressure from beneath the retreating glacier, carrying gravel, sand, and mud into the sea. These water-laid sediments mingled with debris slumping from the edge of the glacier. During winter months, the ice front stabilized and pushed against the sediments on the sea floor, shaping them into moraine ridges. The forward oscillations of the glacier are indicated by deformation structures (folds and thrust faults) in the sediment layers, and by lodgement till plastered against the north sides of the moraines. These features are often seen in active gravel pits and other fresh excavations (**Figure 2.12**).

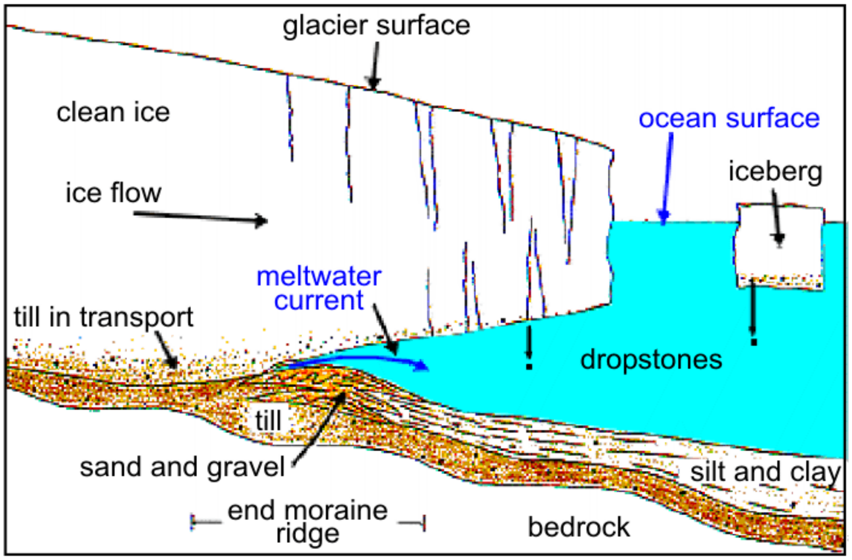


Figure 2.11. Schematic cross section of the glacier margin in contact with the sea as the last ice sheet retreated from Maine's coastal lowland.

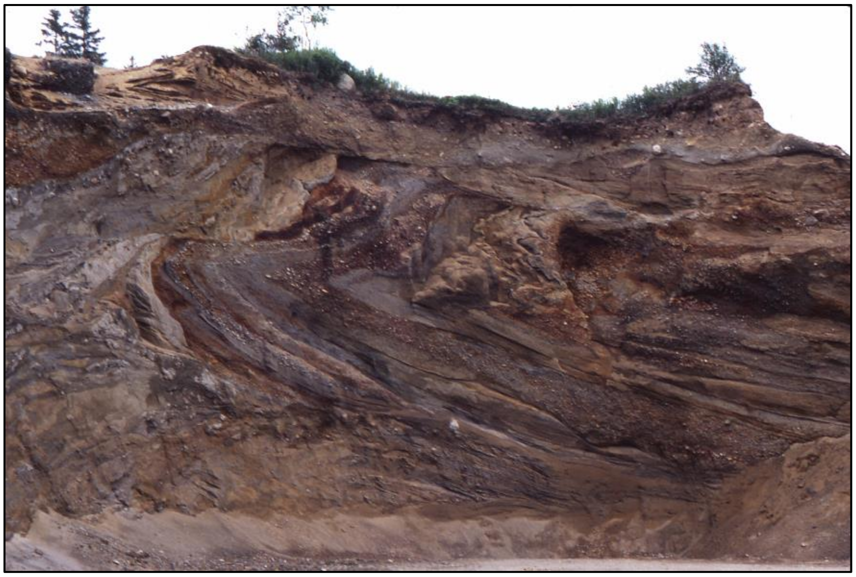


Figure 2.12. Pit face showing cross section of large stratified moraine in Addison. The ice margin readvanced slightly from left to right, forming a recumbent fold in the sand and gravel beds.

The moraine ridges trend generally east to northeast, but local deviations indicate that the ice front had a lobate shape. End moraines and striations reveal that the glacier withdrew more quickly in certain coastal valleys. This probably occurred because of more rapid iceberg calving in the deeper water of the valley centers. The result was that ice flow converged into the valleys from either side. A good example is the Kennebec Valley between Augusta and Gardiner, where the latest ice flow was toward the ESE on the west side of the valley and WSW on the east side.

Deposition of Water-Laid Glacial Sediments

Tremendous amounts of water poured from the Laurentide Ice Sheet as it melted and retreated from southern and central Maine. Meltwater streams flushed some of the rock debris from the glacier. Rocks that were broken and jagged from glacial transport became progressively more rounded as they were swept along by these rapidly flowing streams. In many cases the sediments also became sorted into layers of differing particle size, such as silt, sand, and gravel. Depending on local circumstances, deposition of these sediments occurred either within or next to the glacier, or at some distance beyond the ice margin. Much of the sediment washed from the ice sheet in southern Maine was dumped into the ocean, while above the marine limit it came to rest on stream beds or in lakes. These environments are discussed below.

Eskers:

Early meltwater drainage from the ice sheet was concentrated in ice-walled tunnels at the bottom of the glacier. The tunnels formed extensive branching networks – especially across central and southern Maine – with tributaries that fed into major trunk streams in the downstream direction.

Most of the rock debris carried by the glacier was in the basal part of the ice sheet, so a lot of that material was picked up by subglacial streams. The sediment-laden water flowed to the ice margin, where it discharged from the tunnel mouths. The silt and clay (collectively called "mud") dispersed out into the ocean or inland glacial lakes. The coarser and heavier sediments (sand and gravel) were dumped at the edge of the glacier, forming various marine and terrestrial deposits described below.

Large parts of the ice tunnels eventually became more-or-less filled with gravel and sand, such that when the surrounding ice melted away, ridges of these coarse deposits were exposed and now mark where the tunnels used to be. The ridges are called "eskers", but they have also been given more colorful names by New Englanders, such as "horsebacks" and "whalebacks" (**Figure 2.13**). Maine is famous among glacial geologists for its extensive and accessible esker network. The abundance of these deposits can be seen on the surficial geologic map of the state (Thompson and Borns, 1985).

Figure 2.13. Aerial view looking north at esker ridge that crosses Kezar Five Ponds in Waterford as it approaches Kezar Falls Gorge.

Marine environments:

Where the glacier margin stood in the ocean and remained stationary for a time, perhaps for a few years, coarse sediments accumulated rapidly at the mouths of ice tunnels. These deposits formed mounds of sand and gravel called "subaqueous fans" on the sea floor.

In places where the ice margin stabilized for longer periods, the fans built up to the ocean surface and became flat-topped deposits called "glacial-marine deltas" (**Figure 2.14**). Unlike the huge delta of the Mississippi and many other modern rivers, these glacial deltas consist mostly of coarse-grained sand and gravel. They are sometimes called "Gilbert deltas" in reference to G. K. Gilbert, who described deltas of this type that were deposited into a very large lake (Lake Bonneville) that existed in Utah during the cool, wet Ice Age climate.

Figure 2.14. Aerial view of Popple Hill delta in Deblois. Note kettle depressions (left) resulting from melting of buried glacial ice masses in the ice-marginal part of the delta. Photo by Joseph T. Kelley.

As long as the sediment supply continued, each delta expanded seaward, and the stream channels on the delta plain extended to keep pace. Pit excavations often show that both fans and deltas commonly overlie esker gravels that were deposited earlier in the deglaciation process. This association resulted from progressive recession of the glacier margin, causing the mouths of ice tunnels to retreat as the subglacial environment gave way to lower-energy subaerial deposition of sediments in front of the ice.

Meltwater streams and currents from the late Wisconsinan glacier carried a great quantity of silt and clay in suspension. This muddy material washed out into the ocean, where it settled to the bottom. The subsequent emergence of the coast has exposed extensive deposits of glacial-marine sediment in southern Maine (**Figure 2.15**). Bloom (1960) named it the "Presumpscot Formation" after the Presumpscot River valley in Cumberland County. The Presumpscot Formation covers many lowland areas below the marine limit, and in places it laps against or completely overlies older moraines and glacial sand and gravel deposits.

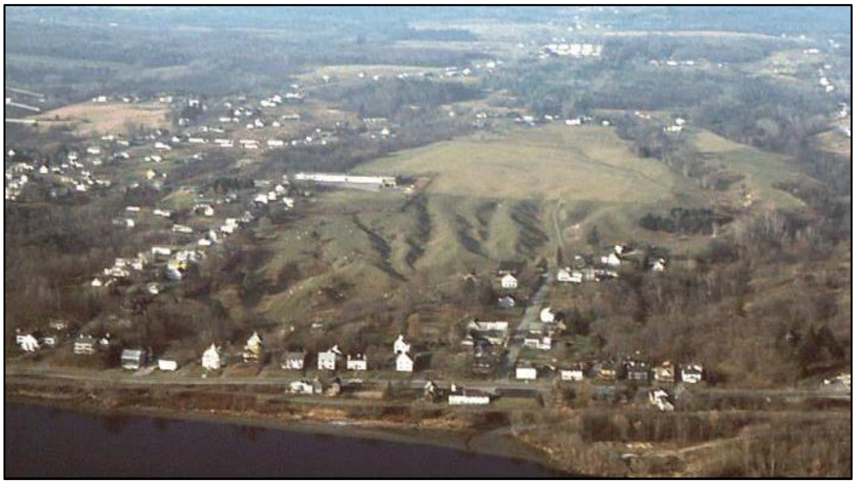


Figure 2.15. View looking across area of glacial-marine clay on west side of Kennebec River valley in Farmingdale. The gullies (center) have been eroded into the original sea-floor surface (large field).

Terrestrial environments:

Some of the sediments that washed out of the glacier did not reach the ocean. They accumulated in streams and lakes in the interior of Maine. Glacial-stream deposits formed in relatively high-energy environments, where the coarsest gravel and sand was apt to settle on stream beds near the ice. The finer sand, silt, and clay-size particles were carried farther downstream and were more likely to be deposited in a lake. These two environments are often called “glaciofluvial” and “glaciolacustrine” respectively.

Terrestrial deposits, especially the sands and gravels, commonly were laid down on top of or alongside remnants of melting glacial ice, and thus are called “ice-contact” deposits. These deposits typically accumulated against the ice in well-defined layers (beds). Then when the ice melted, the adjacent sediments more-or-less lost their support and collapsed downward. The original layering became scrambled by folds and faults. In extreme cases, beds that were originally horizontal could end up being vertical. Examples of these ice-contact features are often exposed in the fresh vertical faces of gravel pits (**Figure 2.16**).

Figure 2.16. Steeply collapsed ice-contact gravel and sand beds at Chadbourne Pit in Newry.

In situations where sand and gravel was deposited on top of scattered blocks of stagnant ice, depressions called “kettles” were left when the ice melted. In some areas kettles are prominent features of the landscape. They range from small and circular to large, irregular, coalescing depressions hundreds of feet across and up to 100 ft deep. Kettles are locally common in the headward parts of glacial-marine deltas, as well as areas above/inland from the marine limit. Many of them extend below the water table and contain ponds and various types of wetland vegetation.

“Kames” are ice-contact sand and gravel deposits with irregular mound shapes. Some of them have flat tops due to grading by glacial streams and are called "kame terraces." Kames and kame terraces formed in both fluvial and lacustrine environments. Their common association with kettles has led to the expression “kame-and-kettle topography. These terms are often encountered in the literature of glacial geology. They can be useful for describing landforms of uncertain origin, but otherwise have become somewhat archaic as geologists prefer to classify glacial deposits according to how they formed.

“Outwash” deposits are composed of sand and gravel deposited by glacial meltwater streams in valleys or broad lowlands beyond the ice margin. They are absent along the present-day Maine coast, because most of this area was below sea level when it was deglaciated. However, outwash does occur in some areas above the marine limit. Examples include the outwash plains in the Crooked River valley, north of Sebago Lake, and in parts of the upper Androscoggin River valley (**Figure 2.17**).

Figure 2.17. Glacial outwash gravel in the Androscoggin River valley, Gilead.

Meltwater Channels

Meltwater channels are erosional features that formed where streams issued from glacial ice. They resemble modern stream channels, except most of them are dry today or carry little water in proportion to their size. Some meltwater channels occur on deltas and outwash plains. These channels are easiest to see where the land has been cleared, such as the blueberry fields on the large glacial-marine deltas of eastern coastal Maine.

Other channels were carved on hillsides where the gradients of meltwater streams were so steep that erosion took place. Many of these channels formed as water flowed along the margin of the retreating glacier, between the ice and adjacent valley walls. They may lead to sand and gravel that the streams deposited where their gradients became gentler. In some cases, a series of parallel hillside channels formed next to the thinning ice, with successively younger channels at lower elevations. **Figure 2.18** shows an example of a meltwater channel.

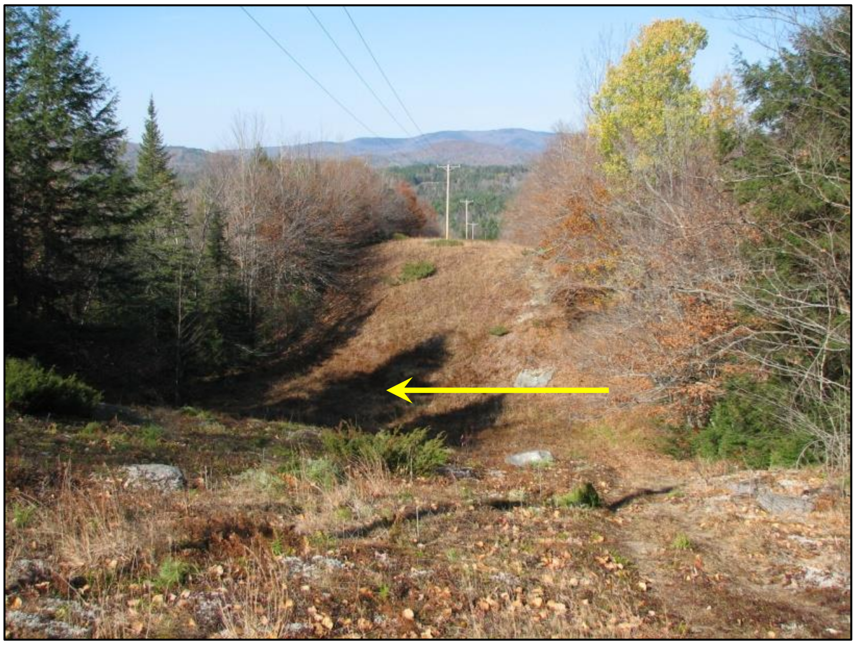


Figure 2.18. View looking northwest across meltwater channel in West Paris. Arrow shows direction of former meltwater flow.

Another type of channel developed in upland areas where glacial meltwater flowed through gaps among hills and mountains. Some of these channels carried water in three stages: first via tunnels at the base of the ice, then briefly from the ice margin as it retreated through the gap, and finally from the drainage of a temporary glacial lake caught between the gap and the ice margin to the north. Other channels simply were *spillways* for water escaping from glacial lakes, and some lakes had multiple spillways as glacial retreat opened successively lower escape routes through which they could drain.

The floor of Grafton Notch in the Mahoosuc Range of western Maine is a good example of the "multi-purpose" channel. A subglacial stream flowed though Grafton Notch when the area was still under the ice. Screw Auger Falls (just south of the notch) probably formed during this time, when bedrock on the valley floor was scoured by sand and gravel carried under high pressure in the ice tunnel. Then as the glacier backed off to the north, glacial Lake Cambridge briefly spilled through the notch. The cumulative result of all this water action is the swampy abandoned channel floor seen today along the highest part of Route 26.

Many channels are floored by till or bedrock, so their flat or gently sloping bottoms tend to be poorly drained and support swampy or marshy wetland vegetation. If the accumulated organic material is not too thick, you may see boulders left behind after all the finer-grained sediments on the channel floors had been eroded away.

Glacial Readvances

There were times when retreat of the Laurentide Ice Sheet was interrupted and the ice margin stabilized or advanced short distances. Pauses in glacial retreat are called "stillstands", and episodes of renewed ice-sheet growth and forward movement of its margin are known as "readvances". These anomalies are especially interesting to geologists because they occurred when the climate was becoming warmer overall, so their causes have been the subject of much research and speculation.

Some of these stillstands and readvances are marked by large moraines. The Pond Ridge Moraine near East Machias formed about 15,600 years ago. The large Pineo Ridge Moraine in the Columbia area is younger – about 14,800 yrs B. P. – and consists of several large closely spaced moraines and associated deltas (Borns *et al.*, 2004; Thompson *et al.*, in review).

Minor readvances of the glacier margin were more common and probably occurred over the span of a few years or decades. These fluctuations sometimes produced cross-cutting moraines, a good example of which is seen just east of South Pond in Warren. During the South Pond Readvance, the local direction of ice flow shifted from southward to east-southeast, and a moraine was built that cross-cuts a series of minor moraines that had been deposited earlier (Thompson, 2012; http://www.maine.gov/dacf/mgs/explore/surficial/facts/dec11.pdf).

Late-Glacial and Postglacial Events

Uplift of the land began in late-glacial time and proceeded rapidly as Maine recovered from the weight of the thick ice sheet that had covered it. The radiocarbon ages of shells from marine sediments that are now above sea level indicate that southern Maine was deglaciated by about 14,000 years ago and had emerged from the sea by about 12,800 years ago (Retelle and Weddle, 2001).

Worldwide sea level rose as glacial ice sheets melted and released water into the ocean, but initial uplift was so rapid in Maine that the coastal lowland emerged from the sea. So *relative sea level* fell at the same time *global sea level* was rising. Figure 2.19 shows this precipitous drop in relative sea level, followed by the more gradual rise as ice sheets continued to melt. Wave action became stronger in the shoaling sea, causing sand and gravel to be eroded from glacial deposits such as eskers and deltas. This coarse sediment washed down over the marine clay-silt that had been laid down earlier in deeper water.

