Surficial Geology Handbook for Coastal Maine

Maine Coastal Program
Natural Resource Planning Division
Maine State Planning Office

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SURFICIAL GEOLOGY HANDBOOK
for
COASTAL MAINE

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Dear Reader:

Lay citizens as well as professional planners and resource developers frequently find themselves sharing responsibility for land use decisions affecting their community. Large and small subdivisions, solid waste disposal sites, aquifers containing private and public water resources, commercial and industrial complexes and other land uses all represent major long term commitments of natural resources.

The diverse materials making up that portion of the earth's surface which lies between the soils on top and the bedrock underneath vary widely in their ability to absorb the impacts from, or to serve the purposes of, various kinds of land use activities. Better judgments of the future impact on the land from various resource development proposals can be made by those who have an awareness of the location and properties of surficial materials.

This handbook provides the lay citizen as well as the developer or professional planner a convenient explanation of how the various materials making up the land surface of coastal Maine were deposited and rearranged by glacial, marine and fluvial processes in the last few thousand years and what the suitability of these materials is for the various land uses that are possible.

The "Surficial Geology Handbook of Coastal Maine" is one of several publications issued by the State Planning Office to assist members of the coastal community to achieve a practical understanding of selected natural sciences which are basic to intelligent land use planning and management. Other titles in the series include "Groundwater Handbook for the State of Maine" (released in 1978) and "Marine Geology of the Maine Coast" and "The Ecology of Maine's Intertidal Habitats" which are scheduled for release in 1979.
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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 A. M. Hussey, II.
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CHAPTER I

INTRODUCTION

The purpose of this handbook is to provide planners with information about the origin, characteristics, and applications of surficial geologic deposits in coastal Maine. Surficial deposits are the unconsolidated 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. Continental glaciation resulted in the deposition 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. Swamp, 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, sanitary landfill or sewage disposal sites, building 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. The present report is intended to familiarize planners with surficial materials and give them some of the information that is needed to make sound land-use decisions. However, it is not intended to be a substitute for the detailed on-site investigations that are necessary for specific projects.

The area covered by this handbook includes all of the towns that are part of the State Planning Office's Coastal Inventory, as well as neighboring towns. Most of this region was submerged by the sea in late-glacial time, so its surficial geology differs in major respects from that of the interior upland. 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 Soil Conservation Service, U. S. Department of Agriculture, for information about Maine's soils and their parent materials.

The information contained in this handbook is based largely on surficial geologic mapping that was done for the Coastal Planning Program of the Maine State Planning Office by the Maine Geological Survey, Department of Conservation. Mapping was carried out in the Maine Coastal Area from 1974 to 1977. Plate I shows the names of geologists who have mapped each block of towns in the Coastal Zone and neighboring areas.

Measurements in this report are in metric units. Elevations are also given in feet because this is the unit of measurement on most of the U. S. Geological Survey's topographic maps. (See Appendix B for an English-metric conversion table.)
CHAPTER II

ORIGIN OF SURFICIAL MATERIALS

HISTORY OF GLACIATION IN MAINE

The blanket of surficial sediments that covers coastal Maine owes its existence in large part to the glaciers that once covered the state. Some materials were deposited directly by glacial ice; others were washed into the ocean or deposited in meltwater streams that flowed off the ice. The continental glaciers that spread across Maine also modified the preexisting topography. 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 -- more than 600 million to about 100 million years old (Bennison and others, 1976). 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 at least a few meters 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 swamps and lakes 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 have covered Maine at least two times and perhaps more during the Pleistocene Epoch, or "Ice Age". This interval of time extended from about 2,000,000 to 10,000 years ago (Figure 1). The time at which the Pleistocene Epoch began is still uncertain -- until recently it was thought to have begun only 1,000,000 years ago. The time at which the Ice Age ended is also debatable, if in fact it has ended. In Figure 1, the upper limit of the Pleistocene Epoch in New England is arbitrarily fixed at 10,000 yrs B.P. (years before present). The last glacier had retreated into Canada by this time, and coastal Maine had emerged from the sea (Stuiver and Borns, 1975).

The ice sheets that invaded Maine were continental glaciers, in contrast to the much smaller valley glaciers that still exist in high mountainous regions elsewhere in the world. During the onset of each glaciation, the 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 reached Maine and advanced southward across the state. During the warmer period that followed the peak of each glaciation, the ice
PLATE I
Extent of Surficial Geologic Mapping in Coastal Maine by the MAINE GEOLOGICAL SURVEY

- J. T. Andrews
- H.W. Borns, Jr.
- P.E. Calkin & R.K. Fahnestock
- G.W. Smith
- W.B. Thompson
Figure 1

Geologic time chart showing subdivisions of the Quaternary Period.

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<th>QUATERNARY PERIOD</th>
<th>Recent Epoch</th>
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<td>Pleistocene Epoch (&quot;Ice Age&quot;)</td>
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<td>General warming of climate, with occasional cold periods and expansion of alpine glaciers.</td>
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<td>Wisconsinan glacial stage</td>
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<td>Sangamonian interglacial stage</td>
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<td>Illinoian glacial stage</td>
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<td>Yarmouthian interglacial stage</td>
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<td>Kansan glacial stage</td>
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<td>Aftonian interglacial stage</td>
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present

2,000,000 yrs. ago
sheet waned as melting exceeded ice accumulation. The position of the ice margin then retreated to the north, but the ice continued its internal forward motion as long as the glacier was active. This cycle of glacial advance and retreat was probably repeated on a statewide scale during each of the stages and substages listed in Figure 1.

The Pleistocene glaciations removed great quantities of regolith. However, remnants of disintegrated bedrock (rottenstone) still exist in Maine. They represent weathering that occurred during preglacial and/or interglacial times. Each of the glaciers 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 swamps formed their characteristic deposits during the interglacial stages. However, Wisconsinan ice scraped off or covered most older materials. The oldest glacial products that one can now see in Maine are tills of probable Early Wisconsinan age. The history and pervasive effects of the final, Late Wisconsinan glaciation are discussed in the following section.

LATE WISCONSINAN GLACIATION AND SURFICIAL DEPOSITS

The last continental glacier that covered Maine advanced across the state about 20,000 years ago, in Late Wisconsinan time (Schafer and Hartshorn, 1965). It flowed toward the south-southeast, past the present coastline and out onto the continental shelf. The 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). They were probably deposited by the Late Wisconsinan ice when it overrode the area.

Indicators of Ice Movement Directions

Several lines of evidence indicate the direction(s) of glacial ice movement. Many ice-scoured ledges exhibit scratches (striations) that were made by stones as they were dragged along at the base of the glacier. Striations are parallel to the direction of ice flow, and their intersection characteristics reveal changes in this direction. Curved fractures (crescentic marks) on ice-scoured bedrock are also directional indicators (Figure 2). They may be convex or concave in the direction of movement (Flint, 1971). Neither striations nor crescentic marks indicate the absolute direction of flow, but they limit it to two possibilities - northwest to southeast, or southeast to northwest. The distribution of glacially transported stones (erratics) indicates that the ice sheet advanced from northwest to southeast instead of the opposite direction. The combination of glacial erosion and deposition caused many hills to be streamlined in the direction of ice flow. These hills are called "drumlins", and they can be used as directional indicators in the same manner as striations (Figure 3). In some areas, ice movement formed long ridges and furrows on the surface of till deposits. The ridges are similar to drumlins, but usually have a greater length/width ratio and are typically less than 3-5 m high. They may grade into drumlins and are commonly associated with them. Till deposits with this grooved surface are called "fluted ground moraine".
Figure 2

Crescentic gouges (center) on granite ledge in Augusta. Gouges are convex in direction of ice movement (south-southeast in this example).
Figure 3

Northeastward view of two drumlins on Chandler Parker Mtn., Blue Hill. Long axes of these drumlins trend south-southeast.
Glacial Processes

It is difficult to determine the amount of erosion by the Late Wisconsinan glacier, but it was probably not more than a few meters 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 drumlin formation to create a prominent linearity in the modern topography (Figure 4). Elsewhere the structure of the bedrock is such that it creates its own linear topographic elements, which commonly trend northeastward in the coastal region (Figure 5). As the glacier moved over hills, it tended to smooth their northerly slopes and pluck large pieces of rock from their south sides. Thus, many hills have steep and rocky south flanks. Certain rock types (such as granite) were resistant to being ground up in the glacier, and they now form boulder fields to the southeast of their source areas.

Part of the rock debris that the glacier had incorporated was deposited directly from the ice as a discontinuous layer of till. Till is a heterogeneous mixture of sand, silt, clay, and stones. Some of it (basal till) was laid down at the bottom of the ice sheet when the glacier was still active. Accretion of basal till to thicknesses of over 30 m has occurred in drumlins and other areas of heavy till deposition (though some of this till is probably older than Late Wisconsinan). The south ends of many drumlins have bedrock outcrops (places where bedrock appears at the ground surface), so rock knobs may have been nuclei for till accumulation in some cases.

Warming of the climate caused the last glacier to withdraw from the Maine coast between about 13,300 and 12,700 years ago. Events and sedimentary deposits associated with its disappearance are said to be of "late-glacial" age. The ice margin retreated to the northwest at the rate of at least 0.3 km/yr (Stuiver and Borns, 1975). However, the forward flow of the ice continued even as the extent of the glacier diminished in the coastal region. Till-laden ice was transported to the terminal zone, where it melted in place or calved into the sea as icebergs. Rock debris that was released from the melting ice is called "ablation till". 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 till accumulated in ridges (end moraines) along the edge of the glacier. Sand and gravel that washed out of the ice was incorporated into many of these end moraines (Figure 6). Moraines are abundant in coastal Maine and mark successive positions of the ice margin (Figure 7). The morainal ridges trend generally 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, causing the ice flow to converge toward the valley axes.

Marine Submergence of Coastal Maine

The weight of the Late Wisconsinan glacier depressed the Earth's crust in Maine by about 240 m (Stuiver and Borns, 1975). Even though sea level was lower in late-glacial time than at present (because more water existed as glacial ice), this depression caused a marine invasion of the coastal region. The sea flooded southern Maine to present-day elevations of up to 400 ft (122 m) or more.
Bloom (1960) demonstrated that the marine limit (elevation of maximum submergence) in southwestern Maine rises from about 220 ft (67 m) near Sanford to an elevation of about 300 ft (92 m) in the Sebago Lake area. The latter elevation is also the approximate elevation of the marine limit in the Ellsworth-Machias area. The sea extended far into central Maine—past Waterville in the Kennebec Valley and Bangor in the Penobscot Valley (Figure 8; Goldthwait, 1949). The elevation of maximum submergence is higher as one proceeds north or northwest from the modern coastline. This variation resulted from differential uplift 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.