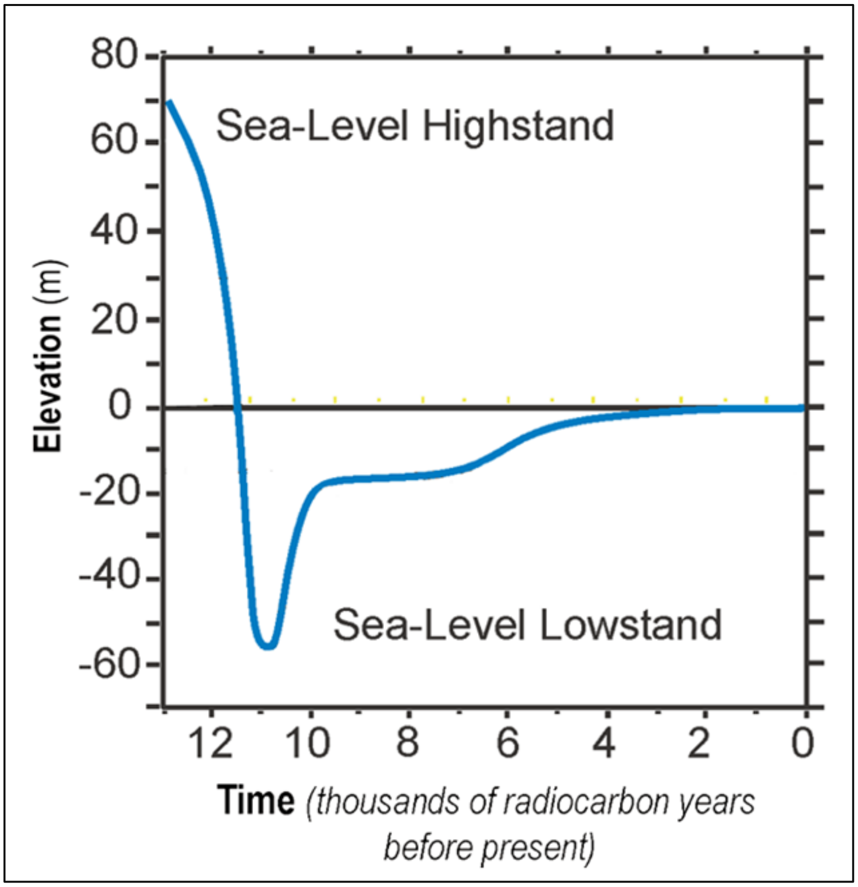


Figure 2.19. Relative sea-level curve for coastal Maine. Modified from Dickson (1999) and Barnhardt et al. (1995). Note that the time line shown here is based on radiocarbon ages of organic material, so the actual timing of sea-level events was somewhat older. Sea level along the present Maine coastline is rising at a rate of about 7.5 inches per century (P. A. Slovinsky, pers. comm., 2015).

Glacial till on hillsides below the marine limit was likewise subjected to wave erosion and reworked to form local patches of beach gravel. Wave-cut bluffs and associated terraces developed in some places where the sediments were easily eroded or wave attack was sustained (**Figure 2.20**). Most of these ancient shorelines are not easy to see from the ground, but they are striking features on lidar imagery of the earth’s surface (**Figure 2.21**).

Figure 2.20. Raised marine beach gravel (near treeline), and broad exposure of granite ledge in pit floor, Bremen.

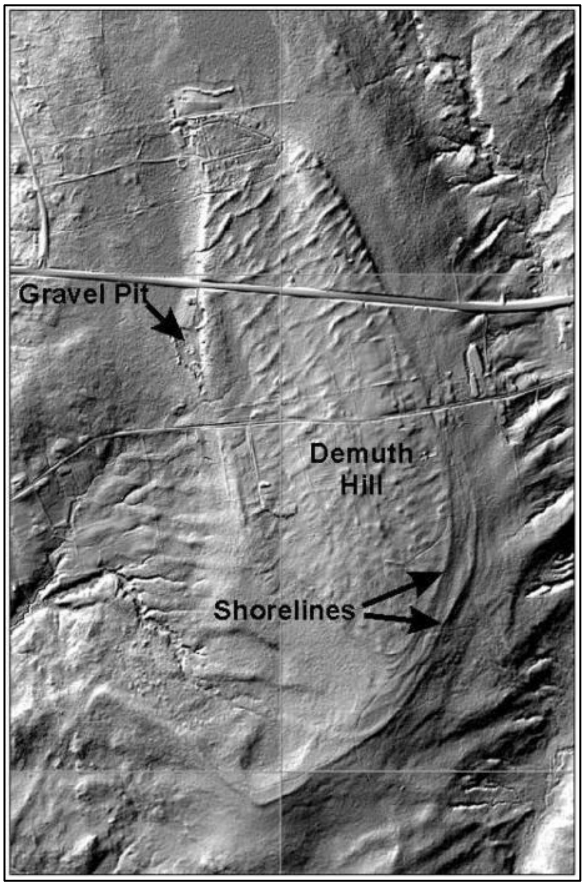


Figure 2.21. Lidar image of Demuth Hill in Waldoboro, showing raised marine shorelines eroded in till-covered hillside. Glacial moraine ridges can be seen both above and below the shoreline zone.

As relative sea level fell, every place below the upper marine limit was "shorefront property" at some point in time. Wave-washed sand and gravels at the marine limit are most likely beach deposits, but at lower elevations it is often hard to determine whether such materials formed right along a shoreline or slightly offshore in shallow water. So in many cases the latter deposits are shown on geologic maps as "*marine nearshore deposits*".

Crustal rebound caused the sea to recede far out from the position of today's Maine coastline. However, global sea level continued to rise and is still rising today as the climate warms and glaciers melt. This process has drowned portions of coastal river valleys, converting them to tidewater estuaries. It is also promoting erosion and related landslide activity in areas where shoreline bluffs consist of soft sediments, rather than bedrock (Kelley *et al.*, 1989).

The establishment of the modern stream network followed deglaciation and the emergence of low-lying areas from the sea. Streams in areas formerly drowned by the sea have expended much of their energy in cutting down through thick glacial-marine sediments that filled their valleys. This process was promoted by uplift of the land. Erosion of the Presumpscot Formation has produced intricate branching drainage patterns and steep-walled gullies.

The courses of major rivers such as the Saco and Androscoggin show the disruptive influences of glaciation. Their valleys are broad in places but very narrow in others. Gently-sloping stretches of river channels commonly are interrupted by rapids and waterfalls. These irregularities resulted from multiple episodes of glacial erosion and deposition acting upon a preglacial landscape with varied topography, rock types, and rock structures.

Presumably the drainage network was less irregular in preglacial time. For example, it has been proposed that the Androscoggin River took a more direct route to the sea, in contrast to its present zig-zag course that includes large waterfalls in towns such as Rumford and Lewiston (Crosby, 1922). These bedrock-controlled waterfalls have provided good sites for dams to power mills and generate electric power.

Plugs of glacial sediment blocked narrow parts of many New England river valleys. These natural dams impounded lakes until they were eventually eroded away and the lakes emptied. Some of the obstructions were deposits of glacial till, from which large boulders were left behind in the river beds and now form rapids. The Saco River valley was occupied by a series of temporary lakes, collectively known as glacial Lake Pigwacket (Thompson, 1999), all the way from the marine limit up to North Conway, New Hampshire.

Flood plains are the low flat areas along today's rivers which are occasionally inundated during periods of heavy rain and/or rapid snow melting (**Figure 2.22**). Higher stream terraces occur locally where earlier flood plains were abandoned as rivers incised their valleys. Alluvium is deposited on flood plains during times of high water, and both current and former flood plains include rich agricultural lands. The broad valley of the Saco River in Fryeburg and Lovell is a prime example.

Figure 2.22. Partially submerged flood plain on south side of Androscoggin River valley in East Bethel.

The vegetation cover in Maine probably was sparse for a short time just after deglaciation. Strong winds eroded sand from marine and terrestrial sediments and deposited it as dunes or a patchy uneven blanket in the downwind direction (**Figure 2.23**). The orientations of many dunes indicate that the prevailing wind blew generally from west to east, as it does today (McKeon, 1972, 1989). Most of the windblown (eolian) sand is stabilized by vegetation at the present time. However, human activities have locally disturbed the land surface and caused dune migration. An example is the "Desert of Maine" in Freeport.

Figure 2.23. Sand dune on south side of Androscoggin River valley, along Jewett Hill Road in Canton.

A great number of wetlands have formed in southern Maine during postglacial time. **Figure 2.24** shows some common types of wetland environments. They are generally located in areas with poor drainage and a high water table. Many large wetlands have low-permeability substrates such as glacial-marine clay. Others are located in small rock-floored basins or in depressions (kettles) left by melting of buried glacial ice in areas of sand and gravel.

Figure 2.24. Cross-section diagram showing common wetland environments.

There are three principal types of Maine wetlands: *swamps*, which are more or less tree-covered; *marshes*, characterized by open grassland vegetation; and *heaths* (bogs), which have substantial thicknesses of partially decomposed plant material (peat).

Modern lake sediments include lake-bottom deposits, beaches, and deltas. Fine-grained sediments from streams and shoreline erosion are being laid down on modern lake bottoms, but these deposits are difficult to observe. They are composed mostly of silt, clay, and organic material. Sediment cores from the deepest parts of many ponds typically have a basal unit of gray, mostly inorganic mud and sand that was deposited just after the glacial ice melted. This material is overlain by mucky organic-rich sediment called *gyttja*, which has accumulated throughout postglacial time.

Beach deposits are forming by wave attack on lakeshores, especially where the shores are composed of easily eroded sand and gravel. Some of the sand on large beaches has been moved by wave action to form sandbars (*spits*) extending out into open water.

There are many steep, rocky hillsides and cliffs in mountainous areas of southern Maine, and talus deposits are accumulating at the bottoms of these slopes. Talus consists of angular stones (including large boulders) that have broken loose from the bedrock and fallen to form a jumbled heap at the base of a mountain.

Till

Till was deposited directly from glacial ice. It is one of the most widespread surficial materials in Maine. In most places, till is also the oldest layer of surficial sediment. It occurs both above and below the limit of marine submergence. Till generally overlies bedrock, but there are a few small areas where it overlies sediments that were deposited by glacial meltwater.

The texture of till is its most recognizable characteristic. It is a more-or-less random mixture of sand, silt, clay, and stones (**Figure 3.1**). Because of this diversity in particle size, till is said to be "poorly sorted." Most of the stones are subangular to angular, and they range in size from granules and pebbles to the largest boulders. The texture of till is often described by the percentages of clay, silt, and sand that it contains. Sand is usually the most common particle size in the matrix (finer-than-2mm portion) of southern Maine tills. It probably constitutes over 50 percent of the typical till matrix. Another textural characteristic of till is the absence or weak development of stratification. Till may contain thin, discontinuous beds of washed sediments, but pervasive stratification is rare. (See Folk, 1980, p. 23, for sediment grain-size scale.)

Figure 3.1. Glacial till exposure in Jefferson (vertical pit face).

Both the composition and particle-size distribution of till depend on the nature of the local bedrock. Most of the stones in till have not been transported more than a few miles from their sources. Till that is derived from granite, for example, is likely to contain many large granite boulders that the glacier pried loose along joint surfaces. The matrix of this same till typically contains much sand that resulted from glacial crushing of granite into its constituent mineral grains.

Other types of source rocks are fine-grained and relatively "soft." They yield a till that contains a high percentage of silt and clay and few large stones. Many sedimentary rock formations and micaceous metamorphic rocks are in this category. Till may be very heterogeneous if the glacier crossed several types of bedrock within a short distance, as in parts of southwestern Maine (Bloom, 1960, p. 21). A small percentage of stones in till may have traveled tens of miles, or more, from their points of origin. They can be used to determine the direction of ice movement if they are a distinctive rock type whose source is known.

Color is another characteristic that can be used to describe till. It varies according to the interrelated effects of texture, composition, moisture content, and degree of oxidation. Till in southern Maine is usually a shade of gray or brown. The exact color can be defined numerically by reference to the Munsell Soil Color Chart (published by Munsell Color Co.). It should be observed consistently in all-moist or all-dry samples because till appears darker when it is moist.

Entire books have been written about the glacial environments in which varieties of till formed and how to classify till. However, it is adequate for most purposes to simply distinguish two broad genetic types of till that occur in Maine – *lodgement till* and *ablation till*. Lodgement till – also called basal till – was laid down at the bottom of a glacier. It is fine grained, compact, and often difficult to excavate, so this kind of till is sometimes called "hardpan." It generally contains more silt and clay than ablation till, and there are fewer stones (mostly pebble to cobble size). Lodgement till may have joints (planar fractures), usually including one set more-or-less parallel to the ground surface (**Figure 3.2**). The latter set is better developed and more closely spaced near the surface, causing the till to readily crumble into small blocky fragments in the zone of weathering.

Figure 3.2. Compact sandy lodgement till in road cut west of Allen Hill, Peru. Note the joint planes (fissility) in the freshly scraped face (center).

Ablation till was deposited by the settling out of particles from melting glacial ice. In southern Maine it is loose, sandy, and light colored except where iron-bearing minerals have rusted. Its lesser coherency makes it easier to excavate than basal till. Much ablation till in southern Maine is very stony and some of it contains large boulders (**Figure 3.3**). This kind of till grades locally into washed sand and gravel because running water was present in its depositional environment. Thin sand lenses may be so numerous in places that the till has a stratified appearance.

Figure 3.3. Gravelly ablation till in bank along Davis Road in Union. This view looks northwest at an oblique cross section through a low southwest-trending moraine ridge.

Oxidation of lodgement till has been noted in a few places. The author described a locality in Winthrop, Maine, where rust-stained lodgement till showed an abrupt contact with an overlying ablation till (Thompson and Smith, 1988). Rounded inclusions of the lodgement till were found in the upper till, suggesting that the contact was erosional. The upper till at this locality was non-weathered and was deposited during the last glaciation. The lower till appeared to be the product of an earlier ice advance, but it is uncertain whether it formed during a separate (and much older) pre-Late Wisconsinan glaciation.

Till can also be classified as ground moraine or end moraine. Ground moraine is a general term for the blanket of till that covers much of Maine. The surface of ground moraine may be smooth or hummocky, depending on how the till was emplaced. Many boulders litter the surface of ground moraine in some areas.

End moraines (henceforth called "moraines") are ridges of till, or till interlayered with sand and gravel, that accumulated in the marginal zone of a glacier (**Figure 3.4**). Hundreds – and more likely thousands – of moraines were deposited in the sea along the edge of the last ice sheet as it receded across the submerged southern Maine lowland in late-glacial time. These moraines are discussed further below.

Figure 3.4. View looking southwest along the bouldery crest of a minor moraine ridge, on the border between Cherryfield and Steuben. The glacier advanced from right to left.

The thickness of till deposits is highly variable. In general, till is thinner with increasing elevation on hillsides, and bedrock is exposed on many hilltops (**Figure 3.5**). Also, there are locally extensive areas in coastal Maine where till and other surficial deposits are thin and patchy. Bedrock outcrops are very common in these areas. Some of the exposed ledges occur along former ocean shorelines where they were washed bare by wave action during the late-glacial marine submergence (**Figure 3.6**). It is desirable to map the areas of abundant bedrock outcrops because of the problems that they may cause in excavation, drainage, and waste disposal.

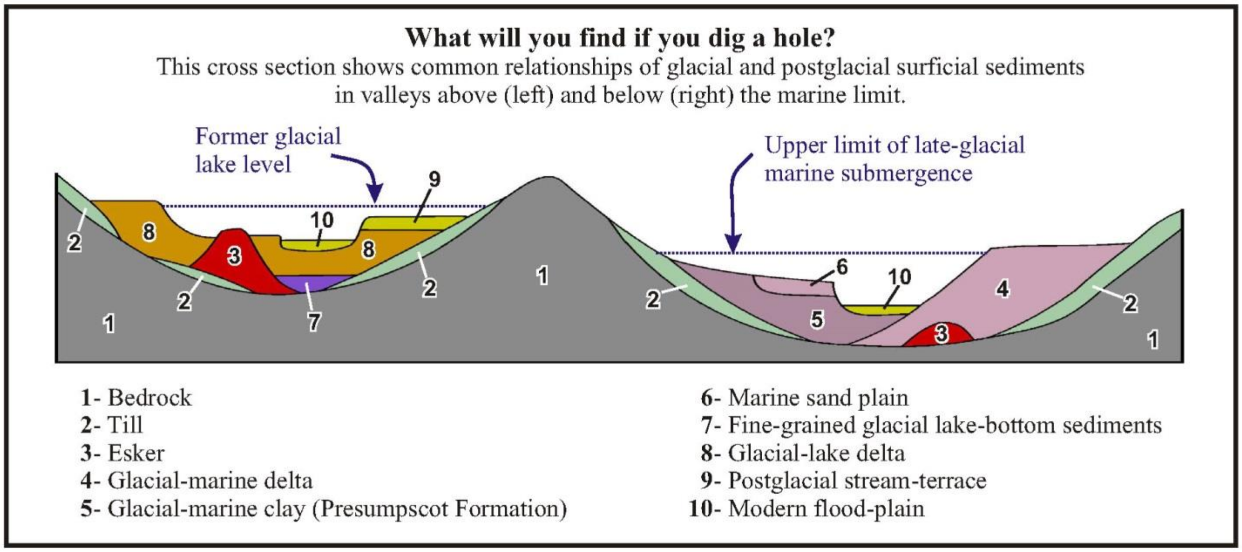


Figure 3.5. Schematic cross section showing typical stratigraphic relationships between glacial and postglacial sedimentary deposits in southern Maine.

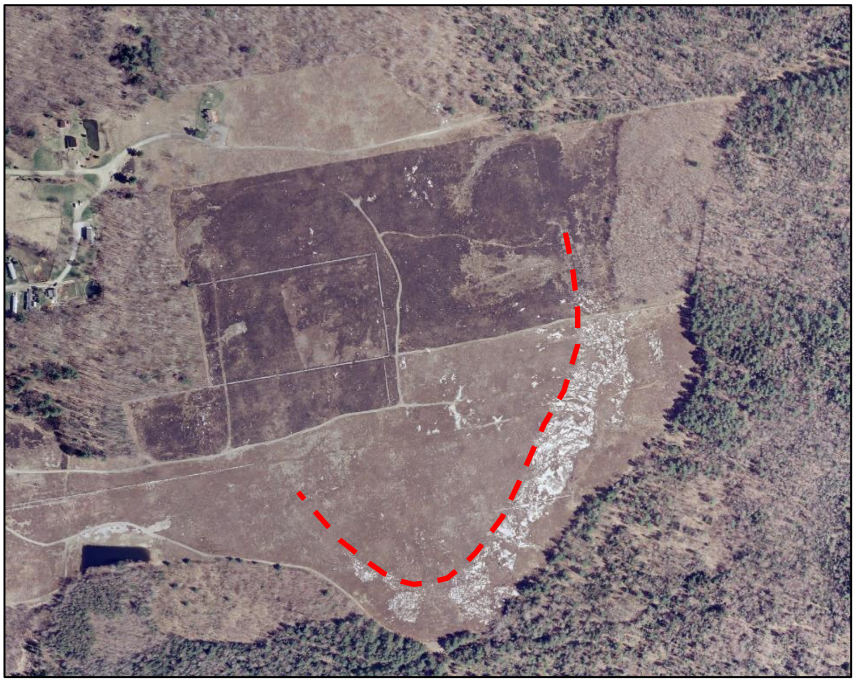


Figure 3.6. Air photo showing a former marine shoreline (dashed line) on Willett Hill in Waldoboro. The white area is bedrock that was exposed by wave action removing the surficial sediment cover along the shoreline.

Thick till deposits occur where the ground surface was built up by prolonged till accumulation beneath flowing glacial ice. These areas may contain over 100 ft of till. They typically occur in ridges that were smoothed and streamlined parallel to the direction of ice flow. A few such ridges, notably those in Eliot and York, are classic drumlins composed entirely of glacial sediments (till and some associated waterlaid sediments) that were molded into oval hills (**Figure 3.7**). More commonly there is a bedrock core or exposed bedrock hill against which the till was thickly plastered. Thus we often see long, smooth till surfaces that rise up the north (upglacier) sides of hills in southern Maine, while the summits have exposed ledges and steep cliffs occur on the south sides due to glacial plucking of bedrock blocks.

Figure 3.7. Very thick exposure of drumlin till, Great Hill in Eliot. Photo by Joseph T. Kelley.

Moraines

Moraine ridges typically have a relief of 3-30 ft above the surrounding land surface. The smaller ones may be only 20-50 ft wide, while some of the large moraines are more than 300 ft across. The true size of some end moraines is not apparent because they are partly buried by glacial-marine sediments. Small moraines are known by various names such as “washboard moraines”, “DeGeer moraines”, or simply “minor moraines”. These are composed mostly of till and are very common in mid-coastal to southwestern areas of the state. Large moraines consisting of sand and gravel and varying percentages of till are abundant to the east of Penobscot Bay. Moraine ridges range in length from 100 ft to a few miles, and many of the long ones occur as discontinuous segments.

Although the moraine ridges in southern Maine generally trend east to northeast, the marine-based tidewider glacier margin had a lobate shape with indentations in areas of more rapid recession and presumably greater iceberg calving. These “calving bays” developed where the water was deeper or ice retreat was otherwise promoted by factors such as high-volume meltwater discharge from ice tunnels. The resulting variations in late-glacial ice-flow directions are reflected in clusters of arcuate moraines and cross-cutting striations on bedrock. For example, striations along the sides of the lower Kennebec and Penobscot River valleys reveal that the latest ice flow converged toward the valley axes.

Boulders are common in end moraines, where they have been dumped at the glacier margin (**Figure 3.4**). Moraines in areas of granitic bedrock are especially bouldery and can often be recognized by linear concentrations of large granite boulders along their crests. However, these same areas of granite and sandy soils are favorable for commercial blueberry fields. Changing techniques for blueberry harvesting in recent years have resulted in the boulders being cleared from the fields and deposited in large piles, thus altering the character of the original glacial landscape (**Figure 3.8**).

Figure 3.8. Piles of boulders resulting from clearing of blueberry field, south of Tunk Lake.

Some moraines can be distinguished on aerial views and topographic maps by their occurrence in clusters, the members of which are closely spaced and parallel. The crests of moraines are better drained than the intervening swales, so they appear lighter colored on air photos. It is easy to recognize moraines in open land, but the smaller ones are difficult to see if they are located in wooded areas. Another pitfall in recognizing moraines is their resemblance to till-covered bedrock ridges, many of which have similar orientations.

Lidar to the rescue! Since about 2010, the difficulties in recognizing moraines and many other types of glacial landforms in Maine have been overcome by a type of imagery called lidar (short for **LI**ght **D**etection **A**nd **R**anging). The raw data used to produce lidar imagery is acquired by planes equipped to shoot multiple laser beams at the landscape while flying overhead. The laser beams are reflected back to the plane and the vast number of recorded arrival times yield numerical data that can be processed to reveal images of either the ground surface or features such as buildings and tree cover. The "bare earth" imagery is especially useful to geologists because it renders the forest cover invisible and shows the Earth's surface in startling detail! Thousands of subtle moraine ridges – some of them only 3-5 ft high – have been revealed in this way (**Figure 3.9**).

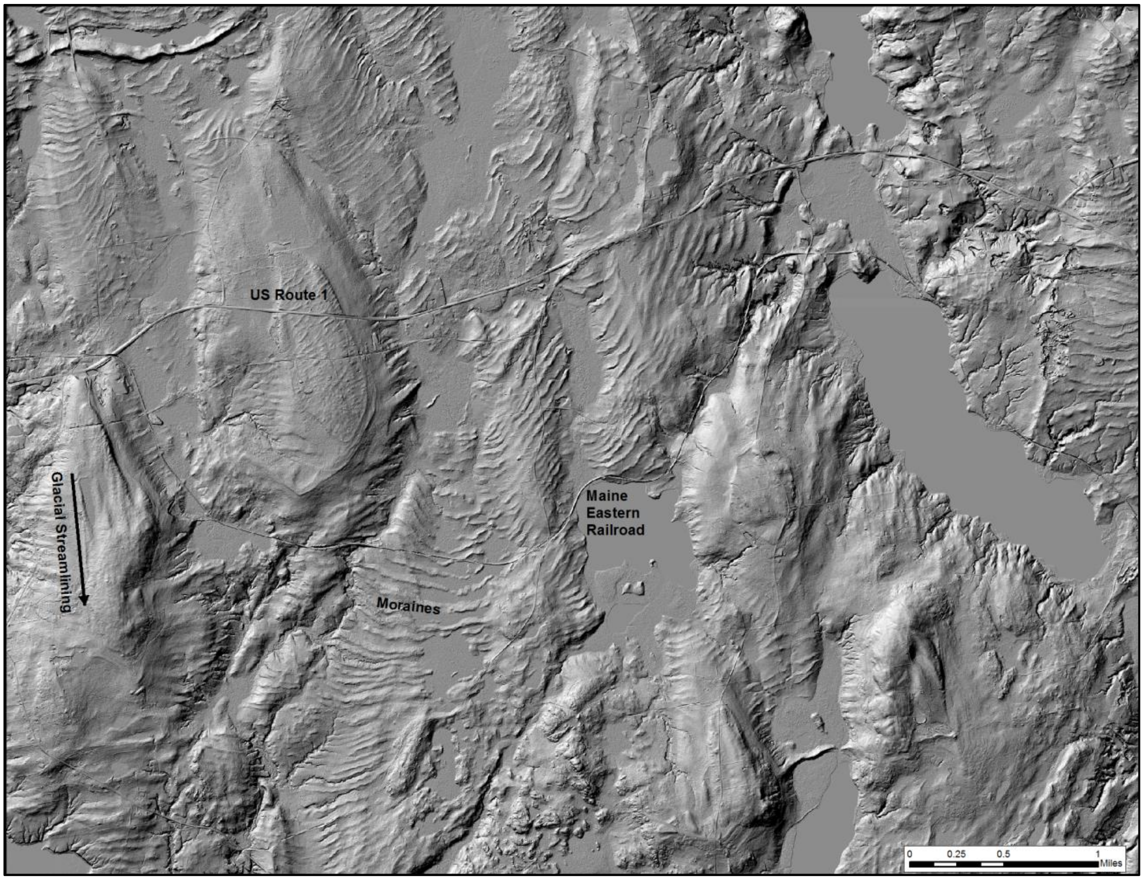


Figure 3.9. Lidar image showing large number of moraine ridges and other glacial features in Waldoboro and Warren.

Stratified Moraines

The term "stratified moraine" is used here to refer to certain moraines in Maine's coastal lowland that are usually larger than the minor moraines and composed mostly of sand and gravel. Much of this waterlaid sediment was deposited in layers, giving the moraines their characteristic stratified appearance when exposed in gravel pits and coastal bluffs (**Figure 3.10**). Stratified moraines are most common in southern Hancock and Washington Counties in eastern Maine.

Figure 3.10. Pit face showing cross-section of stratified moraine in Warren. Glacier margin stood on right side of the ridge as seen here. Note deformation of sand and gravel beds resulting from ice shove in the left of the photo.

Some of these moraines are as much as 50 ft high and over 1000 ft across, and may be thousands of feet long. Their composition varies from sand to boulder gravel, and this wide range of particle sizes is typically present in a single moraine. Some deposits are well bedded, and the sediment particles in each layer have a fairly uniform size (i.e. they are "well sorted"). Other stratified end moraines are chaotic, poorly sorted mixtures of sediment textures.

Stratified end moraines can be confused with eskers, which are also ridges of sand and gravel. However, moraines are parallel to former positions of the ice margin, while esker ridges were usually deposited perpendicular to the edge of the glacier. The identity of some moraines is also supported by the presence of bedrock striations oriented perpendicular to the moraine ridges. If bedding is well developed in a stratified moraine, its direction of slant (dip) should reveal that the meltwater flowed perpendicular to the ridge (not along its axis, as in the case of eskers). For additional confirmation, it is locally possible to trace a stratified moraine into one that is composed of till; or it may be parallel to nearby till moraines.

During the years since the first edition of this handbook, much work by geologists has clarified the stratigraphy and origin of Maine's stratified moraines (Ashley *et al.,* 1991; Hunter and Smith, 2001). The waterlaid sediments first issued from the mouths of numerous ice tunnels along the glacier margin, building each moraine as a linear series of small coalescing submarine fans. Occasional forward pulses of the glacier deposited till lenses within and on top of the moraines, while also folding and faulting the sand and gravel beds. These large stratified moraines are important sources of commercial aggregate. They are especially abundant in coastal Hancock and Washington Counties.

Eskers

Maine is well-known among glacial geologists for the great number and length of its eskers. These deposits were described as long ago as the 1800s, notably in a large volume by George Stone of the U. S. Geological Survey (Stone, 1899; **Figure 3.11**). Eskers are long ridges of gravel and sand deposited by glacial meltwater streams flowing through ice-walled tunnels at the base of the last ice sheet. As used here, the term “esker” refers to the ridge-shaped landform (**Figure 3.12**). Many eskers actually are combinations of sediments laid down by the subglacial streams, and slightly younger fan deposits (described below) that drape over the relatively narrow esker core. The ridges are typically 20-100 ft high and tens to hundreds of feet across.

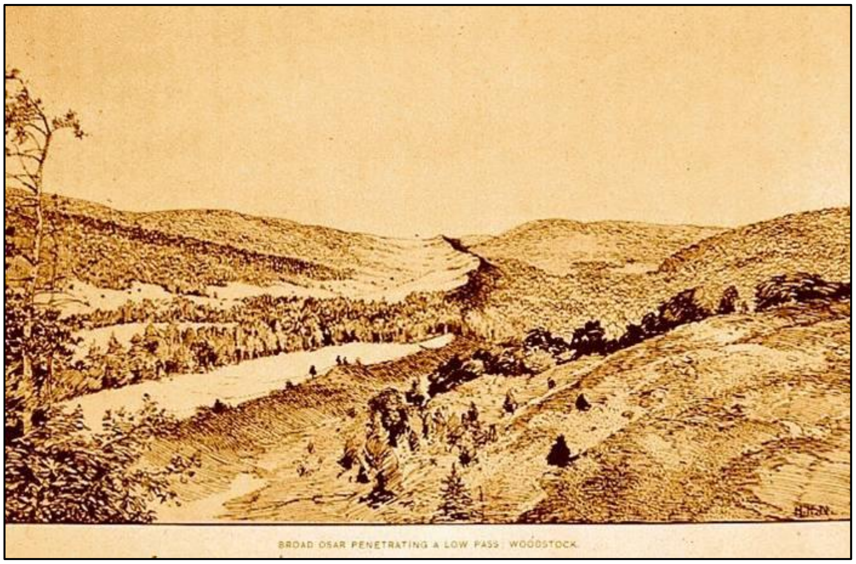


Figure 3.11. Figure from Stone (1899), showing view looking south along esker ridge (lower-left to center) in Woodstock.

Figure 3.12. Esker ridge near junction of U. S. Route 2 and Route 26 in Newry.
From Thompson (2003) and Thompson *et al*. (2014).

Some eskers can be traced (with breaks) for many miles. They generally trend north-south or northwest-southeast and form extensive networks. These networks typically originate in central Maine and each of them has a dendritic pattern in which the eskers coalesce toward the coast. Individual esker chains usually have some gaps due to non-deposition or later erosion. They may also branch and rejoin, or abruptly terminate at their downstream ends. Some eskers climb north-facing slopes, indicating that the water in the subglacial tunnels was under great pressure beneath the ice sheet.

As the ice walls of the esker tunnels melted away, and the mouths of the tunnels receded, the bedding (where present) in the sand and gravel often slumped and became deformed due to removal of the supporting ice. The resulting contortions include complex folds and faults. Parts of some eskers were buried by ice-marginal fans and deltas during deglaciation. Below the marine limit, we often see marine silt and clay overlapping the sides of eskers or even totally covering them (**Figure 3.13**). Finally, waves attacked the ridges as the sea withdrew, causing sand and gravel to wash off the esker crests and spill down over the abutting clay. Sometimes all the features mentioned here can be seen in a single gravel pit, revealing just how complex and interesting the eskers can be!

Figure 3.13. Cross section of esker (brownish gravel) overlain by glacial-marine clay-silt of the Presumpscot Formation on the east side of the Kennebec River in Pittston.

The eskers in Maine used to be called "horsebacks" or “whalebacks”. They probably were used by early Native American inhabitants of the state – and certainly by later settlers – as convenient high-and-dry routes through swampy areas. Roads often follow their crests for the same reason. Portions of eskers have been dug away to utilize their sand and gravel for construction material. However, as with other glacial deposits of similar composition, the deeper parts of many eskers are saturated with ground water and thus protected because of their importance as aquifers. The water yield of esker gravels is very high, with some wells capable of producing hundreds or thousands of gallons per minute.

Water-laid Marine Deposits

Glacial-marine Fans and Deltas

This section describes glacial-marine fans and deltas, but similar deposits formed in glacial lakes (discussed below). Marine fans and deltas are composed of sand, gravel, and silt with a wide range of textures and particle sizes depending on local conditions when they were deposited. Sites of high-energy meltwater discharge are likely to have the coarsest material, which may include boulder gravel with stones up to 3-6 ft in diameter. Quieter locations accumulated layers of finer gravel, sand, and even silt.

Glacial-marine fans were deposited at the mouths of ice-walled tunnels, where subglacial meltwater streams discharged sediment into the ocean. The coarse sand and gravel accumulated as mounds (fans) along the ice margin, while much of the finer-grained material (silt and clay) dispersed farther out to sea as plumes of mud. The sand and gravel fan deposits commonly show internal layering formed by the build-up of sediments over time (**Figure 3.14**).

Figure 3.14. Well-stratified sand and gravel in submarine fan exposure near South Jefferson. The parallel relationship between the bedding and ground surface suggests that this fan did not experience any erosion by marine processes after it was deposited.

Prolonged accumulation of fan deposits resulted in some of them building up to the ocean surface, forming flat-topped glacial-marine deltas. As long as the sediment supply continued, a newly formed delta would then expand seaward and radiate out from its source. Many deltas had an ice-contact origin, having been fed by sediment discharge from ice tunnels as described above. Others were deposited where subaerial glacial outwash streams reached the sea and dumped their sediment loads.

A cross section through a typical marine delta reveals horizontal "topset" beds (sediment layers) that overlie inclined "foreset" beds (**Figures 3.15 and 3.16**). The topset beds were deposited in stream channels that shifted back and forth across the delta tops. These beds usually consist of coarse gravel, which was the heaviest part of the stream sediment load and thus the first to be deposited. The foreset beds are composed of finer-grained sand and gravel that reached the ends of the channels and cascaded down the face of the delta. The very fine-grained sediment (sand, silt, and clay) spread onto the sea floor as "bottomset" beds.

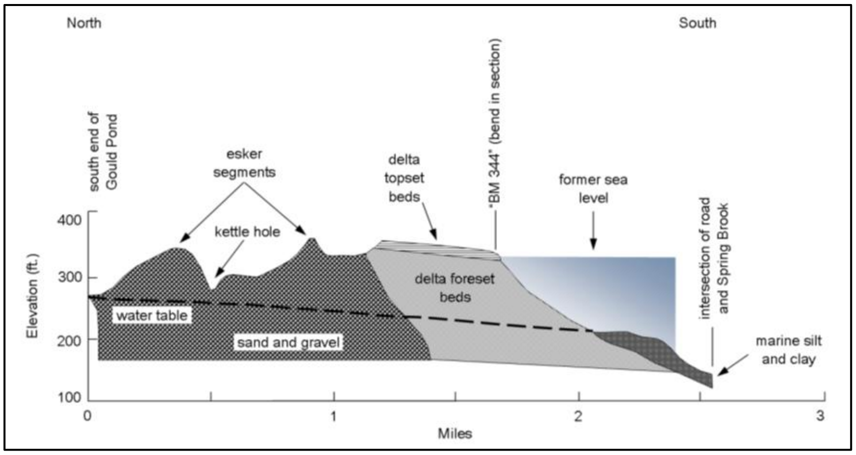


Figure 3.15. North-south topographic profile of the Summerhaven glacial-marine delta and associated esker north of Augusta. The diagram shows the internal structure of the delta and general profile of the water table.

Figure 3.16. The Palmer Hill glacial-marine delta in Whitefield. The upper part of the pit face shows the contact between the horizontal topset beds and inclined foreset beds, which marks the position of sea level when the delta was deposited.

One can determine the approximate position of sea level when the delta was built by measuring the elevation of the contact between the topset and foreset beds. This information is important in locating the limit of marine submergence in Maine (Thompson *et al.*, 1989).

Many borrow pits have exploited the valuable sand and gravel deposits in fans and deltas. Active pits often provide excellent opportunities to identify and study these deposits. Fresh pit faces may display prominent foreset beds, which are the dominant and most obvious constituent of both fans and deltas. A fan or delta typically includes one or more overlapping and lobate sets of foreset beds, because the location and direction of principal meltwater discharge shifted over time (like aiming a giant fire hose in various directions, as one geologist aptly described it to me).

As with eskers, the deeper portions of many of these deposits are saturated with groundwater and are significant aquifers (**Figure 3.15**).

Presumpscot Formation

The Presumpscot Formation consists of silt, clay, and fine sand that washed out of the melting Late Wisconsinan glacier and accumulated on the ocean floor (**Figure 3.17**). It is very widespread on the Maine coast and extends far inland along the Kennebec and Penobscot Valleys. The formation may occur as high as the marine limit, but in any particular area it was usually deposited to elevations that are 50-100 ft lower. For example, marine shoreline and deltaic deposits indicate that the Richmond area in the Kennebec Valley was submerged to an elevation of 300 ft. However, most of the Presumpscot Formation in this town occurs at elevations of less than 200 ft. The formation commonly has a flat or gently sloping surface (marking the former sea floor) where it has not been dissected by stream erosion (**Figure 2.15**). The regional elevation of this surface ranges from about 20-40 ft along parts of the coastline to over 200 ft farther inland.

Figure 3.17. Clay-silt beds of the Presumpscot Formation, exposed at a 2008 construction site on the east side of the Kennebec River valley in Augusta.

The Presumpscot Formation has partly filled many valleys and caused their floors to become higher and flatter (**Figure 3.5**). The thickness of the silt and clay in these areas locally exceeds 100 ft. Elsewhere the formation is a thinner blanket deposit that has subdued – but not totally concealed – the preexisting topography. One may encounter great variations in the thickness of the Presumpscot Formation, even within distances of a few yards. The marine sediment fills many small gullies and kettle holes, but it tapers to lesser or zero thickness on the higher parts of underlying deposits. Most of the Presumpscot Formation overlies till or glacial sand and gravel deposits (**Figure 3.18**).

Figure 3.18. Clay-silt beds (Presumpscot Formation) draped over stony till (probable moraine), at same Augusta site as Figure 3.17.

Postglacial stream erosion has carved steep-walled gullies in the Presumpscot Formation, creating a distinctive drainage pattern that is evident on topographic maps, aerial photographs, and Lidar imagery. The rills and gullies form intricately branching networks with dendritic patterns. Landslides have occurred on the gully walls in many places. Similar marine deposits in Canada's St. Lawrence Lowland and elsewhere are occasionally affected by hazardous slumps (Hodgson, 1927), and some destructive landslides have occurred in Maine. The movement is usually triggered by one or more of the following causes: high water content, oversteepening of slopes by stream erosion or artificial excavation, or the occurrence of an earthquake or other shock (see Chapter 5).

The Presumpscot Formation is often called "clay," but silt-size particles are more abundant than clay at many localities. The samples studied by Goldthwait (1953) and Caldwell (1959) contained an average of about 40 percent clay-size particles (defined by Caldwell as finer than .0039 mm). The formation may appear massive or well stratified, and thin layers of fine sand are commonly interbedded with the silt and clay.