Field evidence indicates that the sea was in contact with the ice margin as the glacier withdrew from the Maine coast. End moraines are concentrated in the formerly submerged area, so it appears that they were formed most easily in a submarine environment. Morainal sediments are locally interlaid with marine deposits, a fact which demonstrates that the glacier terminus was in the ocean. Rapid calving of ice in coastal bays was responsible for the previously mentioned lobation of the ice margin.

**Deposition of Water-Laid Glacial Sediments**

Meltwater streams emerged from the glacier and deposited large deltas into the ocean. A cross section through a delta usually reveals gently inclined "topset" beds (sediment layers) that overlie steeper "foreset" beds (Figures 9 and 10). The topset beds were deposited on the bottom of the stream as it entered the sea and dropped the heaviest part of its load. Therefore, the topset beds of many deltas consist of coarse gravel. The foreset beds are composed of finer-grained sand and gravel that reached the end of the stream channel and was dumped on the face of the delta, where the current slackened. The very fine-grained sediment (sand, silt, and clay) spread onto the sea floor as "bottomset" beds. 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. It is also possible to determine the marine limit from the elevations of beach deposits and wave-cut benches, but the marine invasion was too short-lived for the widespread development of these strandline features.

Meltwater streams and currents from the Late Wisconsinan glacier carried a great quantity of silt and clay in suspension. This material washed into the ocean, where it eventually settled to the bottom. The subsequent emergence of the coast has exposed extensive deposits of glacial-marine sediment in southern Maine. Bloom (1960) named it the "Presumpscot Formation" after the Presumpscot River valley in Cumberland County. The Presumpscot Formation was laid down within the area shown in Figure 8.

Much of the sand and gravel that washed out of the glacier did not reach the ocean. It was laid down by meltwater streams in various glacial environments. Deposits formed in this manner are said to be "glaciofluvial" or "glacial-stream deposits". They include ice-contact deposits, which were emplaced within or adjacent to stagnant ice, and outwash deposits, which were formed in front of the ice margin.
Topographic grain created by glaciation, Lincolnville. Several drumlins can be seen in this area. Their orientation indicates that the glacier locally flowed toward the southeast.
Bedrock-controlled topography in Harpswell. This area has parallel bedrock ridges that trend north-northeast. Surficial deposits are thin or absent on these ridges.
Cross-section of the margin of a glacier, showing the manner in which many end moraines in coastal Maine are believed to have been formed. Part of the moraine ridge consists of sand and gravel that is deposited by meltwater currents emerging from beneath the glacier along the grounding line. Sand and gravel in the seaward part of the moraine is interstratified with silt and clay that washes out of the glacier and settles to the ocean floor. The latter unit contains dropstones released from the bottom of the glacier and from icebergs. The till in the central and landward parts of the moraine is deposited by minor readvances of the active ice. This ice movement deforms the morainal sand and gravel. (Model developed by H. W. Borns, Jr., and the author).
Figure 7

Topographic expression of end moraines in Buxton. Each moraine ridge marks a temporary location of the ice margin as it retreated toward the northwest. Contour interval is 20 ft.
Figure 8

Map showing extent of glacial-marine clay (Presumpscot Formation) in Maine (from Goldthwait, 1949).
Figure 9

Cross section of esker and glacial-marine delta west of North Augusta. Diagram shows internal structure of delta and general profile of water table.
Figure 10

Glacial-marine delta east of Orcutt Mtn. in Bucksport. Photo shows gravelly topset beds (top of pit face) overlying sandy foreset beds.
Many of the ice-contact deposits are eskers or kames. Eskers are long ridges of sand and gravel that were deposited by running water in tunnels within or beneath stagnant glacial ice. Some of these tunnels were feeder channels in which meltwater carried sediment to the marine deltas. Kames are irregular mounds of sand and gravel that formed in several environments. Some of the kames that occur above the marine limit have flat tops, which reflect the grading influence of streams. These are called "kame terraces". Other kames were formed below sea level by subglacial meltwater currents that emptied into the ocean.

Above the marine limit, meltwater channels occur in the vicinity of many ice-contact deposits. These channels developed in areas where the gradients of meltwater streams were so steep that erosion took place. They are most common on till-covered hills and may connect with glacial-stream deposits in the downslope direction. Meltwater channels are rarely deeper than a few meters. An example is shown in Figure 11.

Outwash deposits are composed of sand and gravel that was deposited in meltwater streams beyond the ice margin. They are scarce or absent along the present-day Maine coast, because most of this area was below sea level when it was deglaciated. However, they are found just northwest of the marine limit. An example is the outwash plain in the Crooked River valley, north of Sebago Lake. Bloom (1960) describes outwash deposits in York County that overlie the Presumpscot Formation. This is additional evidence of the contemporaneity of deglaciation and marine submergence.

Glacial Readvances

Several readvances of the ice margin occurred along the Maine coast during the overall retreat of the Late Wisconsinan glacier. The Kennebunk Readvance has been dated at about 13,200 yrs B.P., and the Pond Ridge Moraine near East Machias formed about 13,300 years ago (Stuiver and Borns, 1975). The large Pineo Ridge Moraine in the Columbia area is younger—about 12,700 yrs B.P. (Borns, 1973). Minor oscillations of the ice margin were common and may have occurred annually. Thus, there are small areas along the coast where till was deposited on top of water-laid sediments. The meltwater streams associated with glacial readvances (or prolonged pauses in the glacial retreat) may have deposited the sand that overlies the Presumpscot Formation in parts of coastal Maine, especially in Cumberland and York Counties.

LATE-GLACIAL TO POSTGLACIAL EVENTS AND SURFICIAL DEPOSITS

Uplift of the land began in late-glacial time and proceeded very rapidly (Figure 12). The radiocarbon ages of shells indicate that coastal Maine was deglaciated by about 12,700 years ago and had emerged from the sea by about 12,100 years ago (Stuiver and Borns, 1975). The ice margin was still near the coastline when the land started to recover from the weight of the thick ice that had covered it. A large marine delta formed in association with the Pineo Ridge Moraine in Cherryfield and Columbia, Maine. The top of this delta is at an elevation of about 265 ft (81 m). This elevation is lower than the local
marine limit, so uplift was already causing the regional sea level to drop at the time of the Pineo Ridge Readvance. The scarcity of raised beaches also indicates that postglacial uplift was rapid. However, Borns (personal communication, 1977) has noted some prominent wave-cut benches at an elevation of 240 ft (73 m), so there was probably at least one break in the continuity of uplift.

The late-glacial retreat of the ocean from coastal Maine affected the geology of the area in several ways. Currents became stronger in the shoaling sea, causing minor deposition of sand over finer-grained marine sediments. Sand and gravel also eroded from glacial-stream deposits such as eskers and deltas and washed down onto the Presumpscot Formation. Glacial till was subjected to wave erosion and was reworked to form small, thin patches of beach gravel. In rare instances, wave-cut benches developed on till or sand and gravel deposits.

The establishment of the modern stream network accompanied and followed the emergence of the coast. Postglacial erosion has created intricate drainage patterns and steep-walled gullies in the Presumpscot Formation. Large streams have expended much of their energy in cutting down through the glacial deposits that filled their valleys. Downcutting was probably hastened by the uplift of the land. Rivers soon cut through the glacial and early-postglacial alluvial deposits in their valleys, and stream terraces were created by the abandonment of previous flood-plain and stream-bed levels. Some terraces were formed so early that their surfaces have kettle holes (depressions resulting from the melting of buried blocks of glacial ice) (Bloom, 1960, p. 35-36). Alluvium is still accumulating on flood plains today. However, the flood plains of even the largest rivers in coastal Maine are generally narrow and discontinuous. The presence of bedrock outcrops on valley walls has contributed to reducing the amount of lateral erosion.

The vegetation cover in coastal Maine was sparse in some areas for a short time after deglaciation and the marine regression. Strong winds eroded glacial outwash sand and deposited it as dunes or a simple blanket over bedrock, till, and the Presumpscot Formation. The orientations of many dunes indicate that the prevailing wind blew from the west-northwest. 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.

Many swamps have formed in southern Maine during postglacial time. Figure 13 shows the common types of swamp environments. Most of them resulted from the obstruction of drainage by glacial deposits. Swamp deposits are also accumulating in small depressions that the glacier eroded on bedrock.

Fine-grained sediments from streams and shore 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. Beach deposits are forming by wave attack on lakeshores, especially where the shores are composed of easily eroded sand and gravel. Beach deposits have been moved about by currents to form spits on a few lakes.

There are many steep, rocky hillsides and cliffs in coastal 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.
Figure 11

Meltwater channel cut in till, Readfield.
Figure 12

Curves showing the uplift of the Maine coast and its relation to worldwide sea level during the past 13,000 years (modified after Schnitker, 1974, and Milliman and Emery, 1968).
Figure 13

Cross section of several types of swamp environments.
CHAPTER III

DESCRIPTION OF SURFICIAL MATERIALS

This chapter describes surficial deposits that occur in coastal Maine. Most of these deposits are units that have been mapped by the Maine Geological Survey. They are discussed in the approximate order in which they were formed in any particular area.

TILL

Till was deposited directly from glacial ice. It is the oldest and one of the most widespread surficial materials in the coastal region and in Maine in general. 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 random mixture of sand, silt, clay, and stones (Figures 14 and 15). Because of this great 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 Maine tills. It probably constitutes over 50 percent of the typical till matrix (finer-than-2 mm portion). Either silt or clay may be dominant in the remainder. Another textural characteristic of till is the near absence of bedding (stratification). Till may contain thin, discontinuous beds of washed sediments, but pronounced bedding is rare.