In some areas the upper part of the Presumpscot Formation consists entirely of fine to pebbly sand deposited during the shallowing (regressive) phase of marine submergence. Extensive marine sand plains can be seen in Scarborough and elsewhere in Cumberland and York Counties. The contact between the silty and sandy zones may be sharp, or there may be a thin-bedded transitional zone that is sandier toward the top. Minor amounts of gravel are locally present in the Presumpscot Formation. Pebbles and larger stones that are actually mixed with the silt and clay were introduced by submarine slumps or by falling from icebergs (dropstones).

The color of the Presumpscot Formation ranges from brownish gray through gray to dark bluish gray (**Figure 3.19**). This sequence of colors is observed with increasing depth below the present ground surface, but one seldom finds all three colors in a single exposure. Chemical analyses cited by Caldwell (1959) indicate that the brown color is the result of weathering and oxidation of iron-bearing minerals. The degrees of fossil preservation support Caldwell's conclusion. Marine shells are locally abundant in the Presumpscot Formation. They are well preserved in the bluish-gray, unoxidized zone; however, shells in the brown or gray zones commonly exist only as impressions (the actual shell material having dissolved). Dark-brown iron/manganese-oxide staining and a blocky fracture pattern typically occur in the upper, weathered part of the formation.

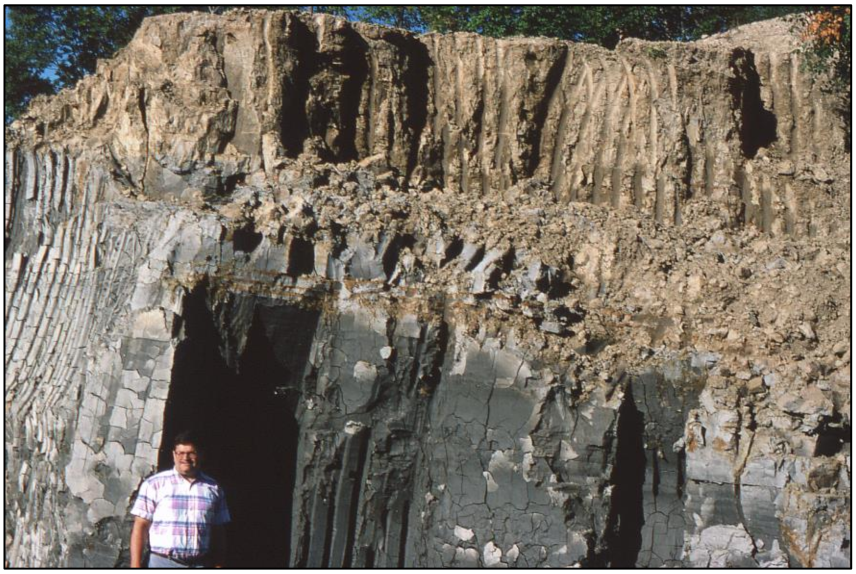


Figure 3.19. Exposure of the Presumpscot Formation at a 1997 construction site on the west side of the Kennebec River valley in Gardiner. Note the color contrast between the brownish weathered clay in upper part of section and the non-oxidized fresh gray clay at depth.

The Presumpscot Formation is much less permeable and well drained than glacial-stream deposits and other coarser-grained surficial materials. The silt and clay mixture becomes sticky and difficult to manage when it is wet. Conversely, it is very hard when it dries.

Fossils in the Presumpscot Formation include remains of clams, mussels, scallops, barnacles, and other shellfish (**Figure 3.20**). Extremely well-preserved spruce logs with associated branches, needles, and cones have been found in the glacial-marine clay at Portland (Thompson and Hyland, 1978; Thompson *et al.*, 2011). Organic material from the Presumpscot Formation has been dated by the radiocarbon method to help establish the chronology of deglaciation and sea-level change in coastal Maine (Stuiver and Borns, 1975, and many later authors, e.g. Dorion *et al.*, 2001; Retelle and Weddle, 2001; Borns *et al.*, 2004; Thompson *et al.*, 2011).

Figure 3.20. Well-preserved marine fossils collected from the Presumpscot Formation at the Webb Pit in Prospect, including mussel, clam, scallop, barnacle, and other shells. A walrus toe bone is seen in upper-left part of photo. Specimens collected by Ray Webb.

Late-glacial Shorelines and Nearshore Deposits

Raised beaches in southern Maine are composed of gravel and sand deposited along the ocean shore in late-glacial time, when relative sea level was higher than at present. Many of the raised beaches occur at or near the upper marine limit, where the sea stood long enough for wave action to rework glacial sediments and form gravelly shoreline and nearshore deposits. Those which formed right at the marine limit are called “high-stand” shorelines. Lower beaches formed during the marine regression, when the land rose in response to the disappearance of the Laurentide Ice Sheet.

A few raised shorelines stand out on air photos because they are manifested by linear zones where the bedrock has been stripped bare by wave attack (**Figure 3.6**). Each of these shorelines follows the contour of the land, having developed when local sea level was at a particular elevation. Most of them are subtle features that are not readily apparent on air photos. However, a great many shorelines – both high-stand and regressive – have been revealed by the recently available lidar imagery (**Figure 3.21**).

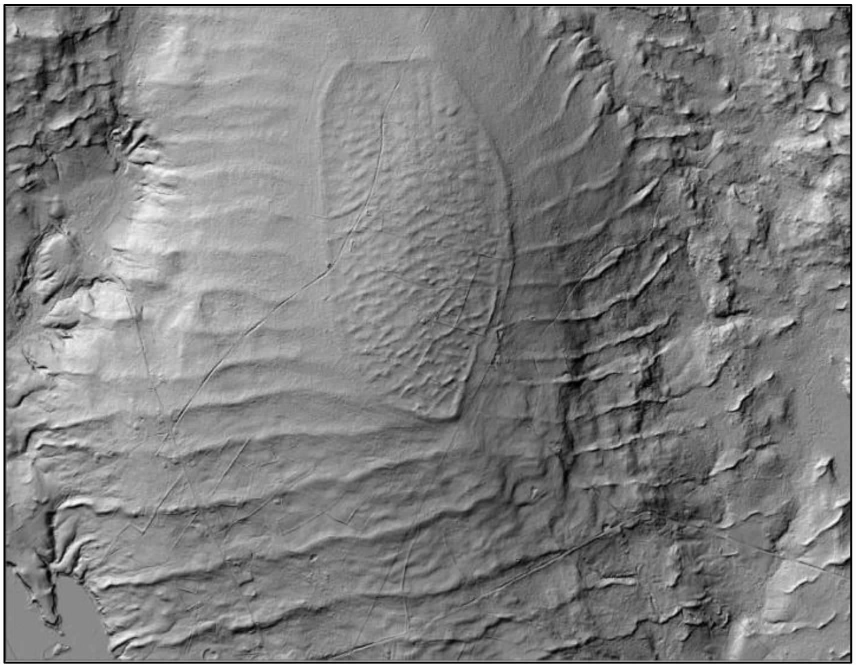


Figure 3.21. Lidar image of moraines (east-west ridges) and a shoreline (center) that formed in Penobscot during the late-glacial marine submergence of coastal Maine. The shoreline is at the upper limit of submergence and completely surrounds Grey Ridge. The area seen here is about 2 miles wide.

Beach deposits derived from till usually consist of angular, poorly sorted gravel that was not transported and abraded to a great extent. Beaches formed on submarine fans and deltas tend to contain better-rounded gravel and a higher percentage of sand inherited from their parent material. The latter type is more apt to exhibit good beach morphology because it developed on material that could be eroded more quickly than till. Prominent beaches can be seen on the seaward faces some glacial-marine deltas such as those in Cherryfield and Columbia Falls.

Numerous small pits have been excavated in the former shorelines of mid-coast Maine, a part of the state where glacial gravel deposits are uncommon and supplies are much in demand. However, these beach deposits are typically less than 10-20 ft thick, and many pits were exhausted when they hit ledge.

Much of the sand and gravel resulting from marine erosion is not concentrated in distinct beaches. Rather, it is spread somewhat randomly across the area of former marine submergence. In many cases it is uncertain whether this material was deposited along shorelines or in shallow waters offshore. Therefore it is often mapped under the general heading of “marine nearshore deposits”.

Marine Regressive Sand Plains

Regressive sand plains are areas, in some cases very extensive areas, where streams shifted back and forth across low flat areas near the coast and deposited sandy sediments. These deposits occur in the Topsham-Brunswick area and farther southwest in Cumberland and York Counties. They used to be mapped as glacial outwash (Bloom, 1960) until it was realized that they were graded to sea levels much lower than when the glacier stood in those areas.

Regressive sand plains may range from fluvial to thin deltaic deposits built into a shallow marine environment as relative sea level dropped. They show local development of stream channels and terraces. In places the sand plains overlie marine clay of the Presumpscot Formation. This situation has led to formation of deep gullies carved by a combination of surface runoff, springs issuing from the sand plains, and slumping within marine clay. Good examples can be seen in the Kennebunk sand plain.

Water-laid Deposits Above the Marine Limit

Outwash

Outwash consists of sand and gravel deposited by glacial meltwater streams in valleys above the marine limit. Outwash plains have flat, gently sloping upper surfaces. Many of them have been modified by human activities including gravel extraction, but in places there are still remnants of the stream channels. These channels are most clearly expressed in Lidar imagery. They show a “braided” pattern consisting of many ephemeral interconnecting channels that typically form where glacial streams are heavily laden with coarse sediments.

These deposits commonly occupy parts of river valleys, where they stand at higher elevations than younger river terraces and modern flood plains. Outwash usually has better internal stratification than eskers. It consists of alternating beds of different (but well-sorted) particle sizes. These layers appear to be nearly level, but they may contain smaller-scale "cross-bedding" that is more steeply inclined. The dip direction of cross-bedding, along with other sedimentary structures, can be used to determine the direction in which glacial stream was flowing (**Figure 3.22**).

Figure 3.22. Glacial outwash sand and gravel on the west side of the Little Androscoggin River valley in Paris. The inclination of cross-bedding seen here (center) indicates stream flow from left to right.

The upstream parts of outwash plains formed closest to the glacier margin and thus may show depressions of various sizes and shapes, called "kettles" or "kettle holes" (described in Chapter 2).

Glacial-lake Deposits

Outwash plains are a staple of geology textbooks, but in reality are quite rare in New England. This contradicts our expectation that glacial streams would have flowed without hindrance down the south-draining river valleys, leaving great amounts of outwash in their paths. However, many south-draining valleys were blocked in places by accumulations of glacial sediments, causing glacial lakes to form behind the obstructions. In most cases these sediment dams were eventually eroded away, and the modern rivers developed.

In other situations, valleys were blocked by deltas formed at the inland marine limit, and as ice retreat progressed, those marine deltas dammed freshwater lakes that extended farther up the valleys. This appears to have been the situation in the Saco River valley.

Valleys that sloped generally northward (toward the retreating glacier) were often blocked by the ice margin itself, forming ice-dammed glacial lakes. These lakes received water and sediment from two sources: from the melting ice sheet, and to some degree from the non-glacial input of ground and surface waters coming from those parts of the river basin from which the ice had already departed.

- **Glacial-lacustrine deltas**

Deltas formed in glacial lakes, sometime completely filling them (e.g. in the Saco Valley). These and other sediments deposited in lakes are called "lacustrine". Glacial-lacustrine deltas in Maine are very similar to those deposited in the sea. They have both topset and foreset beds, with the contact between these units marking the former lake level.

The stratigraphy of the deltas is usually best exposed in gravel pits (**Figure 3.23**). However, many deltas have been eroded and terraced by postglacial rivers. It may be difficult to tell whether an upper layer of stream-laid gravel is the original topset unit, or whether it resulted from later downcutting of the delta and is merely a stream-terrace gravel that is lower than the former lake level. Regardless, the deltas are important sources of groundwater (aquifers) and commercial sand and gravel resources. Their good drainage, ease of excavation, and level tops also make them very favorable for development.

Figure 3.23. The Langtown Delta, which was built eastward into glacial Lake Langtown from ice in the Kennebago Lake valley (Thompson *et al*., 2006). This section mainly shows the foreset beds, but fine-grained horizontal bottomset beds are exposed in the foreground.

- **Lake-bottom deposits.**

Glacial lakes also trapped fine-grained sediments (clay, silt, and fine sand) that settled to the lake floors. Ideally, each spring and summer melt season usually produced a thicker and lighter-colored layer of silty-sandy bottom sediments, followed by a darker clay layer when the winter freeze-ups allowed the clay particles to settle out. Each year’s pair of summer-winter layers is called a “varve”.

Thousands of years of varved clays have been recorded and dated in a vast glacial lake called “Lake Hitchcock”, which occupied the Connecticut River valley from central Connecticut north to Littleton, New Hampshire, and St. Johnsbury, Vermont (**Figure 3.24**). These deposits have enabled a detailed chronology of glacial retreat to be worked out for much of New England (Ridge *et al*., 2012).

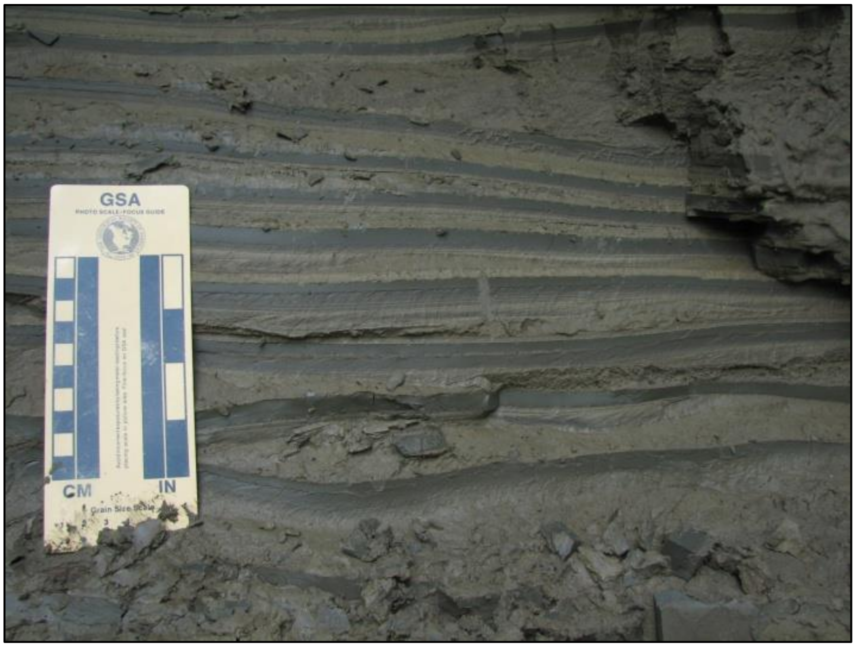


Figure 3.24. Varved sediments deposited in glacial Lake Hitchcock, Barnet, Vermont.

Unfortunately, there are few good exposures of varved clay in southern Maine. Test borings suggest they exist deep under the lacustrine delta fillings of major valleys such as the Saco in Fryeburg and the Androscoggin in Bethel. Lake clays have been seen in the lower Crooked River valley just north of Sebago Lake, raising the possibility that a large mass of remnant glacial ice remained for a time in the Sebago basin and dammed the valley drainage to the north. Glacial-marine deltas occur around the west, south, and east sides of the lake, but no marine sediments have been identified on the north side.

In years past, the limited exposures of lake clays were used by early settlers to make bricks. The clay banks in the brickyards are now slumped and overgrown to the point of having disappeared, but some inland villages such as Lovell have old brick houses that most likely were built using local clay deposits.

Late-glacial to Postglacial Deposits

Eolian (Windblown) Deposits

Eolian sand was deposited by wind, mostly in late-glacial time. It was eroded from sandy marine and glacial-stream deposits, and is now found overlying till or water-laid sediments (**Figure 3.25**). The windblown sand occurs as two kinds of deposits. In some places it forms a blanket on older materials; elsewhere the wind has shaped it into dunes. Extensive sand deposits occur in several areas of southern Maine. Examples can be seen around Fryeburg in the Saco Valley, near Bethel and Livermore falls in the Androscoggin Valley, in the western parts of Wayne and Fayette (**Figure 3.26**), southwest of Rich Mill Pond in Standish, and the "Desert of Maine" in Freeport and Pownal. Sand dunes are locally well developed in these areas.

Figure 3.25. Eolian sand overlying gray till, west of Keys Pond in Sweden. The sand was derived from glacial lake deposits in the Kezar River valley to the west.

Figure 3.26. Eolian sand dune in the "Desert of Wayne".

The orientations of longitudinal and transverse dunes indicate that the prevailing wind blew from the west-northwest. Both types of dunes are ridges, and they may be as long as 0.5-1.0 km. Other dunes are crescentic or irregular mounds of sand.

Eolian sand is moderately well sorted. It ranges from very fine to very coarse grained. The dunes and other deposits may be stratified (**Figure 3.27**) or appear massive and structureless. The sand is loose and extremely easy to excavate. It is very permeable and thus readily transmits ground water.

Figure 3.27. Eolian sand on east side of Bog Brook valley in Canton. The sand beds dip to the west.

Most of the sand dunes are no longer moving because they have been stabilized by vegetation. However, there are areas where plowing, grazing, or forest fires have resulted in renewed wind erosion and dune migration (Caldwell, 1965; Gerber, 1969). Much eolian sand is now exposed in the Desert of Maine and until recently was clearly visible in the "Desert of Wayne". In places one can see dunes that wrap around trees or cover man-made structures.

Lakeshore Deposits

Lakeshore deposits result from wave erosion of the surficial materials surrounding Maine's lakes. Most of these deposits are sand and gravel beaches. Wide sandy beaches have formed from reworking of water-laid glacial deposits, while till usually has eroded more slowly to yield angular beach gravel and a scattering of boulders. Lakeshore deposits are best developed on large water bodies such as Sebago Lake that experience more wind and wave action. The beach sediments have moved along the shore and formed spits in some cases (**Figure 3.28**).

Figure 3.28. Sand spit on front edge of Crooked River delta, north side of Sebago Lake. Photo taken in November, 1984.

Ice is also an agent of change on the shores of New England lakes. Lake ice commonly shoves against the shoreline and pushes up low ridges of debris (ice-push ramparts; **Figure 3.29**) (Buckley, n.d.). The effects of ice are well known to people whose wharves have been damaged by this shoving action. The same process can also build offshore ridges of cobbles and boulders in areas of shallow water. These ridges may or may not be submerged and are a potential hazard to boats.

Figure 3.29. Boulder rampart formed by shoving action of lake ice, east of Salmon Point on shore of Lake Auburn.

Little research has been done on ice-push ramparts in Maine. Bouldery ramparts derived from till are up to 6 ft high next to some lakeshores, and are slightly above and landward from the modern shoreline. This suggests they were more active sometime in the past when natural lake levels were higher. Raising and lowering of lake levels by dams or other human activities have been known to drown or otherwise change the situation of ice-push ramparts in certain cases.

Wetland Deposits

Wetland deposits are composed of peat, silt, clay, and sand that have accumulated in poorly drained areas (**Figure 2.23**). We may think of wetlands collectively as "swamps", but the wetlands are classified into several major types based on vegetation. A true swamp is occupied by shrubs and trees, while marshes (both freshwater and saltwater) are grasslands. Bogs and heaths are distinguished by peat accumulations. Many wetlands in southern Maine are the result of glacial obstruction of drainage patterns. They are especially common on the flat upper surfaces of silt and clay deposits of the Presumpscot Formation.

Stratigraphic information on wetlands has come from test borings, retrieval of core samples for academic studies, and economic investigations of peat deposits. Bore holes have penetrated over 6 m of organic sediment in Kennebec County (Thompson, 1976a). Trefethen and Bradford (1944) described 12 freshwater peat bogs that are distributed throughout southern Maine and have peat thicknesses of 3-25 ft, with an average of about 10 ft. According to Cameron (1975), the commercial peat in Washington and Aroostook Counties is up to 7.5 m (~25 ft) thick, and most deposits average at least 1.5 m (~5 ft). However, many other wetland deposits are probably thinner than these averages. A cross-section through a typical wetland shows that it grades from peat at the top to mainly inorganic sediments at the bottom. The peat is usually underlain by silt, clay, and sand that washed into the basin during the time of harsh late-glacial climate, before much organic material could accumulate. This barren sediment may in turn overlie older stream, lake, or ocean deposits (generally of glacial origin).

The ages of wetland deposits can be determined by obtaining radiocarbon ages of plant and insect remains. Moreover, radiocarbon ages from the deepest and oldest organics in wetlands and lake bottoms place minimum limits on when different parts of Maine were deglaciated. Wetland sediments also contain pollen grains from plant species that vary in species and abundance according to their position in the vertical section. The pollen assemblage in a particular sediment layer reflects the vegetation that grew in the area when that layer was deposited. This information can be used to help reconstruct the past climate and how it changed with time.

Stream Alluvium

Stream alluvium is water-deposited sediment found on flood plains and terraces along modern rivers (**Figure 3.5**). It may be composed of sand, gravel, silt, and clay in various proportions. A flood plain is a low, flat area adjacent to a stream; it is covered by water when the stream overflows its banks. Stream terraces are the remains of former flood plains and river beds that now lie above the modern flood plain and may seldom or never be flooded (**Figure 3.30**).

Figure 3.30. View looking northwest along the Androscoggin River in Canton, showing the river flood plain (left to center) and two levels of stream terraces in the distance.

The top of a stream terrace is simply a flat horizontal or very gently sloping surface, and that surface may be erosional (cut into whatever was there prior to the terrace), or it may be veneered with alluvial sediments derived from upstream as the terrace was developing. Many stream terraces were eroded into coarse water-laid glacial sediments, so any deposits left on these terraces are likely to be sand and gravel that originally had a glacial origin.

Surface exposures on major river flood plains indicate that they are composed of fine-grained sediments, commonly consisting of silt to fine sand. However, the flood-plain alluvium along steeper upland brooks and streams is usually gravel. Coarse-grained sediment is also found in stream channels, where the currents move faster than floodwater.

Many stretches of flood plains and terraces along southern Maine rivers are quite narrow. This is because the rivers have not caused a great amount of lateral erosion during the relatively brief time since the Ice Age. Even major rivers such as the Kennebec and Androscoggin have narrow valleys that are hemmed in by the surrounding hills. Notable exceptions include several broad intervales, such as those along the Saco River in the Fryeburg area, and the Androscoggin Valley at Bethel.

Colluvium

"Colluvium" is a general name for several types of surficial materials that have accumulated at the bottoms of slopes and cliffs. They have been transported mainly by the force of gravity, supplemented by the disruptive effects of frost action, surface runoff of water, plant roots, and burrowing animals. The colluvium in Maine includes talus (rock piles at the bottoms of cliffs) and hillside deposits that were derived from surficial sediments and/or bedrock.

Hillside colluvium may be discontinuous, and it is hard to see and differentiate because it typically has the same overall composition and surface appearance as the parent material which is usually till. Consequently, these colluvial deposits are not shown on most surficial geologic maps.

Talus is confined to where there are large bedrock cliffs from which blocks have toppled and piled up at the base (**Figure 3.31**).

Figure 3.31. Talus on steep east side of Pond Hill, adjacent to Lake Passagassawaukeag in Brooks.

Chapter 4 - Mapping Procedures

Surficial Geologic Maps

A surficial geologic map shows the distribution of unconsolidated materials at the Earth's surface. Based on local geology of the area being mapped, a geologist must decide what units (specific types of materials) will be represented on the map. A combination of field and office work is carried out to draw the contacts (boundary lines) between those map units.

The smallest area that is distinguished on the map depends on the map scale and the desired level of detail. A practical limit is the smallest area that can be circled by a contact line. It is sometimes desirable to ignore certain surface materials if they are very thin or sparsely distributed in relation to underlying deposits. For example, many large and important gravel deposits in coastal Maine are overlain by a thin or discontinuous mantle of clay, but it may not always be feasible to distinguish the clay unit on a geologic map.

Various symbols are used on surficial geologic maps to show features of practical and/or scientific significance. These symbols may represent landforms, directions of glacial movement, and other specific observations. It is worthwhile to show the locations of borrow pits and the kinds of sedimentary materials exposed in them, even in cases where the pits have been reclaimed. Information on the depth to bedrock and the positions of bedrock outcrops is also useful.

The Maine Geological Survey’s mapping program presently includes several types and scales of surficial geologic maps. The most detailed maps are plotted on the series of 1:24,000-scale topographic maps from the U. S. Geological Survey. These maps are called “7.5-minute quadrangles” (“quads” for short). Each quad has a name and covers 7.5 minutes of latitude and longitude. The surficial geologic map of a particular quad is accompanied by a surficial materials map that shows much of the field data on which the geologic map was based.

When enough area has been completed at 1:24,000, maps of neighboring quads are combined to yield a regional 1:100,000-scale surficial geologic map. Each of the latter maps encompasses 32 7.5-minute surficial quads. This product is likewise plotted on a USGS base map, though contours may be replaced by a shaded-relief depiction of the topography for sake of clarity. The 1:100,000 series is expanding over time and provides good geologic overviews for sizable areas of Maine.

The smallest-scale surficial map of Maine covers the entire state at a scale of 1:500,000. This map was published in 1985. It was based on rapid reconnaissance-level field mapping involving many people in a three-year project to generate a map showing an overview of Maine’s surficial geology and glacial history (Thompson and Borns, 1985).

Every geologic map is accompanied by an "explanation," which gives the meanings of the colors and symbols used on the map. Explanations should be concise, and often are used in lieu of a report to give a brief description of the map units. An abbreviated symbolism may be used to show a lot of information on a map, but it should be explained clearly and should not clutter the map. The map explanation may include photos of sites within the map area or generic photos showing good examples of surficial sediments in other parts of Maine.

Selection of Map Units

The units on a surficial geologic map are usually genetic - each unit represents a deposit that was formed by a certain process. This system offers a compromise between units that are strictly chronologic (defined according to age) and ones that show just materials (sand, clay, etc.). It has the disadvantage that several units may be composed of the same or similar materials. However, it enables the geologist to differentiate materials that formed in various ways and to put them in a historical perspective.

Collection of Map Information

The basic data sources for surficial geologic maps are field work, subsurface information, remote sensing by means of aerial photographs and other imagery, and previous publications in geology and related sciences.

Field work is a fundamental requirement for producing a detailed geologic map. The distribution of surficial deposits can be determined in large part by examining exposures where the soil and vegetation cover have been stripped away. These include both natural and man-made exposures, such as stream banks, bluffs on ocean and lake shores, borrow pits, foundation holes, highway excavations, and trenches for utility lines. Ready-made exposures may be scarce, especially in remote areas. It is often necessary to use a shovel or auger to penetrate the ground far enough to identify the surficial sediments. In some cases, one can recognize surficial deposits by their topography and other clues.

Subsurface information includes well and test-boring logs, seismic records, and ground-penetrating radar. Taking samples from wells and test borings is a direct means of determining the identity and thickness of surficial sediments that are beyond the reach of manual excavations. Boring logs from building sites, highway construction, and other projects commonly yield the only available information in many urban areas. If deep boring data are lacking and too expensive for the project budget, a backhoe or similar equipment may be used to dig test pits that reveal more details than a shovel or auger hole.

Seismic records may provide indirect information about subsurface materials if there are no borehole data. They are obtained by setting off a small impact or explosion at the surface and recording the arrival times of seismic waves at a nearby station. The thickness of successive layers of earth materials can then be determined if there are sufficient differences in their densities or other properties that affect wave transmission. The use of ground-penetrating radar is a newer technology based on similar principles, except it uses radar waves to profile buried strata and other features.

Remote sensing is a valuable supplement to field work, especially when it is not possible to cover the ground in detail. The technique includes several means of data collection, but it generally involves direct photography and other types of imagery.

Ordinary black-and-white or color aerial photographs have been used for many years in surficial geologic mapping. They are available at various scales and have the advantage that they can be viewed in pairs with a stereoscope to produce a three-dimensional image. There are several features visible on air photos that help identify surficial deposits. The important ones are topography, drainage, vegetation (including crops), land use patterns, and gray tones. Gray tones are the different shades of gray that one sees on a black-and-white photograph. In open areas their darkness commonly depends on the composition and drainage of the surface materials. However, the gray tones of forests and fields are locally influenced more by vegetation than by geologic variables. Photo interpretation may be especially difficult in urban and densely forested areas. Bedrock features may also obscure the surficial geology in regions of thin overburden. Nevertheless, it is often possible to use a combination of clues to approximate the contacts between surficial deposits.

Satellite imagery became an important geologic mapping tool in the 1970s (Baker, 1975). NASA's Landsat 8 satellite, launched in 2013, telemeters images of the Earth in eleven wavelength ranges called “bands” (http://landsat.gsfc.nasa.gov/?page_id=5377). These images can be used singly or in combination to produce black-and-white or color-composite pictures that resemble true photographs. They may be adequate for spotting certain large features (such as broad end moraines), but they are not suitable for detailed surficial mapping.

One of the newest tools has proven incredibly useful for imaging the Earth’s surface. This remote sensing technique is called “lidar”, which is short for Light Detection and Ranging. It is similar to radar but uses light pulses instead of radio waves. Lidar produces detailed data about objects by bombarding them with laser pulses and recording the reflections of the laser beams from their surfaces.

There are various types and applications of lidar. “Bare-earth” lidar is preferred for mapping and studying geology because it shows the earth’s surface as it would appear without any tree cover. In forested areas (including much of Maine) this has the great advantage of revealing details that could never be seen on air photos or othoimagery. Depending on the resolution of the data, it is possible to see objects as small as 6 ft across. Further details and examples of the use of lidar to identify geologic features can be found on the Maine Geological Survey website: http://www.maine.gov/dacf/mgs/explore/surficial/facts/dec11.pdf.

Information from publications is often helpful in preparing surficial geologic maps. There is a vast body of literature on the geology of Maine and other parts of the world that proves useful in understanding what we see in our state. For example, some reports by the Water Resources Division of the U. S. Geological Survey contain well and test-boring logs. The Natural Resources Conservation Center (formerly the Soil Conservation Service) of the U. S. Department of Agriculture has published detailed soils maps. There is a correlation between soils and their parent materials, so a soils map aids in identifying the underlying surficial deposits.

In compiling maps, the surficial geologist synthesizes information from the above sources to delineate the map units. For publication purposes, the compiler should select a base map whose scale is compatible with the level of accuracy of the geologic work. Geologists take advantage of many technological advances to facilitate the compilation, manipulation, and transfer of map data. Global Positioning Satellite (GPS) units are important for navigation and precisely recording the locations of sites in the field, while a Geographic Information System (GIS) enables digital compilation of all sorts of geologic features to produce the final map.

However, the map user should remember that enlarging a map on the computer screen does not make it more accurate!

Accuracy of Maps

There are two intrinsic variables (directly involving the data) that determine the accuracy of a surficial geologic map. They are the intensity of the field work, and the amount of information that can be gathered from other sources. Extrinsic variables include factors such as the amount of time, equipment, and money that are available to support the mapping project. And the experience of the mapper is very important!

In accordance with the above principles, three levels of surficial mapping are defined here - regional, reconnaissance, and detailed. *Regional mapping* is often intended to provide a rapid geologic overview of a large area in which coverage by detailed work is lacking or incomplete. It involves some degree of field work in areas that are easily accessible by roads, but it is accomplished largely by interpretation of topographic maps, air photos, and remote sensing imagery such as lidar. The locations of contacts between units are very approximate over much of the map area.

In *reconnaissance mapping*, the geologist maps along all passable roads and carries out off-road investigations where necessary. The best exposures of surficial materials (such as active borrow pits) are examined, and gaps in the field mapping are filled in by air photo and lidar interpretation. The contacts on a reconnaissance map are accurate to varying degrees, depending on their locations. It the early 1970s the Maine Geological Survey began a program of reconnaissance surficial mapping in the southern part of the state. The program was accelerated in the early 1980s to generate sufficient data for compilation of a 1:500,000-scale surficial geologic map of the entire state (Thompson and Borns, 1985). The latter map synthesized about 15 years of reconnaissance and rapid regional mapping. At that time, mappers often had to compile their field data on 1:62,500 topographic maps because much of Maine still lacked 1:24,000 coverage.

In *detailed mapping*, field work is expanded from road networks to insure that the map units are delineated as accurately as time permits. The mapper examines most borrow pits and other exposures of surficial materials. It is generally necessary to use shovel or auger holes and collect other available subsurface data to locate the boundaries between stratigraphic units. Air photo and lidar interpretation is still necessary to guide the field work and locate features that may not be visible on the ground. Many of the contacts on a detailed map are as accurate as the map scale allows, but it is usually necessary to locate them approximately in some places, especially where existing pits and other exposures are scarce.

Chapter 5 - Economic and Environmental Significance of Surficial Deposits

Natural-Resource Value of Surficial Materials

Four types of surficial materials in Maine have actual or potential natural resource value. They are: sand, gravel, clay, and peat. With the possible exception of peat, these materials generally have low "unit value" (value per ton). In many cases, it is not economical to transport them more than a few miles to markets or processing plants. Moreover, quality or location alone may not determine the usability of a deposit. For example, a sand and gravel deposit may be located near a construction project, but may not be exploitable because of zoning laws or existing land-use patterns. The following sections consider only the inherent value of surficial materials.

Sand and Gravel

Geologists usually define "sand" as sediment particles that range in diameter from 0.0625 to 2 mm. Larger grains are called "gravel." Both sand and gravel are divided into size categories such as "very fine sand" or "cobble gravel". According to Bates (1969), the lower size limit of “industrial” (commercial) sand is 0.053 or 0.074 mm, depending on the mesh size of the sieve that is used to retain the smallest grains. Industrial gravel ranges from a lower limit of 2.00-6.35 mm to an upper limit of 7.62-8.89 cm. However, the unprocessed gravel that is excavated from borrow pits may be naturally mixed with sand in various proportions.

The sand and gravel in southern Maine was derived mostly from igneous and metamorphic rocks. The sand grains are generally small particles of quartz, feldspar, and other common rock-forming minerals. Gravel, on the other hand, is mostly composed of rock fragments that contain more than one mineral. The properties of the rock types affect the value of gravel for construction purposes.

Most of the sand and gravel that is produced in Maine is used in the construction business. It is important for road base, concrete aggregate, fill, road sanding in winter, and other applications. In 2009, Maine companies produced 9,090 metric tons of sand and gravel with a value of $59,300,000 (USGS 2009 Minerals Yearbook): http://minerals.usgs.gov/minerals/pubs/state/2009/myb2-2009-me.pdf

The sand and gravel that is commercially excavated in southern Maine comes principally from deposits left by glacial meltwater, as described in Chapter 3. Eskers, deltas, and other coarse-grained water-laid deposits provide very large quantities of sand and gravel. Gravel is the most abundant material in many eskers, while deltas and other deposits formed at or beyond the glacier margin may contain a high percentage of sand. There is considerable variation in the degree to which different particle sizes have been separated (sorted) by natural processes.

Significant quantities of sand and gravel also occur in the large stratified end moraines where glacial meltwater was an agent of sediment transport and deposition. Late-glacial to postglacial river terraces are another important source in some places. Modern stream alluvium may include abundant gravel, but its exploitation may be prohibited because of potentially adverse impact on stream dynamics (e.g. erosion hazards) and fish and other aquatic life.

Three principal types of sand and gravel operations are: dry pit, wet pit, and dredging. Dry pits are located above the water table. In the past, some pits in Maine were excavated down to or below the water table and then abandoned, in part because of the increased cost of operating them. Today, pits that are 5 acres or more in size require a 5-foot separation above the seasonal high water table, in order to protect the underlying aquifers. Excavation is allowed below the water table through a permit process provided that no impacts occur to any protected natural resource or private and public water supplies.

Wet-pit operations involve the use of a dragline, long-reach excavator, or barge to remove sand and gravel from below the water table. The use of a long-reach excavator is the most common method used in this type of operation. To date, approximately 1,300 acres has been permitted for wet-pit operations in Maine. Dredging can be used to remove sand and gravel from rivers, lakes, and marine environments. Dredging is rare in Maine because of economic and environmental considerations, though it is conceivable that some material could be produced as a byproduct of river channel or harbor dredging.

Sand and gravel aggregate processing plants typically have facilities for screening, washing, crushing, and classifying the various particle sizes. The methods used at large aggregate plants have evolved into sophisticated computerized operations. A good overview of modern aggregate plants is available on the following website hosted by Pit & Quarry magazine: http://www.pitandquarry.com/pit-and-quarry-university/

Newport and Moyer (1974) described the removal of unwanted fines (silt, clay, and organic material) during gravel processing. These authors stated that (at the time of their study) at least 600 gallons (2274 liters) of water are typically needed to remove fines from a ton of sand and gravel. Obtaining the water, clarifying it after use, and disposing of the waste fines are considerations for pit operators. Discharging sediment-laden water into streams and lakes creates environmental problems and thus is prohibited. One solution to the waste problem is to allow the fines to settle from suspension in a holding pond. However, the continued accumulation of fine sediment may cause a space problem. It is desirable to remove the fines from the plant area if there is a use for them. Newport and Moyer pointed out that they may be suitable for fill, topsoil, or an ingredient in bricks. Adding fertilizer or sewage sludge to the sediment improves its soil potential.

There are several quality considerations in the production of sand and gravel. Since most of the output is used for construction aggregate, the requirements for this application are especially important. According to Bates (1969), sand and gravel utilized as aggregate ideally should be -

1. clean - free of dirt, mica, fines, and organic matter, as well as coatings on the particles;
2. resistant to abrasion;
3. sound - free of fractured or otherwise crumbly rock types; resistant to freeze-thaw and wet-dry cycles;
4. suitably sorted - having the necessary range of particle sizes; and
5. composed of rounded and equidimensional particles.

When cement hardens it releases alkalis - calcium, sodium, and potassium hydroxides. These chemicals react with glassy or fine-grained siliceous rocks to form water-soluble silicates. This process is called "alkali-aggregate reactivity" and it may cause concrete to crack or blister. Therefore, rocks such as chert, flint, rhyolite, and siliceous limestone should not be used as aggregate. The reader is referred to Lenhart (1960) and Ladoo and Myers (1951) for more information about sand and gravel aggregate properties. Fookes and Walker (2011, 2012) provide an extensive overview of the physical and chemical properties of natural aggregates in relation to the durability of concrete.