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 kilometers 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 contains much sand that resulted from glacial crushing of granite into its constituent mineral grains. On the other hand, certain 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 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 southwestern Maine (Bloom, 1960, p. 21). Some stones in till have travelled hundreds of kilometers 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 distinguish varieties of till. It varies according to the interrelating effects of texture, composition, moisture content, and degree of oxidation. Till is usually a shade of gray or brown. The exact color can be defined numerically by reference to the Munsell Soil Color Chart (Munsell Color Co., 1975). It should be observed consistently in all-moist or all-dry samples because till appears darker when it is moist.
Two major genetic types of till occur in Maine -- basal till and ablation till. Basal till was laid down at the bottom of a glacier. It is fine grained, compact, and difficult to excavate. Hence, this kind of till is often called "hardpan". It generally contains more silt and clay than ablation till, and there are fewer stones (mostly of pebble to cobble size). Basal till tends to break in slabs along nearly parallel planes of weakness (joints). The distance between joints typically decreases toward the ground surface, and their surfaces may be coated by dark-brown iron or manganese oxides.

Ablation till was deposited by the settling out of particles from melting glacial ice. 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. Most ablation till is very stony and contains large boulders. 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.

Iron-oxide staining of basal till is pronounced in places. The author examined a locality in Winthrop, Maine, where the stained variety of basal till is separated from fresh ablation till by a sharp contact. Rounded inclusions of the lower (basal) till were found in the upper till, which suggests that the contact is erosional. The upper (ablation) till at this locality forms a bouldery end moraine that was definitely built during the last glaciation. Field evidence and comparisons with till deposits in New Hampshire and southern New England indicate that the jointed, iron-oxide stained basal till in Winthrop and elsewhere in southern Maine was probably formed by an earlier glaciation. However, it is unlikely that this till is older than Early Wisconsinan, because most of its stones are not appreciably more weathered than those of the younger till. The older till may be equivalent to Caldwell's (1959) New Sharon till in the vicinity of Farmington, Maine, or one of the lower tills studied by Borns and Calkin (1977) in west central Maine.

Till can also be classified as ground moraine or end moraine. Ground moraine is a general term for the blanket of till -- both ablation and basal -- that covers much of Maine. The surface of ground moraine may be smooth (as on drumlins) or hummocky, depending on how the till was emplaced. Many boulders are likely to be present where bedrock is at a shallow depth.

End moraines are ridges of till or sand and gravel that accumulated in the marginal zone of a glacier (Figures 16 and 17). In Maine the majority occur in areas that were submerged by the sea in late-glacial time. Most end moraines in the coastal part of the state are composed of till, but they may grade into or consist entirely of sand and gravel (the latter type is described in the following section). The till in end moraines is generally ablation till, but a few contain the basal variety. End-moraine ridges typically have a relief of 1-10 m above the surrounding land surface. They are usually 5-15 m wide, but exceed 100 m in some cases. The ridges range in length from 50-100 m to several kilometers, and many of the long ones occur as discontinuous segments. The true size of some end moraines is not apparent because they are partly buried by glacial-marine silt and clay of the Presumpscot Formation.
Figure 14

Exposure of sandy till in Bridgton. Soil profile can be seen in upper half of pit face. The till was deposited during the most recent (Late Wisconsinan) glaciation.
Figure 15

Close-up of till shown in Figure 14. Note diversity in particle size and general absence of stratification.
Figure 16

Valley glacier (Isfallsglaciären) in northern Sweden. End moraines in foreground mark former extent of glacier. Oldest moraine is about 2500 years old. (Photo by G. H. Denton, 1972.)
Figure 17

Close-up of glaciated terrain in front of Isfallet. Note glacial lakes contained by end moraines. Upper-left part of photo shows fluted drumlins. (Photo by Wibjorn Karlén, 1971.)
Boulders are common in end moraines, where they have been concentrated by glacial processes (Figures 18 and 19). Moraines in areas of granitic bedrock are especially bouldery and can often be recognized on aerial photographs by this characteristic. Some end moraines can be distinguished on photographs by their occurrence in clusters, the members of which are closely spaced and parallel. The crests of the moraines are better drained than the intervening areas, so they are lighter colored. Moraine ridges generally trend east to northeast, with local deviations occurring in some valleys. It is easy to recognize end moraines on photographs of 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 also trend northeast.

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 20). However, drumlins are important exceptions. The thickest till deposits (mostly basal till) are found in drumlins and other places where the ground surface has been built up and smoothed by till accumulation. These areas may contain over 30 m of till. Local thickening of till deposits also occurs in end moraines, but not as much as in drumlins. There are extensive shallow-to-bedrock areas in coastal Maine where the till and other surficial deposits are thin and patchy. Bedrock outcrops are common in these areas, and the surficial materials are rarely thicker than 3 m. It is desirable to map the areas of thin overburden because of the problems that they may cause in excavation, drainage, and waste disposal.

GLACIOFLUVIAL END MORAINES

End moraines that are composed of sand and gravel were formed by glacial meltwater streams (an origin that is called "glaciofluvial"). Some excellent examples of this type of moraine occur within the area of late-glacial marine submergence. It is practical and worthwhile to distinguish them from till moraines because they may contain significant sand and gravel or ground-water resources.

Glaciofluvial end moraines are typically larger than end moraines that are composed of till. Some are as much as 15 m high and 500 m across, but most are smaller. Their composition varies from sand to boulder gravel, and several particle sizes are usually present in a single moraine. Some deposits are well bedded, and the sediment particles in each layer have a fairly uniform size (are "well sorted"). Other glaciofluvial end moraines are chaotic, poorly sorted mixtures of all sand and gravel sizes (Figure 21).

Glaciofluvial end moraines are apt to be confused with eskers, which are also ridges of sand and gravel. However, end 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 many end moraines is further supported by the presence of bedrock striations that are oriented perpendicular to the moraine ridges. If bedding is well developed in a glaciofluvial end 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 glaciofluvial moraine into one that is composed of till; or it may be parallel to nearby till moraines.

GLACIAL-STREAM DEPOSITS

Glacial-stream deposits consist of sand and gravel that was laid down in meltwater streams from the last glacier. These deposits are classified according to their environment of formation:

<table>
<thead>
<tr>
<th>Name</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kame</td>
<td>Randomly deposited on, within, beneath, or adjacent to melting glacial ice</td>
</tr>
<tr>
<td>Kame terrace</td>
<td>Usually deposited between stagnant ice and a nearby valley wall; upper surface was graded by streams and is flatter than a kame</td>
</tr>
<tr>
<td>Esker</td>
<td>Deposited in a tunnel within or beneath stagnant ice</td>
</tr>
<tr>
<td>Delta</td>
<td>Built into a lake or the ocean; may have formed in contact with glacial ice or at the end of an esker, whence the varieties &quot;kame delta&quot; and &quot;esker delta&quot;</td>
</tr>
<tr>
<td>Outwash plain</td>
<td>Formed beyond the margin of the glacier; may terminate in a delta if the meltwater stream entered standing water</td>
</tr>
</tbody>
</table>

Each type of glacial-stream deposit has a characteristic shape and distribution of materials. An understanding of its makeup should lead to better land-use planning and aid in the search for aquifers and certain kinds of sand and gravel.

Kames and Kame Terraces

Kames occur both above and below the limit of marine submergence in coastal Maine. They are mounds of sand and gravel with irregular, hummocky topography. Depressions (kettle holes) are found on some kames and mark the former locations of buried masses of stagnant glacial ice. Kettle holes are very common in some areas, and the resultant knobby terrain is called "kame-and-kettle topography". The size of kame deposits is extremely variable. They range from less than 100 m across to several kilometers. Their height varies from a few meters to over 30 m. Many of the largest kames are located on the sides of river valleys and may actually be segments of eskers (Figure 20).

Kame terraces are special types of kames that have flat tops (Figure 22). Their characteristic topography was created by meltwater streams flowing on their upper surfaces long enough to smooth the irregularities. Kame terraces generally
Figure 18

View along the crest of an end moraine, Baffin Island, Canada. Till-laden ice at margin of Barnes Ice Cap can be seen in upper-left part of photo. (Photo by R. P. Goldthwait, 1950.)
Figure 19

End moraine south of Grays Corner in Sedgwick.
Figure 20

Generalized cross section showing relationships among surficial deposits in the Kennebec River valley from Augusta to Pittston.
Figure 21

Pit face showing cross section through gravelly end moraine in the Beaver Brook valley, Readfield.
Figure 22

Kame terrace northeast of Chandler Parker Mtn., Blue Hill. Pit face shows poorly sorted boulder gravel overlying well stratified sand and gravel.
formed above the marine limit, where subaerial streams flowed along the margin of the ice during deglaciation. However, terraced deposits that resemble kames also exist near the coastline. Some of them may actually be deltas, or they may have been deposited by meltwater currents in a submarine environment.

Kames (along with eskers and deltas) are among the largest sand and gravel deposits on the Maine coast. They generally contain more gravel than sand because they were built by fast-moving streams that washed away the fine-grained sediment. Textures may vary greatly in all directions because kames were formed in rapidly changing environments. Chunks of ice would melt or topple over, causing sand and gravel beds to be mixed together and lose their stratification. Masses of dirty boulder-gravel are common in kame deposits. Where bedding is present, it is usually deformed by folds and faults (Figure 23). Figures 24 and 25 show a typical kame deposit. Marine silt and clay locally overlies or is interbedded with kames in areas that were submerged by the sea.

**Eskers**

Eskers are common in both coastal and interior Maine. They are long ridges of gravel and sand that can usually be traced (with breaks) for many kilometers (Figures 26 and 27). The eskers generally trend north-south or northwest-southeast. They are typically 10-30 m high and 100-400 m wide. They are not only discontinuous in many cases, but may also branch and rejoin, or terminate against hillsides. Some eskers climb north-facing slopes, indicating that the water in the subglacial tunnels was under pressure. The eskers in Maine used to be called "horsebacks", probably because they were used as routes through swampy areas.

Eskers are very similar to kames with respect to composition and internal appearance. Gravel is more abundant than sand, and there are large piles of boulders from which the finer sediment has been sluiced away (Figure 28). When the ice walls of the esker tunnel melted, the bedding (where present) slumped and contorted. Marine clay partially overlies most eskers in the area of marine submergence.

**Deltas**

Large glacial-marine deltas are distributed throughout the length of the Maine coast. They are concentrated in a northeast-trending belt that lies about 10-65 km from the present outer coastline. Most of the deltas were built to elevations that mark the marine limit, but a few are at lower elevations. The tops of the deltas are flat and gently sloping, while their backs commonly have steep slopes that were in contact with glacial ice. Delta tops may also exhibit the abandoned channels of the streams that used to flow across them. Eskers or kames connect with the back sides of many deltas and indicate the positions of feeder channels (Figures 9 and 26).