Till

Some borrow pits are excavated in glacial till, but this kind of operation is generally smaller and less common than sand and gravel pits. Till is often used as fill because its wide range of grain sizes makes it readily compactible. However, this same property makes till less economical than sand and gravel for use as aggregate. A great quantity of silt and clay would have to be removed by washing and screening to obtain the textures that are present in naturally washed deposits.

Lodgement till is usually very compact and has a fine-grained matrix, so it is rarely excavated for its own sake. In fact, it is sometimes necessary to loosen this type of till by blasting before it can be excavated by conventional equipment. The cost of a construction project may be greater than anticipated if large quantities of this till have to be removed (Legget, 1974). However, borrow pits are fairly common in ablation till because much of it has been washed to some degree by glacial meltwater, making it easier to excavate than lodgement till (though large boulders may be present). There are no production figures for Maine tills, but the quantity that is used is much smaller than the output of sand and gravel.

Till should contain fresh, solid stones if strength is an important consideration. The soundness of till stones depends on their composition and degree of weathering. The amount of weathering in turn is a function of the age of the till, the kinds of stones that it contains, and the extent to which they had weathered before being incorporated into the glacier.

Clay

Clay consists of mineral particles with diameters of less than 0.002-0.004 mm (2-4 microns), depending on the definition that is accepted, while silt particles are intermediate in size between clay and sand. The silt-clay boundary is 4 microns on the Wentworth Scale, but a 2-micron boundary is better for distinguishing actual clay minerals (formed mainly by the weathering of other minerals) from non-clays (Bates, 1969).

The clay deposits discussed in this report are mostly of glacial-marine origin. They consist of "rock flour" that was derived from glacial scouring of bedrock and deposited on the sea floor. The glacial-marine clays contain unaltered particles of quartz, feldspar, and other rock-forming minerals, but only minor amounts of true clay minerals. Goldthwait (1953) and Caldwell (1959) found that silt-size particles are more abundant than clay in many samples. Nevertheless, the term "clay" is used here to refer to the deposits in an economic sense.

In 1975 clay production in Maine was reported to be 125,000 short tons, with a value of $202,000 (Babitzke and others, 1975). Clay was excavated in five towns, and most of it was used in making bricks and cement. The remainder was used in pottery. By 2005, clay production in Maine had dropped to only 50,000 metric tons (USGS 2007 Minerals Yearbook: http://minerals.usgs.gov/minerals/pubs/state/2007/myb2-2007-me.pdf).

Iron-oxide and organic impurities impart colors to the clay, making it unsuitable for products such as white paper. Fuller (1949) described methods of eliminating the undesirable colors in Maine clays. He leached the iron with sulfuric acid and removed organic material by bleaching the clay. However, these treatments are probably not economically feasible in competition with naturally white clays from other parts of the country.

Several investigations showed that Maine clays are good for making lightweight expanded clay aggregate (Trefethen, 1955; Caldwell, 1959; Doyle, 1962). The major uses of lightweight aggregate are in concrete blocks, structural concrete, and pre-cast concrete structural units (McCarl, 1963; http://en.wikipedia.org/wiki/Expanded_clay_aggregate).

In order to convert clay into aggregate, one must heat it rapidly to 1000-1300°C. It is necessary for the clay to emit gas and simultaneously experience partial melting. The gas is oxygen, sulfur dioxide, or carbon dioxide that results from the breakdown of impurities in the clay (Bates, 1969). The bubbles are trapped in the viscous melt, which is cooled to form a lightweight, porous slag-like material.

In experiments with glacial-marine and glacial-lake clays from Maine, Caldwell found that most samples expanded at least 100 percent upon being heated to 1093°C for 1-5 minutes. Gray clays expanded more than brown clays, and expansion was greater with higher percentages of clay-size particles. Caldwell believed that release of water from clay minerals caused most of the expansion.

No lightweight aggregate is produced from Maine clays at the present time. However, the extensive glacial-marine deposits in the coastal region offer a vast supply of raw material from which aggregate could be made.

Peat

Peat consists of partially decayed plant material that has accumulated in swamps, marshes, and other poorly drained areas. It is used principally as a soil conditioner for agricultural and horticultural purposes. Most of the following information on peat is from a report by Cameron (1975). The general types of peat are:

1. Fibrous and matted - composed of mosses, ferns, grasses, rushes, sedges, reeds, and tree and shrub material
2. Finely divided plant material - too decomposed to be recognizable
3. Non fibrous, colloidal material - deposited on bottoms of ponds and lakes

Several properties of peat determine its commercial value. High water-holding capacity is desirable in peat that is used for soil conditioning. Peat may hold so much water that its weight increases to 10-50 times its dry weight. Ash content is the percent of total sample weight that is composed of inorganic material. It is determined by burning a sample and weighing the residue. True peat must have an ash content of less than 25 percent. Fiber content is the weight percentage of leaves, stems, and other plant fragments in peat. A high fiber content indicates a high water-holding capacity. Peat is generally acidic, with a pH of 3.2-7.5. Most Maine peats have a pH of less than 5.0 and are said to be "calcium-deficient."

Peat may be classified in various ways depending on intended use. The American Society for Testing Materials developed the following classification for commercial peat. It emphasizes fiber content, with fibers defined as plant fragments at least 0.15mm in size.

1. Sphagnum moss peat (peat moss) - at least 66 2/3 weight-percent sphagnum-moss fiber.

2. Hypnum moss - at least 33 1/3 percent fiber, of which hypnum-moss fibers compose more than 50 percent.
3. Reed-sedge peat - at least 33 1/3 percent fiber, of which reed-sedge and other non-moss fibers compose more than 50 percent.
4. Peat humus - less than 33 1/3 percent fiber.
5. Other peat - all other types of peat.

Of the 57 Maine deposits that Cameron studied, 32 deposits are composed of sphagnum-moss peat. Twenty-two deposits contain moss with other plant material, and the remainder are composed of peat humus. The size of the deposits ranges from less than 40 to 1620 hectares (less than 100 to 4,000 acres). The thickness of commercial peat is as much as 25 ft, and most deposits average at least 5 ft.

According to Babitzke and others (1975), three Maine companies produced peat in 1975. Their combined output was 4,000 short tons valued at $207,000. By 1997 (the last year for which peat was listed separately in USGS reports of State mineral production) Maine's output was estimated at about 15,000 metric tons (http://minerals.usgs.gov/minerals/pubs/state/982398.pdf).

Ground-Water Favorability of Surficial Deposits

This section contains general information on the physical properties of surficial sediments that affect their value as aquifers (ground-water supplies). The reader is referred to the Maine Geological Survey's ground-water handbook (Caswell, 1987) for more detailed information on ground-water resources.

Porosity and Permeability of Surficial Materials

Porosity and permeability are very important in determining the availability of ground water from surficial sediments. Porosity is the percentage of a sediment's volume that is occupied by openings between the grains (pore space). It is a measure of the amount of water that can be stored in a surficial deposit. However, a very porous material may yield only small amounts of water if the pores are not interconnected. Permeability is the capacity of a porous material for transmitting a fluid. It is measured as flow in gallons per day (gpd) through an area of one square foot (E. E. Johnson Inc., 1975).

The porosity of a surficial deposit depends on several variables, the most important of which is probably its particle-size distribution. A sediment that is well sorted (has little variation in grain size) is apt to be more porous than one that is poorly sorted. The reason is that the spaces between the larger grains in poorly sorted materials are filled in by the smaller grains. The shapes of sediment grains (rounded vs. interlocking) and the degree of packing also affect porosity. Porosity may be reduced by precipitation of natural cements in the pore space. Iron oxide and calcium carbonate are common cements in certain sand and gravel deposits, but pervasive cementation is uncommon in southern Maine.

Permeability is more important than porosity alone in affecting the ground-water yield of a surficial deposit. The inherent permeability of a sedimentary material is determined largely by its particle-size characteristics. In well-sorted materials, permeability is greater with coarser grain size. Walton (1970) gave the following permeability ranges for unconsolidated sediments:

Clay, silt	0.001 - 2 gpd/ft^2
Sand	100 - 3,000 gpd/ft^2
Gravel	1,000 - 15,000 gpd/ft^2
Sand and gravel	200 - 5,000 gpd/ft^2

The finer grained sediments are less permeable because the smaller pores offer more resistance to ground-water flow.

Decreasing the degree of sorting of a sediment reduces its permeability as well as its porosity. Walton's data show that a mixture of sand and gravel may have less permeability than either sand or gravel alone. Adding gravel to sand decreases the sand's permeability as long as gravel constitutes less than 65 percent of the mixture. The permeability of sand is also reduced by the addition of even a small percentage of silt or clay.

The permeability of a surficial deposit may be affected by the material's structural and stratigraphic characteristics. The presence of fine-grained strata or cemented layers commonly results in diminished permeability in directions (usually vertical) perpendicular to the stratification. For example, a sand deposit that contains layers of silt has less vertical permeability than sand alone. On the other hand, permeability is greater if joint fractures are present.

Other Factors that Influence the Availability of Ground Water

The composition of a surficial deposit may favor the storage and movement of ground water, but the deposit is useless as a water supply if its water-saturated zone is not large enough. Many gravel units in coastal Maine are too small to provide sufficient water for municipal or industrial use. It is necessary to consider both the thickness and lateral extent of a surficial aquifer.

Recharge conditions also have an important bearing on the ground-water favorability of surficial sediments. Recharge is the addition of water to the ground-water reservoir. Under certain circumstances it may be obstructed or barely occur at all. For example, a gravel unit that would normally be a good aquifer may be sandwiched between relatively impermeable materials such as bedrock and clay. Water that is drawn from the gravel may be replaced very slowly in this situation. However, recharge occurs much more quickly if a stream bed intersects the gravel unit, or if the gravel is exposed at the ground surface.

The unconfined (water table) aquifer is the more common type in the surficial deposits of southern Maine. Water can seep down to the aquifer directly from the surface, and the water level in wells rises only as high as the water table (the level below which the ground is saturated with water). In certain cases one may encounter a confined (artesian) aquifer. Such an aquifer is likely to occur where glacial-marine clay (Presumpscot Formation) overlies a sand or gravel deposit. **Figure 3.15** shows a situation in the Summerhaven Delta north of Augusta where artesian conditions might be found. If a well were drilled on the southern end of this delta, the water level in the well would be expected to rise above the clay-sand boundary.

Types of Surficial Aquifers in Southern Maine

Sand and gravel deposits are generally the best surficial aquifers because they are more permeable than finer grained sediments. Some of the sand and gravel was laid down by meltwater streams from glaciers, while other deposits were formed by postglacial streams.

Flood-plain and stream-terrace deposits (**Figure 3.5**) are possible sources of large quantities of water. On the surface, many flood-plain deposits consist of silt and very fine sand of low permeability. However, drilling a test hole may reveal that these materials are underlain by coarser grained channel gravels or older glacial sands and gravels that are good aquifers. Stream terraces are also likely to be composed of sand and gravel. Terraces are at higher elevations than the adjacent flood plains, so the water table is likely to be farther below the surface.

Glacial-stream deposits may also be good aquifers if they are large enough and not too poorly sorted. The most promising deposits in southern Maine are eskers, glacial-lacustrine or glacial-marine deltas and fans, and outwash plains. Outwash plains are apt to be excellent sources of ground water. They contain well-sorted sand and gravel of moderate to high permeability, and they are typically located in valley bottoms where recharge is likely to take place. However, large outwash deposits are not as common as might be expected. They are best developed in river valleys that lie above the limit of former marine submergence, such as the Crooked River valley north of Sebago Lake.

Many of Maine’s glacial-marine deltas are extensive and composed of very permeable sand and gravel. Their large, flat or gently sloping surfaces are favorable for trapping water and recharging the ground-water supply. If a well is drilled on top of a delta, it may have to penetrate a considerable thickness of material to reach the water table. It is more economical to locate the well at a lower elevation on the flank or "toe" of the delta.

Eskers and other ice-contact glacial sand and gravel deposits may extend along valleys for several miles. Eskers in particular are apt to be very long. Caution is necessary when developing water supplies in these deposits. They are heterogeneous and thus may vary greatly in their hydrologic properties over short distances. However, some exceptional well yields have been obtained from ice-contact gravels. A municipal well in an esker in Belfast yielded 1,500 gpm.

Water wells are also developed in till, but they generally have small yields that are adequate only for domestic use. Till may supply enough water for a well if it is coarse grained, contains sand and gravel lenses, or is jointed (Walton, 1970). Ablation till is a better source of ground water than lodgement till because it is coarser grained and may contain considerable washed sand and gravel. Lodgement till is commonly well jointed, but the joint fractures are more widely spaced with increasing depth.

Suitability of Surficial Deposits for Waste Disposal

Types of Waste and Waste Disposal

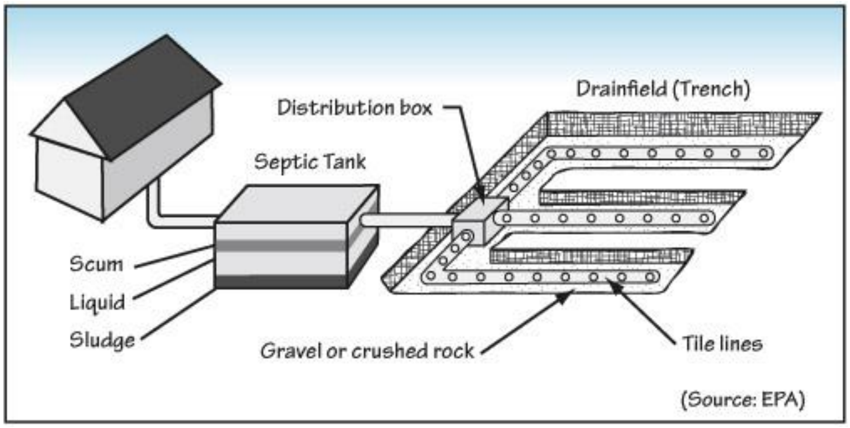
It is important to examine the surficial geology of a proposed waste-disposal site because many landfills and former dumps in Maine are located on surficial sediments. Two general types of waste are discussed here - liquid waste and solid waste.

- **Liquid Waste**

Liquid waste includes domestic, municipal, and industrial sewage. Only the domestic type is considered here. In rural areas domestic sewage is commonly released into the ground via a combination of septic tank and absorption field, as shown in **Figure 5.1**. The earth material in the absorption field acts upon the sewage and reduces ground-water contamination in several ways (Deutsch, 1972):

1. Filtration

2. Sorption, including absorption of chemicals into mineral particles and adsorption onto particle surfaces
3. Ion exchange (exchange of ions between sewage and mineral particles)
4. Dilution and dispersion
5. Oxidation and biochemical processes in the zone of aeration (the zone above the water table)



(Source: EPA)

Figure 5.1. Schematic diagram of a domestic septic tank and absorption field.

Regulations pertaining to the design of private sewage-disposal systems in Maine are set forth in the State's "Subsurface Wastewater Disposal Rules", available online at: http://www.maine.gov/decd/meocd/ceo/publications.html. This code also relates various surficial earth materials to the size of disposal field needed to handle liquid waste. The large volumes of liquid wastes that are produced by cities and factories are usually processed by sewage treatment plants, and the water is released in various degrees of purification.

- **Solid Waste**

Common types of solid waste are (Schneider, 1972):

1. Garbage - vegetable and animal matter resulting from food preparation
2. Rubbish - a wide variety of combustible and non-combustible debris
3. Ash
4. Trash from streets
5. Dead animals
6. Abandoned vehicles
7. Demolition wastes - from tearing down buildings, bridges, etc.
8. Construction wastes

Open dumps used to be a common means of disposing solid wastes in Maine, but they were apt to pollute both ground and surface waters. Burning at the dumps was also a problem because of air pollution. Therefore, landfills have replaced dumps as the principal means of solid-waste disposal. The trash in a landfill is dumped and compacted in successive layers. In many cases the body of solid waste is isolated from the underlying ground by impermeable clay and/or synthetic layers. When the landfill has reached its full capacity and must be closed, it is capped by similar materials to isolate the waste pile from contact with surface and ground waters.

Water that manages to percolate through exposed (uncapped) landfill trash contains biological and/or chemical contaminants. This water is called "leachate." Leachates are apt to have several properties that are harmful to water quality, including high acidity, hardness, nitrate and chloride contents, and biochemical oxygen demand (BOD). A variety of deleterious organic and inorganic contaminants may also be present (Schneider, 1972).

Leachate is a type of liquid waste, and passage through soil beneath an unlined landfill may purify it to some degree, especially if the permeability is such that the leachate seeps slowly through the zone of aeration (Deutsch, 1972). However, ground-water pollution may be severe if part of the landfill is below the level of the water table (in the zone of saturation). Even if the base of the landfill is above the water table, ground-water contamination may occur if the material under the landfill is permeable enough to allow the leachate to migrate down into the saturated zone.

The generation of leachate can be minimized during the operation of a landfill by keeping most of the site covered with low-permeability sediment such as clay or clayey till. It may also be desirable to trap the leachate and treat it separately. In this case the landfill excavation should be located in or lined with an impermeable material (either natural or artificial). Then the leachate can be contained and collected by a drainage system. The reader is referred to Hansen (1977) and more recent sources for further discussion of the geologic aspects of landfill operation.

Selection of Solid Waste Disposal Sites (Landfills)

The siting and design of modern solid waste landfills are complex topics, involving many considerations besides the surrounding geologic materials. There are numerous State regulations, so a detailed discussion of landfill siting is beyond the scope of this handbook. A few basic principles are presented here, and the reader can obtain further information from the Bureau of Waste Management at the Maine Department of Environmental Protection (MEDEP).

Richard Heath (MEDEP Division of Technical Services) provided the following summary of the history of Maine landfill operations and related issues:

> *Prior to the mid-1960's the disposal of solid waste was essentially unregulated. Most Maine communities had a dump that was usually located based on convenience with little regard for potential environmental impact. Initial regulation of solid waste disposal began in 1965 when the U.S. Congress enacted The Solid Waste Disposal Act. Since that time, regulation and management of solid waste has evolved to where today landfills are constructed and operated using current engineering practices which can include sophisticated liner and leachate management systems and even landfill gas-to-energy plants. With a few exceptions licensed landfills are now required to perform some level of environmental monitoring. Monitoring requirements are specific to each landfill and may include monitoring of groundwater, surface water, and air quality.*
>
> *As of 2014 there are 47 active licensed landfills in the State of Maine which are regulated by the Department of Environmental Protection. These include municipal landfills, industrial special waste landfills, construction and demolition debris landfills, wood waste landfills, and wastewater sludge landfills. Some landfills, such as municipal and special waste landfills, are designed with highly sophisticated liners, leachate management systems, landfill gas management systems, and intermediate cover requirements. Once these landfills reach their waste capacity, highly engineered capping systems are required as part of the closure process.*
>
> *In comparison, no liner system is required for a construction demolition debris landfill with a footprint of less than 5 acres. However, each landfill must meet specific siting requirements before construction or expansion.*

> *Many landfills have multiple phases that were constructed over long periods of time when either engineering practices did not exist or were evolving toward present day standards. Therefore, even state-of-the art landfill sites may have earlier phases that create environmental concerns.*
>
> *In addition to the licensed landfills, there is a legacy of well over 400 former municipal landfills in Maine. Most of these unlicensed landfills were operated by cities and towns and caused varying levels of ground and surface water contamination because of inappropriate siting, inadequate design, and/or improper operation. The majority of these sites dated from the 1960's through the 1980's and were often located in old gravel pits where they posed a risk to groundwater supplies. Waste was initially burned but in later years was covered on a daily basis with inert fill material. Solid waste regulations required that these sites be closed.*
>
> *In 1988 the Maine Legislature created the Landfill Closure and Remediation Program to aid communities in the closure of these landfills. The extent of closure activities was dependent on the hazards individual landfills posed to public health and the environment at the time of the closure. Recent encroachment of residential development near some closed landfills has created the risk of groundwater contamination at new water supply wells, and landfill gas migration in the vicinity of new homes.*
>
> *Additional information regarding landfill locations, Maine solid waste disposal regulations, and the landfill closure program may be found at the following State web sites.*
>
> *http://www.maine.gov/dep/waste/*
>
> *http://www.maine.gov/dep/spills/landfillclosure/*
>
> *http://www.maine.gov/dep/gis/datamaps/*

Landfill Siting Criteria

Chapter 401 of the Maine Solid Waste Management Rules (Landfill Siting, Design, and Operation) includes several geologic siting criteria. For example, new landfills and expansions of existing landfills are prohibited within 1000 ft of certain classes of surface waters, or within 300 ft of a significant sand and gravel aquifer.