The internal structure and composition of deltas were described in the previous chapter. Glacial-marine deltas in coastal Maine contain very large deposits of sand and gravel. Most of them are at least 20-30 m high, and they may cover an area of many square kilometers. The insides of some deltas are heterogeneous mixtures of sand and gravel that probably originated as kame
deposits (e.g., the deposit that underlies the Augusta airport). Other deltas show the typical association of topset and foreset beds illustrated in Figure 9. An example is the delta northeast of Columbia Falls (Figure 29). Still others, such as the Sanford-Kennebunk delta, may consist entirely of foreset sand beds (Bloom, 1960, p. 39). Most of the gravel in a typical delta is found in the topset beds. The foreset beds (under the topsets) usually consist of sand, or sand with lesser pebbles to cobble gravel. The bottomset beds can be included with the other sea-floor sediments of the Presumpscot Formation. They are composed of fine sand and silt. Silt and clay of the Presumpscot Formation commonly blankets the fronts of deltas, and it is locally interlayered with the foreset beds.

Outwash Plains

Outwash plains generally occur above the marine limit in Maine. Bloom (1960) described some good examples in York County. They are large expanses of sand and gravel that was carried beyond the glacier margin by meltwater streams. Unlike most ice-contact deposits, outwash plains have flat, gently sloping surfaces. They commonly occupy parts of river valleys, where they stand at higher elevations than modern flood plains and river terraces. However, some terraces have been carved from the outwash deposits.

Outwash plains are composed of sand and gravel in varying proportions. They have better internal stratification than kames and eskers. Outwash typically consists of alternating beds of different (but well sorted) particle sizes. These layers appear to be nearly level, and they may contain a smaller-scale "cross-bedding" that is more steeply inclined. The dip direction of cross-bedding, along with other sedimentary features, can be used to determine the direction in which a glacial stream was flowing (Figure 30).

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. It is very widespread on the Maine coast and extends far inland along the Kennebec and Penobscot Valleys (Figure 8). 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 (15-31 m) lower. For example, marine shoreline and deltaic deposits indicate that the Richmond area was submerged to an elevation of 300 ft (92 m). However, most of the Presumpscot Formation in this town occurs at elevations of less than 200 ft (61 m). The formation commonly has a flat or gently sloping surface where it has not been dissected by stream erosion. The regional elevation of this surface ranges from about 20-40 ft (6-12 m) along parts of the coastline to over 200 ft (61 m) farther inland.

The Presumpscot Formation has partly filled many valleys and caused their floors to become higher and flatter (Figure 20). The thickness of the silt and clay in these areas locally exceeds 30 m. In other places the formation is a thinner blanket deposit that has subdued the preexisting topography (Figure 31).
Figure 23

Cross section through part of a kame in the Crooked River valley, Naples. Photo shows sand beds adjacent to a kettle hole (to right of picture). Melting of stagnant ice in kettle caused slumping and faulting of the sand, which had been deposited against the ice by glacial streams.
Figure 24

Kame on side of valley west of Dressers Mtn., Bucksport.
Figure 25

Close-up of kame shown in Figure 24. Note poorly sorted cobble and boulder gravel.
Figure 26

Map showing topography of eskers and glacial-marine delta west of North Augusta. The depressions are kettle holes. Contour interval is 20 ft. (See also Figure 9.)
Figure 27

Map showing esker southwest of Androscoggin Lake, Leeds.
Figure 28

Boulder gravel in esker, Sheepscot River valley, Whitefield.
Figure 29.
Glacial-marine delta northeast of Columbia Falls.
Figure 30

Cross-bedding in a sandy glacial-stream deposit. Current flowed from left to right in example shown here.
Figure 31

Glacial-marine silt and clay (Presumpscot Formation) overlying an end moraine (?) in Pittston.
One may encounter great variations in the thickness of the Presumpscot Formation, even within distances of a few meters. 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.

Postglacial stream erosion has carved steep-walled gullies in the Presumpscot Formation, creating a distinctive drainage pattern that is evident on topographic maps and aerial photographs. The rills and gullies form intricately branching networks with dendritic patterns (Figure 32). Most gully walls are free of mass-movement scars, but landslides have occurred in a few places. Similar marine deposits in Canada's St. Lawrence Lowland and elsewhere are occasionally affected by hazardous slumps (Hodgson, 1927). The movement is usually triggered by one or more of the following causes: high water content, oversteepening of slopes by hazardous slumps or artificial excavation, or the occurrence of an earthquake or other shock (see Chapter V).

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 be 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. Extensive deposits of this sand 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 interbedded with 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.

The color of the Presumpscot Formation ranges from brownish gray through gray to dark bluish gray. 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 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.

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.

Most of the glacial-marine silt and clay overlies till or glacial-stream deposits. However, it is interbedded with glacial-stream sediments in places (especially on the fronts of deltas). Both the Presumpscot Formation and the associated sand and gravel may be fossiliferous. It is not unusual to find the remains of clams, mussels, scallops, barnacles, and other shellfish. 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). Organic material from the Presumpscot Formation and glacial-stream deposits can be dated by the carbon-14 method to help establish the chronology of deglaciation in coastal Maine (Stuiver and Borns, 1975).

MARINE RAISED-BEACH DEPOSITS

Raised beaches are composed of sand and gravel that was deposited along the ocean shore when sea level was higher than at present. They are uncommon in coastal Maine because the marine invasion was of short duration. Most of the raised beaches occur at the marine limit, though a few are at lower elevations. They are narrow, and rarely have a continuous length of more than 1-2 km.

Beach deposits that were derived from till are likely to be only 1-2 m thick. They consist of angular, poorly sorted gravel that was not transported and abraded to a great extent. Some of the beaches that formed on glacial-stream deposits - especially deltas - contain better-rounded gravel and a higher percentage of sand. The latter type is 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 faces of glacial-marine deltas in the Cherryfield-Jonesboro area.

EOLIAN SAND DEPOSITS

Eolian sand was deposited by wind in late-glacial time. It was eroded from sandy marine and glacial-stream deposits, and it now overlies till and water-laid sediments. 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 are uncommon, but small patches occur in many places. Examples of large deposits can be seen in the following areas: the western parts of Wayne and Fayette, southwest of Rich Mill Pond in Standish, and the "Desert of Maine" area in Freeport and Pownal. Sand dunes are locally well developed in these areas. 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.

The eolian sand is moderately well sorted. Most of it is probably fine to very fine grained. The dunes and other deposits may be stratified (Figure 33) or massive and structureless. The sand is loose and extremely easy to excavate. It is expected to be moderately permeable, but not to the degree of the glacial-stream deposits.

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 "Desert of Wayne". In places one can see dunes that wrap around trees or cover man-made structures.
Map showing erosional topography of the Presumpscot Formation along the headwaters of Bond Brook, Augusta. The sea-floor sediments in this area were deposited as bottomset beds in front of the delta shown in Figures 9 and 26. Contour interval is 20 ft.
Figure 33

Stratified eolian sand deposit in Wayne.
LAKESHORE DEPOSITS

Lakeshore deposits are among the least abundant surficial materials in Maine. They have formed as a result of wave erosion of the surficial materials and bedrock that surround Maine's lakes. Most of the deposits are sand and gravel beaches. However, wide, sandy beaches have formed from glacial-stream deposits, while till has eroded relatively slowly to yield angular beach gravel. Lakeshore deposits are best developed on large water bodies such as Sebago Lake. The beach sediments have moved along the shore and formed spits in some cases.

Ice is also an agent of change on the shores of New England lakes. Lake ice commonly shoves against beaches and pushes up low ridges of debris (lake ramparts). 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 (R. P. Goldthwait, personal communication). These ridges may or may not be submerged and are a hazard to boats.

SWAMP DEPOSITS

Swamp deposits are composed of peat, silt, clay, and sand that have accumulated in poorly drained areas (Figure 13). (The term "swamp" is used here to include true swamps - with shrubs and trees, but little peat - as well as bogs and marshes.) Many swamps are the result of glacial obstruction of drainage patterns. They are especially common on the Presumpscot Formation in coastal Maine.

Most of the stratigraphic information on swamp deposits has come from bore holes and peat studies. Bore holes have penetrated over 6 m of organic sediment in Kennebec County (Thompson, 196). Trefethen and Bradford (1944) described 12 freshwater peat bogs that are distributed throughout southern Maine and have peat thicknesses of 1-8 m, with an average of about 3 m. According to Cameron (1975), the commercial peat in Washington and Aroostock Counties is up to 7.5 m thick, and most deposits average at least 1.5 m. However, many swamp deposits are probably thinner than these averages. A cross-section through a typical swamp 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 before much organic material could accumulate. This sediment may in turn overlie older stream, lake, or ocean deposits (generally of glacial origin).

The ages of swamp deposits can be determined by obtaining carbon-14 dates on wood and other organic matter. Swamp sediments also contain assorted types of pollen, which vary in 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. The combination of carbon-14 and pollen studies has also helped to establish the times at which different parts of New England were deglaciated.
STREAM ALLUVIUM

Stream alluvium is water-deposited sediment found on flood plains and terraces along modern rivers (Figure 20). It is composed of sand, silt, clay, and gravel. 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 are rarely covered by water. Neither type of stream alluvium covers a large part of coastal Maine. This is because the major rivers have not caused a great amount of lateral erosion.

Stream-terrace deposits generally consist of sand and gravel. Many of them were probably formed by the erosion and redeposition of coarse glacial-stream sediments. Surface exposures on flood plains indicate that they are composed of finer-grained material, most of which appears to be silt to fine sand. However, the minor amounts of flood-plain alluvium along youthful upland streams are usually gravel. Coarse-grained sediment is also found in stream channels, where the currents move faster than floodwater.

COLLUVIUM

"Colluvium" is a general name for several types of surficial materials that have accumulated at the bottoms of steep 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 coastal Maine includes talus (rock piles at the bottoms of cliffs) and hillside deposits that were derived from surficial sediments and/or bedrock. The hillside deposits are discontinuous and commonly have the same overall composition as their parent material. Consequently, they are not shown on most maps.
CHAPTER IV

MAPPING PROCEDURES

TYPES OF INFORMATION SHOWN ON SURFICIAL GEOLOGIC MAPS

A surficial geologic map shows the distribution of unconsolidated materials at the Earth's surface. The geologist must first decide on what units (specific materials) will be represented on the map. He then carries out the field and office work that is necessary to draw the contacts (boundary lines) between adjoining units. The smallest area that is distinguished on the map depends on the map scale and the desired level of detail. The only absolute 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 discontinuous mantle of clay, but the clay unit may not be shown 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 materials that are exposed in them. Information on the depth to bedrock and the positions of bedrock outcrops is also useful.

A geologic map is accompanied by an "explanation", which gives the meanings of the colors or symbols used on the map. Explanations should be concise, though they may be used in lieu of a report to give a brief description of the map units. A very 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. Some explanations also include a correlation chart to show the age relations between map units. An example of a map explanation for southern Maine is given in Appendix A.

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 surficial geologist to differentiate materials that formed in various ways and to put them in a historical perspective. Although certain genetic units in Appendix A have broadly similar materials, there are significant differences between most of them.
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 imagery, and publications in geology and related sciences. Field work is a fundamental requirement for producing a detailed or semi-detailed 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, ocean and lake shores, borrow pits, foundation holes, highway excavations, and trenches. 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, test hole, and seismic records. Taking samples from wells and test holes is a direct means of determining the identity and thickness of surficial sediments that are beyond the reach of manual excavations. Test hole logs from building sites and other projects are commonly the only available information in urban areas. 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.

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 imagery or direct photography. Ordinary black-and-white aerial photographs are most commonly used in surficial geologic mapping. They are available at various scales and can be viewed in pairs with a stereoscope to produce a three-dimensional image. There are several features on air photos that one should examine to 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. Unfortunately, the gray tones of forests and fields are locally influenced more by vegetation than by geologic variables. One should be aware of this and other limitations in the use of air photos. 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 locate the contacts between surficial deposits.

Satellite imagery has recently become an important geologic mapping tool (Baker, 1975). NASA's Landsat satellite telemeters images of the Earth in four wave-length bands. These images can be used singly or in combination to produce black-and-white or color-composite pictures that resemble true photographs. Each image covers an area of about 185 x 185 km (115 x 115 mi). They may be adequate for spotting certain large features (such as broad end moraines), but they are not suitable for detailed surficial mapping. One can also obtain an
Overview of the Earth's surface from Skylab and high-altitude aerial photography. The above remote-sensing techniques sometimes reveal major features that are not visible from on or near the ground.

Information from existing publications is often helpful in preparing surficial geologic maps. For example, some reports by the Water Resources Division of the U.S. Geological Survey contain well and test hole logs. The Soil Conservation Service of the U.S. Department of Agriculture has published county reports with detailed soils maps. There is a correlation between soils and their parent materials, so a soils map is useful in identifying the underlying surficial deposits.

In compiling maps, the surficial geologist usually synthesizes information from two or more of the above sources to delineate the map units. Depending on the available cartographic resources, these units may be drawn on various kinds of base maps. U.S.G.S. topographic maps with scales of 1:62,500 or 1:24,000 are commonly used for this purpose. The compiler should select a base map whose scale is compatible with the level of accuracy of the geologic work.

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 (but important) variables include factors such as the amount of time, equipment, and money that are available to support the mapping project. For example, access to a four-wheel-drive vehicle greatly expedites field work in most parts of Maine.

In accordance with the above principles, three levels of surficial mapping are defined here - regional, reconnaissance, and detailed. Regional mapping involves some field work in areas that are easily accessible by roads, but it is accomplished mainly by air photo interpretation. 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. He examines the best exposures of surficial materials (such as active borrow pits) and fill in the gaps in his field mapping by air photo interpretation. The contacts on a reconnaissance map are accurate to varying degrees, depending on their locations. 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 dig holes and collect other data to locate the boundaries between units. Air photo 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.
CHAPTER V

ECONOMIC AND ENVIRONMENTAL SIGNIFICANCE OF SURFICIAL DEPOSITS

NATURAL-RESOURCE VALUE OF SURFICIAL MATERIALS

Four types of surficial materials in Maine are currently in demand as natural resources. They are: sand, gravel, clay, and peat. These materials generally have low "unit value" (value per ton). With the exception of peat, it is not economical to transport them more than a few kilometers 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 1/16 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" (Appendix C). According to Bates (1969), the lower size limit of industrial 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 mixed with sand in various proportions.

The sand and gravel in coastal Maine was derived mostly from igneous and metamorphic rocks. The sand grains are generally small particles of quartz, feldspar, and other common 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. Important uses include bituminous paving, fill, road base, and concrete aggregate. In 1975 Maine companies produced 5,752,000 short tons of processed sand and gravel with a value of $7,613,000 (value per ton: $1.32). During the same year, the state's output of unprocessed sand and gravel was 4,123,000 short tons valued at $2,310,000 (value per ton: $.56). The above figures include both construction and industrial sand and gravel, but nearly all of it was used in construction (Babitzke and others, in press).

The sand and gravel that is commercially excavated in southern Maine comes principally from the glacial-stream deposits that were described in Chapter III. Kames, eskers, deltas, and outwash plains provide large quantities of sand and gravel. Gravel is the most abundant material in many kames and
eskers, while deltas and outwash plains may contain a high percentage of sand. There is likely to be a greater separation (better sorting) of particle sizes in the latter deposits. Significant quantities of sand and gravel also occur in end moraines, especially the glaciofluvial variety. Stream alluvium may be a good source of gravel, but it is utilized less often than the more easily accessible glacial deposits.

There are three principal types of sand and gravel operations: dry pit, wet pit, and dredging (Newport and Moyer, 1974). Dry pits are borrow pits that are located above the water table. They are the easiest type to operate, and hence the most common in Maine. Many pits have been excavated down to (or slightly below) the water table and then abandoned. Wet-pit operations involve the use of a dragline or barge to dredge both above and below the water table. Dredging alone is used to remove sand and gravel from rivers, lakes, and estuaries. The latter method is uncommon in Maine because of economic and environmental considerations.

Sand and gravel processing plants typically have facilities for screening, washing, crushing, and classifying the various particle sizes. Some plants also use liquid of a certain density to remove wood, shale, and other impurities by flotation (Bates, 1969). Figure 34 shows the general sequence of steps in processing sand and gravel.

According to Newport and Moyer (1974), at least 600 gallons (2274 liters) of water are needed to remove the unwanted fines (silt, clay, and organic material) from a ton of sand and gravel. Obtaining the water, clarifying it after use, and disposing of the waste fines are common problems for pit operators. Discharging sediment-laden water into streams and lakes creates environmental problems, which are discussed in a subsequent part of this chapter. One solution to the waste-disposal problem is to allow the fines to settle from suspension in a holding pond. However, adequate space may not be available for such ponds. Some plants add chemicals to hasten the settling process by flocculation. The cost of using settling aids is one to five cents per ton of product (Newport and Moyer). It is possible to reuse the effluent if it can be clarified to a sufficient degree. Thus, a closed system is created, which is the best means of conserving water. The continued accumulation of fine sediment may cause a space problem, though. It is desirable to remove the fines from the plant area if there is a use for them. Newport and Moyer point 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 aggregate, the requirements for this application are especially important. According to Bates (1969), sand and gravel that is utilized as aggregate 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 properties.

Till

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

Basal till is especially fine-grained and compact, so it is rarely excavated for its own sake. In fact, it is sometimes necessary to loosen basal till by blasting before it can be excavated by conventional equipment. The cost of a construction project may be much 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 it is partially washed and easy to excavate (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 sound 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 (Appendix C), but a 2-micron boundary is better for distinguishing actual clay minerals (which form mainly by the weathering of other minerals) from non-clays (Bates, 1969). The clay
Flow chart for a typical sand and gravel processing system (from Newport and Moyer, 1974).
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 the clay production in Maine was 125,000 short tons, with a value of $202,000 (Babitzke and others, in press). Clay was excavated in five towns, and most of it was used in making bricks and cement. The remainder was used in pottery. 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. 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 have shown that Maine clays are good for making lightweight 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). 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, 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. Nonfibrous, 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".

The American Society for Testing Materials has developed the following classification for commercial peat. It emphasizes fiber content, and fibers are defined as plant fragments at least 0.15 mm 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 nonmoss 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 and 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 7.5 m, and most deposits average at least 1.5 m. According to Babitzke and others (in press), three Maine companies produced peat in 1975. Their combined output was 4,000 short tons valued at $207,000.

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, 1978) 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 (Johnson Co., 1966). Permeability can also be expressed in metric units as liters/day/m², but this combination of units is rarely used in the United States at the present time.

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 (1960) gave the following permeability ranges for unconsolidated sediments:

- clay, silt: 0.001 - 2 gpd/ft²
- sand: 100 - 3,000 gpd/ft²
- gravel: 1,000 - 15,000 gpd/ft²
- sand and gravel: 200 - 5,000 gpd/ft²

The finer grained sediments are less permeable because the smaller pores offer more resistance to ground-water flow. The E.E. Johnson Company (1966) reported an experiment in which coarse sand was found to have a permeability of 1,500 gpd/ft², while the permeability of fine sand was only 300 gpd/ft².

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 (Johnson Co., 1966).
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) that are 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 it 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 not 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 is replaced very slowly in this situation. However, recharge occurs much more quickly if a stream bed interests the gravel unit, or if the aquifer is exposed at the ground surface.

The unconfined (water table) aquifer is the more common type in the surficial deposits of coastal 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. In southern Maine, such an aquifer is likely to occur where glacial-marine clay (Presumpscot Formation) overlies a sand or gravel deposit. Figure 9 shows a location where artesian conditions might be found. If a well were drilled on the southern end of the 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 modern streams.

Flood-plain and stream-terrace deposits (Figure 20) 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 glacial-stream deposits 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 usually 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 outwash plains, glacial-marine deltas, and some of the kames and eskers. 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 lowland areas, where recharge is likely to take place. However, outwash deposits are not common near the Maine coastline. They are best developed in river valleys that lie above the limit of former marine submergence. There are sandy marine deposits (a variety of the Presumpscot Formation) that may be considered to be outwash, but they are generally too thin or fine grained to provide much water.

Many of the 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 great 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.