In addition to the prohibitive siting criteria mentioned above, there are also a series of restrictive siting criteria. One of these criteria restricts siting a landfill within 100 ft of other sand and gravel deposits that may provide domestic water supplies, or that would enable contaminant migration to significant aquifers, bedrock aquifers, and surface waters. 100-year flood plains and "unstable areas" are likewise excluded, and the landfill must be "located on soils that contain sufficient fines and clay-size particles to minimize infiltration of leachate". However, in the case of "restrictive siting criteria", it may be possible to obtain a variance in accordance with State regulations. For example, a suitable liner could be designed to avoid landfill leachate migration into surficial earth materials that do not meet the permeability limitation.

Natural Geologic Hazards Associated with Surficial Deposits

This section briefly discusses hazards that are naturally associated with surficial deposits (such as flooding in areas of stream alluvium) and those which are provoked by man's activities. Additional information on the causes of many problems and ways to preventing them can be found in books and websites on geomorphology, hydrology, and engineering geology.

Floods

Floods occur on lowlands along streams and other bodies of water that occasionally overflow their banks. Floods in wetland areas rarely threaten human life or property because these areas are mostly uninhabited. The main problem exists where people have built on deposits of modern stream alluvium, known as flood plains. Flood plains experience frequent inundation, and even stream terraces (old stream deposits that are higher than the present flood plain) may be submerged by floods of great magnitude.

Before building in a lowland area, one should determine whether the property is subject to flooding. This information can be obtained by consulting local residents, government offices, and relevant maps and reports. Surficial geologic maps show the principal deposits of stream alluvium, and detailed maps may differentiate flood plains and terraces. However, in most cases these maps only provide an approximate indication of areas where floods may occur, so they are not definitive maps on which to base regulatory policies.

Accurate flood-prone area maps are very important to the public because they are used in the National Flood Insurance Program. The Maine Floodplain Management Program at the Maine Department of Agriculture, Conservation, and Forestry is a helpful source of flood information. This agency has a website that will link you to floodplain maps and information about obtaining flood insurance: http://www.maine.gov/dacf/flood/.

Deluges

A special case of flooding is the "deluge". As used here, this term refers to a great downpouring of rain that may be brief, and even unexpected, and yet have devastating consquences. Deluges have occurred from time to time in the mountains of Maine and other New England states. Very heavy rains may not only send torrents of water down the mountainsides, but also trigger debris flows resulting from erosion and slope failure in water-saturated surficial sediments. Large boulders and trees are ripped up and carried along in these flows (**Figure 5.2**).

Figure 5.2. Debris swept down Chapman Brook in Bethel by the deluge of 2007. A town reservoir was filled with boulder gravel by this event.

Fortunately, destructive deluges in Maine are uncommon and tend to occur in sparsely populated areas. Even though these events are rare, landowners should consider the possibility of their happening in steep, narrow mountain valleys. The presence of gravelly alluvial fan deposits at the mouths of such valleys indicates that floods have occurred in the past and are possible during extreme rainfall episodes in the future.

The effects of tropical storm Irene in the Green Mountains of Vermont, which occurred in August, 2011, offered proof of what can happen during a deluge! Some of the most dramatic photos of New England flood damage were taken just after this storm (**Figures 5.3 and 5.4**)

Figure 5.3. Severe erosion along U. S. Route 4, Mendon, Vermont, resulting from tropical storm Irene in 2011. Photo by Lars Gange & Mansfield Heliflight.

Figure 5.4. Property overwhelmed by flood deposits from tropical storm Irene in 2011, Routes 4/100 south of Killington, Vermont. Photo by Lars Gange & Mansfield Heliflight.

Shoreline Erosion

Major erosion may occur along the shorelines of lakes, rivers, and the ocean. Erosion is most rapid and noticeable along certain sections of the ocean shore, where houses have been undermined and have fallen into the sea in the course of a single storm. The worst problems occur where the shoreline consists of "soft" glacial sediments, in contrast to durable bedrock ledges. In coastal areas underlain by glacial-marine clay, shoreline retreat is exacerbated by sea-level rise and landslides (see next section).

The natural erosion of undisturbed Maine lakeshores is generally too slow to be appreciable. This is due in part to the relative stability that has been attained by the shorelines in the long time since glaciation. Another reason is that many lakeshores are located in areas of till or bedrock outcrops, which are more resistant to erosion than loosely consolidated sand and gravel deposits. However, rapid lakeshore erosion may occur where sandy glacial deposits are located at the leeward end of a long fetch, resulting in wave attack on windy days.

Lakeshore erosion can be accelerated by damming lakes and raising their levels, causing the shore slopes to be unstable at the new water levels. Caldwell (1976) mentioned examples of rapid erosion of surficial deposits on Spencer Lake in northwestern Maine. The use of motorboats, which can greatly increase wave action in areas of high boat traffic, may also be detrimental to shoreline stability.

Streams and their flood plains are dynamic geologic systems. Ever-changing patterns of erosion and deposition occur during the evolution of a river, especially when it begins to meander and shift its course across the flood plain. Along any particular meander, erosion occurs on the outside ("cutbank") of the bend, while deposition of sediment builds "point bars" on the inside of the meander (**Figures 5.5 and 5.6**). The shifting of meander paths occurs at greatly varying rates, but it is generally most rapid during periods of high water. Erosion of the cut bank may attain a magnitude of feet per day, and streams occasionally shorten their courses dramatically by suddenly cutting across the necks of meanders. It is unwise to build on surficial materials close to an active stream meander, even though the building site may be higher than the flood plain (**Figure 5.7**).

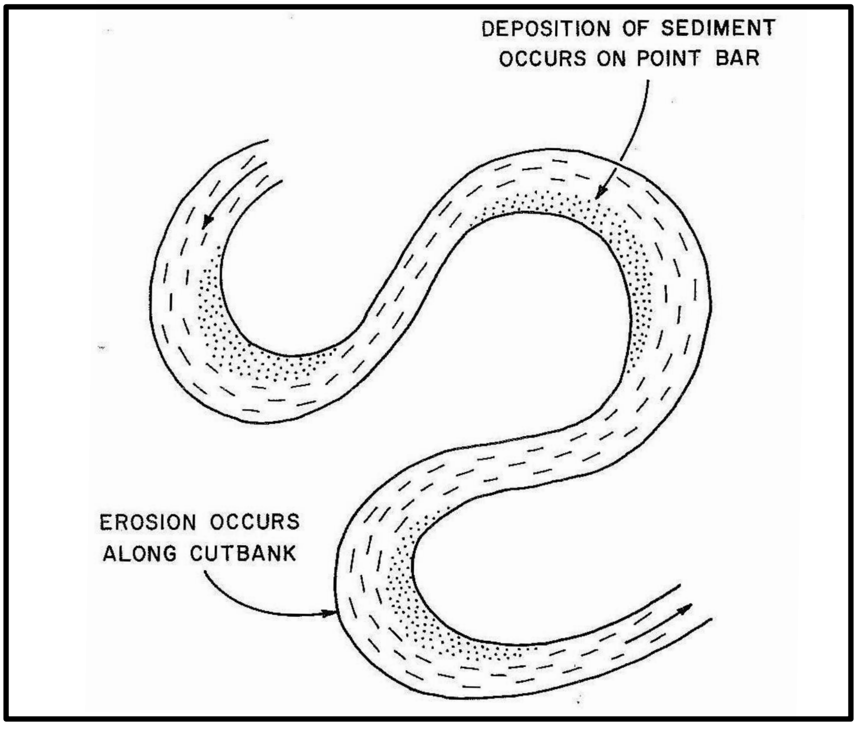


Figure 5.5. Plan view of three stream meanders, showing zones of erosion and deposition.

Figure 5.6. Point bar on inside of meander on the Androscoggin River at Rumford Point. Note the freshly deposited sand left by spring flooding (just to right of the field). Photo taken in April, 1987.

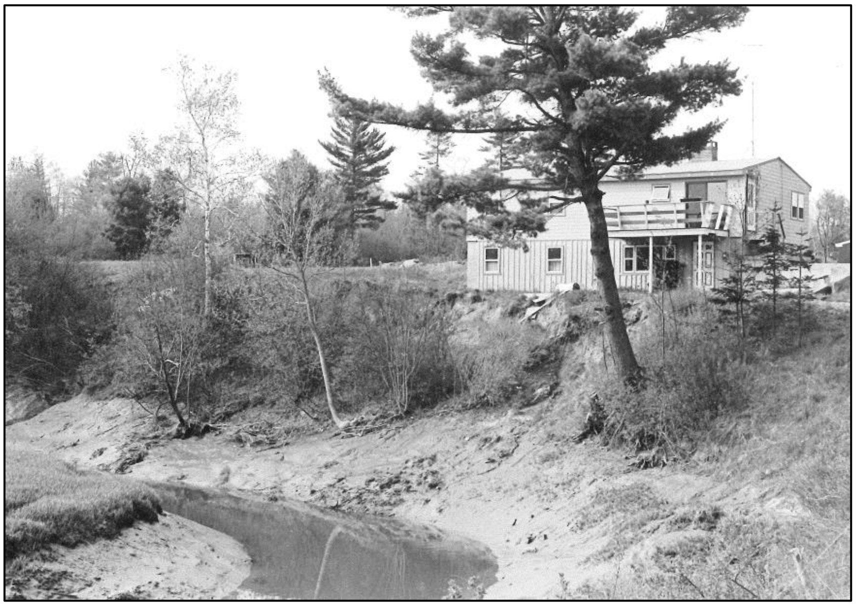


Figure 5.7. Home in precarious location next to eroding cutbank on outside of stream meander. Note the tilted trees on the stream bank.

Landslides

The term "landslide" includes various kinds of downslope movement of earth materials, ranging from moderately to extremely rapid. The driving force is gravity, and the materials involved in a landslide may include rock, earth (mostly sand-size or smaller particles), and/or debris (coarse fragmental materials such as rock-earth mixtures). Types of landslides include rockslides, debris avalanches, mudflows, slumps, and other types of mass movement.

Landslides differ from "soil creep", which is a somewhat continuous and very slow (<1ft/decade) downslope movement that may be widespread on hillsides over a broad area. Creep is caused mainly by gravity, but it may be aided near the ground surface by freeze-thaw action and other processes.

Some of the causes of landslides include:

- oversteepening of slopes
- adding material weight on upper edges of slopes
- adding water to slope materials (due to heavy rain, snow melting, or other causes)
- rapid drawdown of river or lake levels adjacent to slopes
- liquefaction
- earthquakes

Many other factors may also be involved in triggering landslides. The reader is referred to the U. S. Geological Survey's "Landslide Handbook" by Highland and Bobrowsky (2008) for further information on causes and mitigation of landslides: https://pubs.usgs.gov/circ/1325/pdf/C1325_508.pdf

Oversteepening of slopes in Maine may result from natural causes such as stream erosion, or from excavation by humans. Although overloading at the top of a slope could result from natural processes, it is usually a consequence of building construction or the dumping of fill material. Earthquakes of low magnitude occur in Maine, but it is not certain whether they have caused any slides in this state.

Infiltration of water can decrease the stability of sediments in several ways:

1. Eliminating the surface tension of water films in spaces partly filled with air
2. Increasing the weight of the sediment
3. Dissolving soluble cements (probably unimportant in Maine)
4. Raising the potentiometric surface, with an accompanying decrease in the sediment's shearing resistance (The potentiometric surface is an imaginary surface to the level of which water will rise in a well.)

Rapid lowering of water levels in rivers or reservoirs may also cause slides. The reason is that the water table in the adjoining bank cannot drop fast enough to keep pace with the falling level of the surface water. The piezometric head (a measure of water pressure) in the bank becomes high relative to the potential surface of sliding, and a slide is more likely to occur.

Spontaneous liquefaction may occur when a disturbance causes sediment grains to settle into a more stable arrangement. This settlement is not likely to cause a slide if it takes place above the water table. If the material is saturated, on the other hand, it behaves as a liquid until reaching equilibrium. The sediment flows laterally, with disastrous consequences for whatever was at the surface. Coarse silt and fine sand are most likely to be affected by spontaneous liquefaction. Possible causes of liquefaction include earthquakes, blasting, rapid changes in the level of the water table, and erosion of supporting material.

Bukovansky (1977) outlined several methods of preventing or stabilizing landslides. The principal techniques that he suggested are:

1. Change the shape of the slope by:
    - completely excavating the slide-prone materials;
    - excavating just the upper part of the slope;
    - loading the lower part of the slope; or
    - combining excavation and loading.
2. Drain the slope by means of:
    - shallow surface trenches;
    - deep gravel-filled trenches;
    - subdrains (horizontal drainage holes);
    - pumping wells to lower the water table; or
    - a combination of a tunnel and subdrains.
3. Build a buttress, retaining wall, or anchoring system to inhibit slide movement.

Some of the above methods are particularly expensive and thus limited to the treatment of small landslides. However, any of them may be prohibitively expensive if the slide-prone area is very large. Bukovansky's study dealt with landslides in Colorado, but the measures that he described are applicable to varying degrees in Maine.

In southern Maine the glacial-marine silt and clay deposits (Presumpscot Formation) are more slide-prone than most other surficial sediments. Slumps are a common type of slide in the glacial-marine deposits. **Figure 5.8** shows a cross section of a typical slump. It is characterized by rotational movement of the slide mass along a distinct slip surface that is concave upward. This process causes segments of the ground surface to be tilted backward in the upper part of the slide (see cover photo).

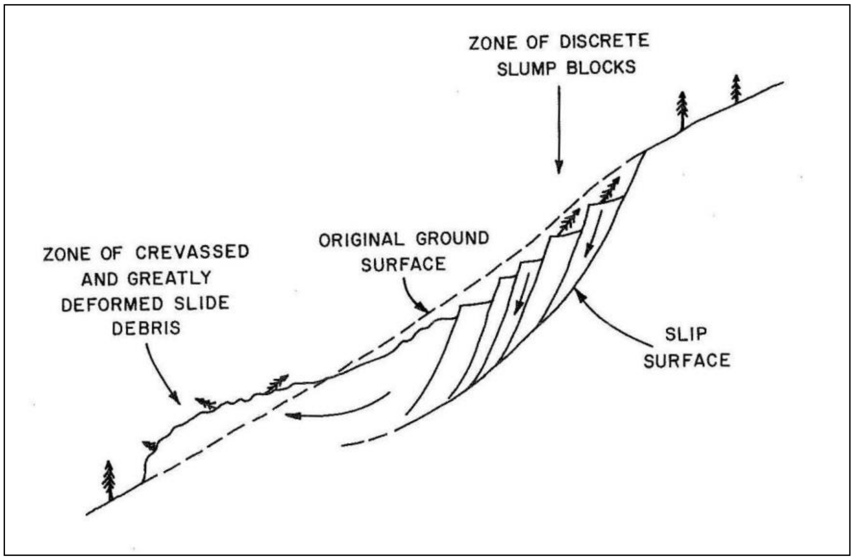


Figure 5.8. Cross section of a typical slump.

Earthflows are another common type of landslide in southern Maine (**Figure 5.9**). Much turbulence and mixing of material occurs within an earthflow. With increased water content and fluidity, this type of mass movement may be classified as a mudflow. Many slides in the Presumpscot Formation are composite varieties whose upper parts are slumps and the lower portions are earthflows or mudflows.

Figure 5.9. Fresh earthflow in the Presumpscot Formation, next to Route 9 in Chelsea. Photo taken in mid 1970s.

Some of the largest slides in the Presumpscot Formation have occurred along the Presumpscot and Stroudwater Rivers. These slides tend to occur on river banks along the outsides of meanders, where oversteepening of the banks by fluvial erosion made the slopes unstable. Landslides are also common in clay bluffs along the ocean shore, where the soft sediments are easily eroded by wave attack. The bluff faces may recede quickly by a combination of marine erosion exacerbated by slumping, resulting in considerable loss of valuable coastal property. A large slump occurred in the Presumpscot Formation on the north shore of Rockland Harbor on January 25, 1973, and another major slide happened in the same part of the harbor in April, 1997 (Berry *et al.*, 1996). The cover photo shows the rotation of slump blocks in the 1973 slide.

Early accounts of landslides in the Portland area were given by Morse (1869) and Hitchcock (1873). A study of a prehistoric slide on the western slope of Bramhall Hill in Portland shows that slope failures due to coastal erosion began over 13,000 years ago, in early postglacial time (Thompson *et al*., 2011).

Siltation of Streams and Lakes Resulting from Sand and Gravel Operations

Newport and Moyer (1974) discussed siltation problems that may result from sand and gravel operations, and most of the following information is from their report. It has been pointed out that the processing of a ton of sand and gravel may generate hundreds of gallons of waste water containing silt, clay, and organic material. This fine sediment may be dumped into streams and lakes, or washed into them by storm runoff from active or inactive pits. A great influx of sediment into surface waters can cause the following problems:

1. The water looks unattractive.
2. The water quality decreases for other users.
3. Organisms that normally purify the water are inhibited.
4. Sediment covers gravel shallows and rocky areas that provide nesting ground for fish.
5. Sedimentation reduces the population of benthic organisms, which consist of algae and invertebrates that thrive on gravel bottoms and are eaten by fish.
6. The turbidity of the water restricts the amount of photosynthesis that can occur and thereby reduces the algae supply for the food chain.

Studies of water turbidity have shown that fish can survive sediment concentrations of several thousand ppm (parts per million) for short periods, such as during a flood. However, long-term concentrations of only 100-300 ppm are harmful. Fish eggs are especially vulnerable because silt adheres to them and blocks their respiration. Newport and Moyer reached the following conclusions about the effects of suspended solids on fish populations:

Concentration:	**Probable effect:**
0-25 ppm	no harm to fisheries
25-100 ppm	good to fair fisheries
100-400 ppm	fisheries not likely to be good
Over 400 ppm	poor fisheries

Chapter 6 - Application of Surficial Geology in Land-Use Planning

The importance of surficial geology in land-use planning is evident from the information that has been presented in this handbook. The characteristics of surficial material should be considered when locating sites for the following purposes:

1. Extraction of surficial resources - sand and gravel, till, clay, and peat
2. Development of aquifers in surficial deposits
3. Disposal of liquid and solid wastes
4. Siting of roads, buildings, dams, pipelines, and other structures
5. Recognition of areas where geologic hazards prohibit or restrict human activities

In addition to the above considerations, there are others that may be less obvious but nevertheless important. Some surficial deposits are significant because they support certain plants or animals. For example, Maine's blueberry barrens are located on deposits with sandy, well drained soils such as glacial-marine deltas and ablation tills. On the other hand, many swamps and marshes may not be utilitarian but they do provide plant and wildlife habitats.