Kames and eskers are usually narrow, but they may extend along valleys for several kilometers. 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 kame and esker gravels. A municipal well in an esker in Belfast yields 1500 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 basal till because it is coarser grained and may contain large masses of washed sand and gravel. Basal 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 very important to examine the surficial geology of a proposed waste-disposal site because nearly all dumps and landfills in Maine are located on surficial sediments. Two general types of wastes are discussed here -- liquid waste and solid waste.

Liquid waste includes domestic, municipal, and industrial sewage. In rural areas domestic sewage is commonly released into the ground via a combination of septic tank and absorption field, as shown in Figure 35 (Bender, 1971). 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)

Regulations pertaining to the construction of private sewage-disposal systems in Maine are set forth in the State Plumbing Code, Part II (Maine Department of Health and Welfare, 1974). This code also describes surficial earth materials in terms of their suitability for sewage disposal. 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.

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 noncombustible debris

3. Ashes

4. Trash from streets

5. Dead animals

6. Abandoned vehicles

7. Demolition wastes -- from tearing down buildings, bridges, etc.

8. Construction wastes

Schneider listed the following methods of solid-waste disposal:

1. Open dumps

2. Sanitary landfills

3. Incineration

4. Onsite disposal by incinerators and garbage grinders

5. Feeding garbage to swine

6. Composting
Diagram showing typical layout of a septic tank and absorption-field system (from Bender, 1971).
Open dumps have been very common in Maine, but they are likely to pollute both ground and surface waters. Burning the dumps has also been a problem because of air pollution. Therefore, landfills are replacing dumps as the principal means of solid-waste disposal. In a landfill operation trash is dumped and compacted in successive layers. Each layer is covered by a thin layer of compacted soil as the buildup progresses. There is typically about 0.3 m of soil for every 1.2-2.4 m of trash. A final soil cover of at least 0.6 m is added to those parts of the landfill that have been completed (Schneider, 1972). State or local regulations may specify the type and frequency of covering. A summary of regulations governing solid-waste disposal in Maine has been published by the Maine Department of Environmental Protection (1976).

Water that has percolated through a dump or landfill contains biological and/or chemical contaminants. This water is called a "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 purifies 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 should be minimized during the operation of a landfill by keeping most of the site covered with a 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 the following section and to Hansen (1977) for further discussion of the geologic aspects of landfill siting.

Selection of Waste-Disposition Sites

This section deals with the selection of sites that are geologically suitable for the disposal of liquid and solid wastes. The principal concerns are domestic sewage-disposal systems and those dumps and landfills that do not have leachate collection facilities (a category that includes most landfills in Maine). It is necessary to examine the geology and drainage characteristics of proposed waste-disposal areas to insure that surface and ground-water supplies are not contaminated.

Permeability and particle size are two basic considerations in selecting a waste-disposal site in surficial earth materials. The surficial sediment should be permeable enough to allow adequate drainage, but it should not be so permeable that nearby ground and surface waters are contaminated. Permeability depends on the particle-size distribution of the material. The sediment should be neither too fine grained (or poorly sorted) nor too coarse grained (or well sorted). Sand and silt filter out more organic contaminants than gravel, but too high a percentage of silt causes inadequate drainage (Schneider, 1972). Of the surficial materials that occur in southern Maine, sandy till deposits (such
as ablation tills) offer some of the best prospects for landfills and domestic sewage systems. The permeability of these tills is generally adequate for the drainage of liquid wastes, but not great enough to endanger nearby water supplies. Certain sand and gravel deposits may also be suitable if they contain enough fine sediment to moderate their permeability. This is the case with some of the poorly sorted glacial-stream and end-moraine sediments. Well-drained sand and gravel deposits and very fine-grained, poorly drained sediments (such as many "hardpan" tills and the marine clays) should be avoided. The Maine State Plumbing Code, Part II, specifically relates the textures of surficial deposits to the types and sizes of sewage-disposal systems that are permitted in them.

Surficial materials that are used for waste disposal should also have an adequate capacity for sorption and ion exchange. The ability of a sediment to perform these functions depends on its mineralogical composition and particle-size distribution. For example, clay minerals are more effective than quartz, feldspar, and many other common minerals in purifying contaminated water. Silt- and clay-size particles (Appendix C) are more reactive than sand or gravel because silt and clay have much more particulate surface area than comparable volumes of coarser material. However, it is important to remember that the finer-grained sediments also have less permeability.

There are several other geological and geographical considerations to keep in mind when locating landfills and sewage systems in surficial deposits. One factor is the depth to the water table. The ground water is directly contaminated if the water table is at or above the base of the disposal site. Sewage and leachates should pass through the zone of aeration if natural purification is to take place. Maine law requires that the base of a landfill be at least 5 ft (1.5 m) above ground water (Maine Department of Environmental Protection, 1976) and that a sewage absorption field be at least 2 ft (0.6 m) above the seasonal high-water table (Maine Department of Health and Welfare, 1974). Similar vertical distances should also exist between disposal sites and the bedrock surface or layers of impermeable surficial materials. The bedrock in southern Maine is relatively impervious to liquid waste. If sewage or leachate seeps downward and encounters a ledge, it is forced to move laterally and may emerge at the ground surface. Bedrock or impermeable surficial strata may also cause the water table to be near the surface.

Waste-disposal sites should be safely distant from bodies of surface water. In any particular area, the amount of separation that is necessary to avoid contamination depends on the local geology. However, the minimum allowable distance is specified by law. Solid-waste disposal sites in Maine must be at least 300 ft (91.5 m) from any classified body of water and at least 1,000 ft (305 m) from potable water supplies (Maine Department of Environmental Protection, 1976). The State Plumbing Code lists the required distances between sewage absorption fields and wells, springs, streams, and other bodies of water (Maine Department of Health and Welfare, 1974). Waste of any type should not be deposited on or in surficial materials in the following areas: flood plains, low-lying stream terraces that are subject to flooding, swamps, tidal marshes, or beaches. Disposal in these areas is likely to contaminate both surface and ground water.
Steeply sloping areas are unfavorable for waste disposal. They are susceptible to rapid runoff of surface water, erosion, and emergence of contaminated water from the subsurface. The aforementioned state regulations specify that original ground slopes at disposal sites should not exceed 15 percent (15 units vertically over a horizontal distance of 100 units). Absorption fields for sewage-disposal systems can be laid out to fit local slope conditions (Bender, 1971), and cut-and-fill methods improve some areas where the surface is too steep, or where the depth to ground water or an impervious layer is insufficient.

GEOLOGIC HAZARDS AND OTHER ENVIRONMENTAL PROBLEMS 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 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 swampy areas rarely threaten human life or property because these areas are uninhabited. The main problem exists where people have built on deposits of stream alluvium. 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 know if his 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. Thus, these maps give a general indication of areas where floods may occur.

The Water Resources Division of the U. S. Geological Survey is one of the best sources of flood information. This agency has produced flood-prone area maps for most of southern Maine, including both coastal and inland regions. They show the areas that are likely to be flooded at least once every 100 years. The USGS and other federal agencies are also compiling detailed flood-prone area maps for the U. S. Department of Housing and Urban Development (HUD). The HUD maps initially are being prepared for the major river valleys in Maine. They indicate areas that differ with respect to the predicted frequency of flooding. The highest flood boundaries on the HUD maps encompass areas that might be covered by a great flood about once every 500 years. Flood-prone area maps are of practical importance to the public because they are used in the National Flood Insurance Program (HUD News, March 10, 1975).
Shoreline Erosion

Rapid 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 natural erosion of undisturbed Maine lakeshores is generally too slow to be appreciable. The slowness is due in part to the moderate degree of stability that has been attained by the shores 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. (The erodibility of silt-clay mixtures is uncertain, but it is less than that of sand because the finer grained sediment is more cohesive (Krynine and Judd, 1957)). Furthermore, numerous lakes in coastal Maine do not have expanses of water that are oriented (with respect to the prevailing wind) in a direction that is favorable for the generation of large waves. However, rapid lakeshore erosion may occur where sandy glacial-stream deposits are located at the leeward end of a long fetch. Caldwell (1976) mentioned examples of rapid erosion of surficial deposits on Spencer Lake in northwestern Maine. He also pointed out that lakeshore erosion has been accelerated by damming lakes and raising their levels. Erosion is more rapid because shore slopes are unstable at the new water levels. Other human activities such as the use of motorboats (which increase wave action) 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 (Figure 36). 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 centimeters or even meters per day, and streams occasionally shorten their courses dramatically by cutting across the necks of meanders. Thus, 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.

Landslides

The term "landslide" includes several kinds of downslope movement of earth materials, all of which are fairly rapid -- at least 0.3 m/yr and commonly much faster. The driving force is gravity, and the slide mass usually moves over a "relatively confined zone or surface of shear" (Gary and others, 1972). Landslides include rockslides, debris avalanches, mudflows, slumps, and other types of mass movement. Terzaghi (1950) distinguished landslides from creep. Creep is a somewhat continuous and very slow downslope movement that may be widespread on hillsides throughout a whole region. It is caused mainly by gravity, but it may be aided near the ground surface by freeze-thaw action and other processes. While landslide velocities typically increase rapidly from almost zero to at least 0.3 m/hr, creep rates average less than 0.3 m/decade.
Figure 36

Plan view of three stream meanders showing zones of erosion and deposition.
Terzaghi listed the following causes of landslides:

1. **External causes** (no change in the affected material's shearing resistance)
   - oversteepening of slope
   - deposition of material on upper edge of slope
   - earthquakes and other shocks

2. **Internal causes** (involving decrease in material's shearing resistance)
   - increase in pore-water pressure of slope material

3. **Intermediate causes**
   - rapid drawdown of river or lake level adjacent to slope
   - subsurface erosion
   - spontaneous liquefaction

Oversteepening of slopes may result from natural causes such as stream erosion, or from man's excavation activities. 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 also occur in Maine, but it is not certain whether they have caused any slides in this state.

According to Terzaghi, it is a popular misconception that rainfall can cause a slide by simple lubrication of sediment grains. Water is actually an anti-lubricant for quartz and other common minerals. Moreover, the sediments in regions with humid climates generally contain enough water at all times to minimize the friction between particles. However, infiltration of water can decrease the stability of sediments in several ways:

1. Eliminating the surface tension of films of water 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 drawdown (with a magnitude of m/day) 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. Rapid drawdown has the greatest effect on fine sand- to silt-size sediments (Terzaghi, 1950).
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 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 --
   a) completely excavating the slide-prone materials;
   b) excavating just the upper part of the slope;
   c) loading the lower part of the slope; or
   d) combining excavation (b) and loading (c).