Land-use planners should also consider the scientific and educational values of glacial landforms. Maine contains some of the largest and best developed esker systems in the United States, as well as superb end moraines, glacial-marine deltas, and even sand dunes. Moreover, coastal Maine exhibits an assemblage of glacial-marine deposits that is unique in the East. It is not practical to preserve every good esker or delta. However, an effort should be made to protect a few exceptional glacial landforms.

In cases involving conflicting land uses, it may be possible for two or more uses to coexist or occur in sequence. A common practice with sand and gravel pits is to operate them until they are depleted or the maximum legal depth is reached. Then the pit area is graded over and the property may still retain its value as an aquifer or building site. If pits are allowed to operate below the water table, the resulting ponds may be used for recreation. It is evident that sand and gravel deposits are worthy of special consideration in the planning process because they are likely to be suitable for more uses than other surficial materials.

Many land-use plans are related to the zoning process. Problems may arise if surficial geology is not considered on an equal footing with other factors in drawing up zoning ordinances. LaFleur (1974) pointed out that zone boundaries have commonly been located on the basis of cultural patterns, with little or no regard for geologic limitations. He described examples in a New York town whose zoning pattern was inappropriate in view of the local geology. LaFleur divided the town into three areas on the basis of its surficial geology and geomorphology: (1) an eastern upland with sandy till and a few ridges of exposed bedrock (this till is moderately well drained); (2) a central area with drumlins and many bedrock outcrops (drumlin till has low permeability); and (3) a western area composed of glacial sand and gravel. The upland was zoned as "open space" because of its rocky terrain, even though much of it was actually suitable for development. The drumlin area was zoned as "residential" - a decision that has caused many problems with sewage disposal in the poorly drained till. The western part of the town had "commercial excavation" zoning, but only where gravel pits already existed.

Future building in this zone would risk permanently cutting off access to remaining sand and gravel resources.

The above example illustrates the importance of surficial geology in formulating land-use policies. It is realized that other, non-geological elements are also important in the planning process. These elements include biologic, climatic, social, economic, and other factors, one or more of which may necessitate a land use that is not best from the geologic standpoint. Nevertheless, the geologic aspect of a land-use decision should be a priority in order to avoid costly mistakes like those described by LaFleur. Applications of surficial geology in various land-use activities are discussed in the following sections.

Locations of Highways

It is necessary to examine the surficial geology of proposed routes for new roads to help minimize engineering problems. While it is possible to build a highway on almost any of the surficial earth materials in Maine, construction costs and potential hazards can be reduced by choosing the route that is most compatible with the local geology. Construction of new public roads and bridges by the Maine Department of Transportation involves careful checking of geologic conditions, but some of the same geologic concerns apply to town highway projects and private roads for housing developments, camps, etc.

Surficial deposits vary in the ease with which they can be excavated. Most materials do not present great difficulties, especially if they are located above the water table. Loose, uncemented sand and gravel deposits and sandy tills are easiest to excavate. However, the cost may be greater than anticipated if very large boulders are present. This is apt to be the case in certain tills and other deposits formed next to glacial ice. According to Way (1973), the presence of large boulders in New England till may necessitate blasting and increase excavation and grading costs.

Compact lodgement till and glacial-marine sediments consisting of silt and clay are relatively difficult to excavate. Lodgement till may be jointed and weathered near the ground surface and yet require blasting for removal at greater depths. The fine-grained marine sediments (Presumpscot Formation) are very cohesive and difficult to dig when they are wet. Wheeled vehicles may get mired in the mud under these circumstances. On the other hand, marine clay is hard and brick-like when it dries. It is most readily excavated where it is penetrated by numerous cracks along which it can be broken apart. These cracks form during periods of drying and are most abundant just below the ground surface.

The thickness of surficial deposits can be as important as their texture and structure in determining ease of excavation. There are many large areas in southern Maine where bedrock is at or near the surface. Blasting is necessary during highway construction in most thin-overburden areas, so excavation costs typically are several times greater than for loose, dry surficial sediments (Way, 1973).

Flat, more-or-less horizontal terrain offers the fewest topographic obstacles for transportation routes. Several of the principal highways in southern Maine are located in part on the flat surfaces of glacial-marine deltas or the Presumpscot Formation. These marine deposits tended to accumulate in river valleys and other lowland areas. The surfaces of the valley fills have been utilized in building the Interstate highway system that connects Portland, Augusta, and Bangor. Many other roads in Maine have been built on the surfaces of glacial outwash and stream terrace deposits. These landforms conveniently follow the valleys. They are gently sloping and rarely flooded. They also have the advantage of being composed of sand and gravel, which is well-drained and may be suitable for construction materials. The low gradient of such deposits is particularly important in the location of railroads as well as highways.

The surface and underground drainage of surficial sediments is likewise important in planning highways. Precautions are necessary when roads are built across flood plains, swamps, and other low, wet areas - both to avoid flooding and to stabilize the roadbeds. Excavation costs are greater if the water table is close to the surface, and they may increase markedly with the presence of organic material (wetland deposits such as peat) (Way, 1973).

Highways generally are engineered so as to avoid obvious water hazards, but other difficulties may ensue if the hydrogeology in the vicinity of each road is not fully considered. Contamination of wells and gravel aquifers by road salt is a common problem in Maine and other northern states. In some cases the salt is washed off the road surfaces, while in others it is leached out of storage piles that are not protected from rainfall. The saline water then percolates down into the ground and may pollute the ground water. Even if there is no reduction in the application of road salt, these problems can be alleviated to some extent by covering salt piles and channeling runoff from highways into the least harmful areas.

The engineering properties of surficial deposits affect their suitability as highway foundations. It is desirable for earth materials to have high shear strengths so that they will not rupture under heavy loads. The volume change of sediments under varying moisture and temperature conditions should be low in order to reduce frost heaving and other shrinking and swelling processes. Sand and gravel deposits are generally favorable in these respects. The most problematical materials in coastal Maine are the glacial-marine silt and clay deposits (Presumpscot Formation) and swamp, bog, and marsh deposits. These are poorly drained materials, and they have greater compressibility and lower bearing capacities than most other types of surficial sediments.

The potential for landslides needs to be considered in highway design and maintenance. Slides may occur along roads in various types of surficial materials under certain slope and groundwater conditions. These movements include a broad range of landslides, depending on the geometry, composition, water content, type of movement, and velocity of the slide mass. Highways built on Presumpscot clay-silt in the coastal lowlands may be prone to slumps or earthflows (see landslide section). In steep mountainous areas of western Maine, some roads are vulnerable to rapid landslides such as debris avalanches and rock falls. For example, the Maine Department of Transportation has addressed a variety of landslide problems where roads are located in deep, narrow valleys along the Wild River and Androscoggin River in the Gilead area (Thompson et al., 2014).

Location of Underground Utility Lines

Various utility lines are buried in surficial deposits. They include pipelines for the transmission of water, sewage, oil, and gas, as well as communication and electric cables. Some of the considerations that apply here have already been discussed in the previous section. Ideally, utility lines should be located in deposits that are easily excavated, well-drained, stable, and not susceptible to rapid erosion by streams and other geologic agents. One or more of these characteristics are lacking in many places, though the problems commonly are not serious enough to prevent lines from being laid.

The thickness of surficial materials has a very important bearing on the cost of laying underground utilities. In New England there are extensive areas of thin overburden where blasting is necessary in trenching operations. Costs are also greater in areas where the water table is near the surface and excavations have to be dewatered while digging is in process. In hilly or mountainous bedrock terrain, additional pumping stations may be required for liquid-carrying pipelines (Way, 1973).

The possibility of leakage warrants consideration in planning pipeline routes. A break in a water line may cause only temporary mechanical problems. On the other hand, the escape of oil or sewage into highly permeable sediments is likely to contaminate ground-water resources and may also affect surface waters. Where possible, pipelines carrying materials that are potentially harmful to water quality should be routed so as to avoid major surficial aquifers.

Home Sites

General Considerations

This section concerns the choice of house lots for one- or two-family dwellings, but much of what is said here also applies to other small buildings. The siting of larger structures (such as many apartment, government, and commercial buildings) is not discussed in this handbook. Depending on their location, these large buildings may require more extensive on-site investigations to solve problems of water supply, sewage disposal, or foundation stability.

Several geologic factors enter into the location of home sites. One of the most obvious of these factors is topography. Most of the landforms in Maine are either composed of glacial sediments or were sculpted from bedrock by glacial ice. Strictly from a topographic viewpoint, it is easiest to build on flat terrain. In southern Maine, flat topography occurs principally on the surfaces of the Presumpscot Formation, glacial-marine and glacial-lake deltas, outwash plains, river terraces, flood plains, and wetlands. The wetland and flood-plain deposits are very poorly drained and obviously prone to flooding.

Although certain flat areas are geologically favorable for home sites, they may be unappealing aesthetically. Hilly terrain is more likely to provide views of the surrounding countryside. For example, cleared fields on the crests of drumlins and other glacially streamlined hills may offer spectacular views. River terraces on glacial and postglacial sand and gravel deposits commonly provide views of the valleys in which they are located, and most of these landforms have the advantage of being above flood limits. Other attractive home sites occur in areas of kame-and-kettle topography, with intermingled small hills and basins. Ponds and lakes occupy the kettle holes if the water table is high enough, and these water bodies boost the local property values. The intervening hills limit the number of houses that can be seen from any particular site, giving a sense of privacy.

Drainage is also important in the selection of building sites. It is closely related to the topography, thickness, and texture of surficial earth materials. Home builders should avoid flood plains and other areas subject to occasional flooding. Caution is also necessary in low-lying areas where the water table is apt to be near the ground surface (such as valleys that are underlain by silt and clay of the Presumpscot Formation). In lowland areas near the Maine coast, some of the most favorable building sites are on the many low glacial moraine ridges that protrude above the surrounding clay. While driving across swarms of these moraines, you will often find that all the old farm houses and barns are right on their crests!

Drainage problems likewise may be encountered on the flanks of hills covered by low-permeability lodgement till. Wet basements constitute one of the greatest annoyances in poorly drained surficial deposits. Sumps, subdrains, or other means of removing water are used in many homes to prevent basement flooding.

As in highway construction, the presence of bedrock at or near the ground surface is likely to increase the cost of building a home. The excavation of basements and trenches in solid rock is expensive compared to digging in surficial sediments. However, some bedrock outcrops are highly fractured or weathered and can be excavated to an adequate depth without blasting. Near-surface bedrock also contributes to problems with drainage and waste disposal because it is a barrier to the movement of ground water and liquid wastes. On the other hand, cliffs and ledges are a scenic attraction in certain residential areas, and they may be very desirable if they do not interfere with construction and the location of utilities.

It is advisable to consider the stability and erodibility of surficial deposits at proposed building sites. In southern Maine, slope stability is most likely to be a problem on steep hillsides or coastal bluffs in the Presumpscot Formation (see section on landslides). If hazardous areas are not recognized, the potential for landslides may be increased by slope and drainage modifications resulting from construction activities.

Houses and other structures that are built next to streams should be located so as to avoid areas of rapid bank erosion. This erosion is most severe on the outsides of migrating stream meanders. Bank erosion may proceed rapidly in loose materials such as sandy glacial-stream deposits. Loss of valuable farm land may result from this process. In extreme cases, a river may abruptly experience a dramatic change in course when flood waters cut a new path (http://www.maine.gov/dacf/mgs/hazards/erosion/sites/apr13.pdf). This change may not be hazardous to local landowners, but can be very inconvenient – for example – if it causes part of a farmer's field to suddenly be on the other side of the river or even in a different town!

The erodibility of surficial materials is most apparent along the ocean shore. Parts of the Maine coastline have retreated landward tens or hundreds of feet in recent years as a consequence of winter storms, normal coastal erosion, and accelerated shoreline retreat due to landslides. Houses have fallen into the sea in places, so people who plan to build along the coastline should make sure that they are locating their homes on stable ground materials.

Housing with On-Site Water Supplies and Waste-Disposal Systems

The type of housing discussed in this section consists mainly of individual homes and low-density developments in rural areas. We will consider situations in which each house has its own water supply and sewage-disposal system. From the standpoint of surficial geology, sewage disposal is often a key factor in siting homes. (Water supplies may be available from bedrock wells if the surficial deposits yield insufficient water or are likely to be contaminated.)

Anyone building or purchasing a new home that will have its own absorption field (leach field) for sewage disposal should be certain that a licensed site evaluator has found a suitable location on the property as required by law. Houses situated on thick, well-drained sandy till often have good sites for absorption fields, and sand or gravel deposits may also be suitable (see section on waste disposal). Careful field work may disclose favorable sites even in areas of thin or poorly drained surficial deposits. As noted above, the crests of many small moraines protrude from the silt and clay (Presumpscot Formation) that partly covers them. These moraines are apt to provide good sites for sewage absorption fields. In areas where bedrock is at or very near the surface, there may still be a possibility of finding pockets of surficial sediments that are thick enough for sewage systems or that can be modified by addition of fill to meet the requirements of the State Plumbing Code. Otherwise it is necessary to resort to the use of holding tanks or other non-discharging systems.

If a domestic water supply is obtained from surficial deposits, the well should be located at a reasonable distance from the absorption field in order to minimize the risk of water contamination. State law requires a separation of at least 100 ft.

High-Density Housing with Municipal Water and Sewage Systems

"High-density housing" consists of residential tracts with town water and sewer lines. In many cases the homes are numerous and closely spaced. This kind of housing can be put on most surficial deposits that are adequately drained and not subject to flooding, landslides, or other hazards.

Since high-density housing and associated urbanization cover large areas of land, the concepts of sequential and multiple land uses help in maximizing the benefits from these areas. As stated previously, sand and gravel deposits may be valuable as aquifers, construction material, and building sites. Any on-site sand and gravel deposits, including what is needed for construction, should be excavated before permanent homes are built on the same site. This principle also applies to areas that border on developments. The reason is that the presence of active pits next to houses is likely to cause problems with noise, dust, traffic, and safety.

Some of the sand and gravel deposits in Maine are important aquifers and worthy of preservation in their natural state. It may be feasible to use the deposits as both home sites and water supplies at the same time. However, the surface of an aquifer should not be covered with so many buildings and paved areas that infiltration of water into the ground is greatly reduced. One way to avoid this problem is to zone the aquifers and specify the minimum allowable size of building lots, as well as limiting coverage by paved parking lots.

Utilization of Terrain that is Poorly Suited for Building Sites

Flood-Prone Areas

Structures built on flood-prone areas should not be susceptible to flood damage or release contaminants into surface and ground waters as a result of flooding. Oil storage tanks, in particular, should not be located in these areas. Surface tanks may be struck by floating debris or undermined by erosion (the latter causing them to settle differentially or be swept away). In either case they may rupture and lose their contents into the water. Both underground and surface storage tanks may be uprooted by buoyancy under certain conditions. Guidelines for the protection of tanks from these hazards can be found in the Flammable and Combustible Liquids Code of the National Fire Protection Association.

Farming is one of the best uses of flood plains, where the level terrain and rich soils are good for growing crops. Undissected stream terraces are also quite level. They are apt to be better drained and underlain by coarser-grained sediments with less organic material than flood-plain deposits. The types of soils that have developed in response to these varying conditions are a determining factor in deciding which crops to raise. Flood plains are also well suited for several other land uses that do not require the construction of vulnerable structures. Popular recreational facilities can be located in flood-prone areas, including parks, athletic fields, and boat launching sites.

Wetlands

Most swamps, marshes, and bogs should be left in an undisturbed condition. They are not suitable for development because of their extremely poor drainage and unstable sediments (both organic and inorganic). Wetlands are important as plant and wildlife habitats, and they store water that might otherwise run off quickly and contribute to flooding. Moreover, some bogs contain large amounts of peat and constitute a significant natural resource.

Maps of Maine’s wetlands have been compiled by the National Wetlands Inventory and are available through the Maine Geological Survey (http://www.maine.gov/dacf/mgs/pubs/mapuse/series/descrip-nwi.htm) or the U.S. Fish and Wildlife Service (http://www.fws.gov/wetlands/).

Bedrock Outcrop Areas

Areas where bedrock is widely exposed at the ground surface are unfavorable for many land uses. Cliffs, broad ledges, mountain tops, and other expanses of barren rock are often left in their natural state, with the notable exception of urban areas where development pressure may result in entire bedrock hills being blasted away. Bedrock areas may have great scenic and recreational value, as in Acadia National Park and other places along the Maine coastline. It is desirable to set aside some of the spectacular bedrock terrain as parks for the enjoyment of the scenery and pursuits such as hiking, rock climbing, and natural history studies.

Generally speaking, areas with thin surficial deposits and/or scattered small outcrops are more common than extensive areas of continuous outcrop. It is possible to utilize many of these outcrop and thin-overburden areas for building sites (as pointed out earlier in this chapter), but the owner may incur expenses and inconveniences that could be avoided elsewhere. Many houses are built in such areas, especially on the rocky (but valuable) land that occurs along the Maine coast.

Areas of thin overburden may also be reserved for the growth and harvest of trees. The feasibility of this land use depends on the thickness and character of the soil, as well as various geographic and climatic factors. Forest reserves have the additional benefits of providing recreational opportunities and wildlife habitats. Another use for certain outcrop and bouldery areas is grazing farm animals, thus freeing better land for growing crops.

Summary

Appendix A summarizes the suitability of various surficial sediments for land uses such as those described here.

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Appendix A

Suitability of Some Common Surficial Materials for Various Land Uses

Use: Material:	Source of sand and/or gravel	Source of clay	Water supply potential (D = domestic only)	Waste disposal (with no containment of liquid wastes)	Location of highways and underground utility lines	Home sites	Parks and other recreation areas with little development	Farming
Lodgement till	P	P	P	P	F	F-G	G	F-G
Ablation till	P-F	P	P-F (D)	G	F-G	F-G	G	F-G
Mixed sand and gravel (stratified moraines, eskers, fans, deltas, outwash, stream terraces, etc.)	G	P	F-G	P-F	G	G	G	F-G
Clean, well-washed gravel (eskers, fans, deltas, outwash, and stream terraces)	G	P	G	P	G	G	G	F-G
Fine to very coarse sand (fans, deltas, outwash, stream terraces, etc.)	G	P	F-G (D)	P	G	G	G	F-G
Clay, silt, and very fine sand (glacial-marine and glacial-lake deposits)	P	P (sandy) to G (clay-rich)	P	P	P (clay) to G (sandy)	F-G	F-G	F-G
Wetland deposits	P	P	P	P	P	P	P-G	P
Stream alluvium (flood plains)	P-F	P	P-G	P	P-F	P	F-G	G

Rating

Poor	P
Poor to Fair	P-F
Fair	F
Fair to Good	F-G
Good	G
Poor to Good	P-G