2. Drain the slope by means of --
   a) shallow surface trenches;
   b) deep gravel-filled trenches;
   c) subdrains (horizontal drainage holes);
   d) pumping wells to lower the water table; or
   e) 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 deposits (Presumpscot Formation) are much more slide-prone than other surficial sediments. The Presumpscot Formation is composed mostly of silt and clay, which are vulnerable to the processes that cause slides. There are few scientific accounts of landslides in Maine, but it is probable that slumps are the most common type of slide in the marine deposits. Figure 37 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. Segments of the ground surface are tilted backward in the upper part of the slide, while much deformation and flowage may take place at the lower end. A large slump occurred in the Presumpscot Formation at Rockland, Maine, on January 25, 1973. Figures 38 and 39 show the rotation of the slump blocks.

Other examples of slumps occur along a branch of the Harraseeket River (Frost Gully Brook, east of the village of Freeport) and along the Presumpscot River. These slides have developed in the Presumpscot Formation, and they are located on the outsides of meanders. Oversteepening of the stream banks by fluvial erosion probably caused the slumping (Robert Gerber, personal communication). Early accounts of slides in the Portland area were given by Morse (1869) and Hitchcock (1873). Hodgson (1927) described landslides in glacial-marine clays of the St. Lawrence and Ottawa valleys in eastern Canada. He con-
Figure 37

Cross section of a slump.
Figure 38

Seaward view of central and lower parts of the Rockland slump of January 25, 1973. (Photo by A.M. Hussey, II.)
Figure 39

Close-up of Rockland slump showing backward rotation of slide block. (photo by A.M. Hussey, II.)
Figure 40

Earthflow on wall of stream gully in the Presumpscot Formation, east side of Kennebec River valley, Chelsea.
cluded that the slides were caused by saturation of sand and gravel layers either underlying or interlayered with the clay deposits.

Some of the slides in southern Maine are earthflows (Figure 40). Like slumps, earthflows involve movement along a basal shear surface, but this surface is "more or less parallel with the ground surface in the downslope portion of the flow, which terminates in lobelike forms" (Gary and others, 1972). Much turbulence occurs within the earthflow, and there is little rotational movement. With increased water content and fluidity, this type of mass movement may be classified as a mudflow.

Siltation of Streams and Lakes Resulting from Sand and Gravel Operations

Newport and Moyer (1974) discussed the 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 generates at least 600 gallons (2274 liters) of waste water containing silt, clay, and organic material. This fine sediment is often dumped into streams and lakes, or it is washed into them by storm runoff from both active and inactive pits. A great influx of sediment into surface waters may 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:

<table>
<thead>
<tr>
<th>Concentration:</th>
<th>Probable effect:</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-25 ppm</td>
<td>no harm to fisheries</td>
</tr>
<tr>
<td>25-100 ppm</td>
<td>good to fair fisheries</td>
</tr>
<tr>
<td>100-400 ppm</td>
<td>fisheries not likely to be good</td>
</tr>
<tr>
<td>over 400 ppm</td>
<td>poor fisheries</td>
</tr>
</tbody>
</table>
CHAPTER VI

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 materials must 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 man's 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 glacial-marine deltas, ablation tills, and other deposits with very sandy, well drained soils. On the other hand, many swamps and marshes may not be utilitarian, but they do provide wildlife habitats.

Planners should also consider the scientific value of glacial landforms. Maine contains some of the largest and best developed esker systems in the United States, as well as superb drumlins, end moraines, and glacial-marine deltas. 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. Sand and gravel deposits in particular are being dug away rapidly in the populous areas of southern Maine. The Maine State Planning Office is encouraging the preservation of select glacial deposits and other natural features by means of its Critical Areas Program.

In cases involving conflicting land uses, planners should establish priorities for the utilization of surficial earth materials. For example, it might be necessary to decide whether to use a gravel deposit as an aquifer or to allow it to be excavated. In other situations it is possible for two or more land uses to coexist or occur in sequence. A common practice with sand and gravel pits is to operate them until they are depleted or a certain depth is reached. Then the pit area is graded over and used for commercial or residential building sites. If the pits were operated below the water table, it may be possible to make use of the resultant ponds. LaFleur (1974) further
suggested that areas with sand and gravel resources could be used as temporary sites for mobile homes prior to the start of excavations. 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.

Zoning is the ultimate result of many land-use plans. Great 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 and boundaries between surficial map units. He described examples in a New York town whose zoning pattern is especially 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 (till is bouldery and moderately well drained); (2) a central area with drumlins and many bedrock outcrops (till is impermeable and ground water is in short supply); and (3) a western kame-esker complex. The upland has been zoned as "open space" because of its rocky terrain, even though much of it is actually suitable for development. The drumlin area is zoned as "residential" -- a decision that has caused many problems with sewage disposal in the poorly drained soil. The western part of the town has "commercial excavation" zoning, but only where gravel pits already exist. Future building is likely to permanently cut off access to undeveloped 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.

LOCATION OF HIGHWAYS

It is necessary to examine the surficial geology of proposed transportation routes 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 can be reduced by choosing the route that is most compatible with the local geology. The considerations that are discussed here mainly concern the siting of highways, but many of the same geologic factors apply in the location of railroads.

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 tills, kames, eskers, 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 by a factor of 4 to 5 (per unit volume) relative to a "deep, dry, moderately cohesive soil".

Compact basal till (hardpan) and glacial-marine sediments consisting of silt and clay are also difficult to excavate. Basal 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 is as important as their texture and structure in determining ease of excavation. There are many large areas in coastal Maine where bedrock is at or near the surface. Moreover, glacial ice has scraped off most of the preglacially weathered rock and left solid ledges. Blasting is necessary during highway construction in most thin-overburden areas, so excavation costs typically are 4 to 5 times greater than for loose, dry surficial sediments (Way, 1973).

The topography of surficial earth materials is another property that affects their suitability for highway location. For example, drumlins have steep side-slopes and commonly occur in groups with hilly topography. Thus, much cut and fill is necessary in building a road through a drumlin field, especially in a transverse direction. End moraines and eskers are also ridge-shaped landforms, but they are generally smaller or easier to excavate than drumlins.

Flat 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 partly fill 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, kame terrace, or 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 the aforementioned deposits is particularly important in the location of railroads as well as highways.

The surface and underground drainage of surficial sediments must also be considered 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 by a factor of 4 or 5 times with the presence of organic material and a high water table (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. Landslides may occur in the Presumpscot Formation under certain slope and ground-water conditions (see section on landslides).

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 telephone 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 progress. In drumlin fields and 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 coastal Maine, flat topography occurs principally on the surfaces of the Presumpscot Formation, glacial-marine deltas, broad outwash fans, swamps, and tidal marshes. The swamp and marsh deposits are very poorly drained, and the same is true of the Presumpscot Formation in places.

Although certain flat areas are generally favorable for home sites, they may be unappealing aesthetically. Hilly terrain is more likely to provide views and (in some cases) a sense of privacy. For example, cleared fields on the crests of many drumlins offer spectacular views. Kames and kame terraces 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, where there are numerous 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 kames limit the number of houses that can be seen from any particular site.

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 swamps, flood plains, and other areas that are continuously wet or 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). Drainage problems likewise may be encountered on the flanks of drumlins and other hills that have low-permeability basal 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 up to 4 or 5 times as expensive as in dry, moderately cohesive surficial sediments (Way, 1973). 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 desirable if they do not interfere with construction and the location of sewage-disposal facilities.

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 Pre-
sumpscot 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 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 (Figure 36) and may proceed rapidly in loose materials such as sandy glacial-stream deposits. The undercutting of stream banks can affect both flood plains and higher ground that is never flooded.

The erodibility of surficial materials is most apparent along the ocean shore. Parts of the Maine coastline have retreated landward many meters in recent years as a consequence of winter storms. 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. It is assumed that each house has its own water supply and sewage-disposal system. From the standpoint of surficial geology, sewage disposal is often the 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.)

Houses situated on thick, well-drained sandy till generally 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. For example, in southern Maine the crests of many small end 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, sealed vault privies, or similar 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 (31 m). In an area where many houses are to be constructed on a major surficial aquifer, the geology of the aquifer should be examined carefully to determine whether there is a danger of ground-water contamination from the absorption fields.

High-Density Housing with Municipal Water and Sewage Systems

"High-density housing" consists of residential tracts with town water and sewer lines. In general, 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. However, construction is more expensive where the cost of excavation is greater.

Since high-density housing and associated urbanization cover large areas of land, the concepts of sequential and multiple land use are especially important in maximizing the benefits from these areas. As stated previously, sand and gravel deposits may be valuable as aquifers, construction material, and building sites. Sand and gravel that is needed for construction must be excavated before permanent homes are built on the same site. This principle should also apply 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. Children have been killed by cave-ins in borrow pits, and many people regard the pits as eyesores. Consequently, sand and gravel operations commonly are banned in residential neighborhoods. The same is true of mines and quarries, so housing developments should be planned so as not to prevent the extraction of valuable geologic resources.

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. Much research remains to be done on the effects of development on sand-and-gravel aquifers. Because of this lack of information, along with the variety of local geologic conditions, no further recommendations are made here.

UTILIZATION OF TERRAIN THAT IS POORLY SUITED FOR BUILDING SITES

Flood-Prone Areas

Any structures that are 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 (1972).

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.
Swamps and Other 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.

Bedrock Outcrop Areas

Areas where bedrock is widely exposed at the ground surface are unfavorable for many land uses. Cliffs, broad ledges, and other expanses of barren rock are usually left in their natural state. However, they 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 studies.

Generally speaking, though, areas with thin surficial deposits and/or scattered small outcrops are more common than the extensive outcrops mentioned above. 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 much of 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.

CONCLUSION

Chapters V and VI have discussed some land-use characteristics of the surficial earth materials that occur in coastal Maine. The table in Appendix D summarizes these characteristics by indicating the degree of suitability of the principal kinds of materials for various uses. The reader is reminded that the information and guidelines presented here are general in many cases because of the variability of surficial deposits. Detailed on-site investigations are necessary for activities that require knowledge of the composition, texture, thickness, and drainage of the surficial materials at specific localities.
APPENDIX A

EXPLANATION TO ACCOMPANY SURFICIAL GEOLÒGIC MAPS OF MAINE

CORRELATION OF MAP UNITS

This correlation chart shows the general age relationships of surficial deposits. There may be considerable overlap in the ages of certain deposits in any particular area.
<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>GEOLOGIC UNIT</th>
<th>MATERIALS</th>
<th>TOPOGRAPHY</th>
<th>ORIGIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qal</td>
<td>Stream alluvium (flood-plain and stream-terrace deposits)</td>
<td>Sand, gravel, and silt. Low to high permeability. Poor to good drainage. Permeability and drainage generally are better in stream-terrace deposits than in modern flood-plain sediments.</td>
<td>Flat to gently sloping.</td>
<td>Deposited on flood plains and stream beds by postglacial streams. Unit may also include minor alluvial fan deposits at mouths of valleys.</td>
</tr>
<tr>
<td>Qs</td>
<td>Swamp and tidal-marsh deposits</td>
<td>Peat, silt, clay, and sand. Poor drainage.</td>
<td>Flat.</td>
<td>Formed by accumulation of sediments and organic material in depressions and other poorly drained areas.</td>
</tr>
<tr>
<td>Qbd</td>
<td>Beach and dune deposits</td>
<td>Sand and gravel. High permeability. Materials are well drained, but water table is close to surface.</td>
<td>Low ridges and mounds, or sloping surface.</td>
<td>Occurs along modern ocean and lake shores. Includes beach sediments formed by wave and current action, and windblown sand derived from these deposits.</td>
</tr>
<tr>
<td>Qe</td>
<td>Eolian deposits</td>
<td>Sand. Moderate to high permeability. Good drainage.</td>
<td>Dune ridges and mounds, or blanket deposit that conforms to surface of underlying unit.</td>
<td>Windblown sand. Derived from wind erosion of glacial sediments and deposited in late-glacial to post-glacial time.</td>
</tr>
<tr>
<td>Qta</td>
<td>Talus deposits</td>
<td>Large, angular rock fragments.</td>
<td>Steeply sloping rock piles at the bottoms of cliffs.</td>
<td>Formed by the accumulation of rock fragments that break loose from a cliff and fall to the slope below.</td>
</tr>
<tr>
<td>Ql</td>
<td>Glacial-lake bottom deposits</td>
<td>Silt, clay, and sand, commonly as thin, interstratified layers of various particle sizes. Low to moderate permeability. Poor to fair drainage.</td>
<td>Flat to gently sloping except where dissected by modern streams.</td>
<td>Composed largely of sediments that washed out of glacial ice and accumulated on the floors of glacial lakes. Map unit may also include a few non-glacial lake bottom deposits.</td>
</tr>
<tr>
<td>Obl</td>
<td>Glacial-lake beach deposits</td>
<td>Gravel and sand. Typically thin and of limited extent. High permeability. Good drainage.</td>
<td>Low ridges or sloping surface. May be associated with wave-cut benches on hillsides.</td>
<td>Formed by wave erosion of till or other materials along shores of glacial lakes. Lakes have since lowered or drained.</td>
</tr>
<tr>
<td>Qps</td>
<td>Glacial-marine deposits (Presumpscot Formation)</td>
<td>Silt, clay, and sand. Commonly a clayey silt, but sand is very abundant at the surface in some places. Locally fossiliferous. Map unit includes small areas of till, sand, and gravel that are not completely covered by marine sediment. Oqs: Mostly sand, but may be underlain by silt and clay. Moderate to high permeability. Fair to good drainage. Oqs: Mostly silt and clay. Low permeability. Poor drainage.</td>
<td>Flat to gently sloping except where dissected by modern streams. Commonly has a branching network of steep-walled stream gullies.</td>
<td>Composed of sediments that washed out of the Late Wisconsinan glacier and accumulated on the ocean floor. Formed during late-glacial time, when relative sea level was higher than at present.</td>
</tr>
</tbody>
</table>
Emerged marine-beach deposits
Gravel and sand. High permeability. Good drainage. Typically thin and of limited extent.

Glacial-stream deposits
Sand and gravel. May include minor till. Commonly overlapped or entirely buried by glacial-marine deposits in the coastal lowland.
Ogo: High permeability. Good drainage.
Qg: Moderate to high permeability. Good drainage.

End-moraine deposits
Till and/or sand and gravel. Commonly overlain by glacial-marine deposits in coastal areas. Permeability and drainage are highly variable, even over short distances in a single moraine.
Qmg: Composed mostly of sand and gravel.
Qmh: Composed of till, sand, and gravel.
Qmt: Composed mostly of till.
Qm: Composition not specified.

Till
Heterogeneous mixture of sand, silt, clay, and stones. Stratification is rare. Includes two varieties: basal till and ablation till. Basal till is fine grained and very compact, with low permeability and poor drainage. Ablation till is loose, sandy, and stony, with moderate permeability and fair to good drainage. Unit generally overlies bedrock, but may overlie or include sand and gravel.

Bedrock outcrops
Dots show locations of individual outcrops. Ruled pattern indicates areas of many outcrops and/or thin surficial deposits (generally less than 10 ft. thick). Symbol “rk” indicates areas of barren ledge. Outcrops mapped largely by interpretation of aerial photography in off-road areas.

Artificial fill
Composed of till, sand and gravel, rock or various man-made materials (mainly trash in large dumps and landfills).
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact</td>
<td>Boundary between adjacent map units. Dashed where inferred.</td>
</tr>
<tr>
<td>Scarp</td>
<td>Separates stream terrace from modern flood plain and adjacent terraces from each other. Hachures on downslope side.</td>
</tr>
<tr>
<td>Drumlin</td>
<td>Glacially streamlined hill that has been elongated in direction of ice movement. Symbol shows direction of long axis. Generally composed of till and/or bedrock (rarely sand and gravel). Till is very thick in parts of many drumlins.</td>
</tr>
<tr>
<td>Glacial striation locality</td>
<td>Point of observation at tip of arrow. Arrow indicates ice-movement direction as inferred from striations (scratches on bedrock caused by glacial abrasion).</td>
</tr>
<tr>
<td>Crescentic mark locality</td>
<td>Point of observation at tip of arrow. Arrow indicates ice-movement direction as inferred from crescentic marks on bedrock surface.</td>
</tr>
<tr>
<td>Grooved till surface</td>
<td>Symbols show lengths and directions of narrow ridges carved in till by flow of glacial ice.</td>
</tr>
<tr>
<td>Area of many large boulders</td>
<td></td>
</tr>
<tr>
<td>Cirque</td>
<td>A steep-walled, half-bowl shaped basin. Formed by glacial erosion in high mountainous areas of Maine.</td>
</tr>
<tr>
<td>End moraine</td>
<td>Ridge of till or sand and gravel deposited at margin of glacier. Barbs point in direction of ice movement. Symbol is used in part to indicate moraines that are mostly buried by water-laid glacial sediment, as well as moraines that are too narrow to be outlined by a contact line at the scale of the map.</td>
</tr>
<tr>
<td>Dip direction of delta foreset beds</td>
<td>Number is approximate altitude in feet of contact between topset and foreset beds, which marks former position of sea level or glacial lake level (generally sea level in coastal Maine). Point of observation at tip of arrow.</td>
</tr>
<tr>
<td>Dip direction of cross-bedding in glacial-stream deposits</td>
<td>Indicates direction of flow of glacial meltwater streams.</td>
</tr>
<tr>
<td>Crest of esker</td>
<td>Shows trend of sand and gravel ridge that was deposited in meltwater tunnel beneath glacier. Chevrons point in direction of meltwater flow.</td>
</tr>
<tr>
<td>Kettle</td>
<td>Depression created by melting of large mass of buried glacial ice and collapse of overlying sediments.</td>
</tr>
<tr>
<td>Meltwater channel</td>
<td>Channel eroded by glacial meltwater stream. Arrow indicates known or probable direction of stream flow.</td>
</tr>
<tr>
<td>Meltwater channel</td>
<td>Flow direction not specified.</td>
</tr>
<tr>
<td>Till or sand and gravel pit</td>
<td>Letter symbols indicate materials exposed in pit:</td>
</tr>
<tr>
<td>active</td>
<td></td>
</tr>
<tr>
<td>inactive</td>
<td></td>
</tr>
<tr>
<td>unchecked</td>
<td></td>
</tr>
<tr>
<td>C.S</td>
<td></td>
</tr>
<tr>
<td>D.B</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>loose, sandy ablation till</td>
</tr>
<tr>
<td>b</td>
<td>compact, fine-grained basal till</td>
</tr>
<tr>
<td>c</td>
<td>flowtill</td>
</tr>
<tr>
<td>d</td>
<td>clay</td>
</tr>
<tr>
<td>e</td>
<td>silt</td>
</tr>
<tr>
<td>f</td>
<td>sand</td>
</tr>
<tr>
<td>g</td>
<td>pebbly to cobbly sand</td>
</tr>
<tr>
<td>h</td>
<td>pebble gravel</td>
</tr>
<tr>
<td>i</td>
<td>cobble gravel</td>
</tr>
<tr>
<td>j</td>
<td>boulder gravel</td>
</tr>
<tr>
<td>k</td>
<td>gravel, undifferentiated</td>
</tr>
<tr>
<td>l</td>
<td>bedrock</td>
</tr>
<tr>
<td>m</td>
<td>rottenstone (decomposed bedrock)</td>
</tr>
<tr>
<td>active or unchecked</td>
<td></td>
</tr>
<tr>
<td>Bedrock quarry</td>
<td></td>
</tr>
<tr>
<td>inactive</td>
<td></td>
</tr>
<tr>
<td>SI-3041</td>
<td>Source of dated sample</td>
</tr>
<tr>
<td>Symbols show collection site and laboratory sample number of 14C-dated shells, wood, or other organic material.</td>
<td></td>
</tr>
</tbody>
</table>
SEQUENCE OF GLACIAL RECESSISON

AND

DEPOSITION OF GLACIAL MATERIALS

13,000 years ago: Continental glacier covered most of Maine, but was beginning to disappear from what is now the coast. Sea was in contact with ice margin.

12,800 years ago: Glacier was receding rapidly and much of southern Maine was ice-free. Land was still depressed from weight of ice, allowing sea to cover coastal lowland.

12,000 years ago: Glacier had disappeared from central and southern Maine. Uplift of land had caused sea to retreat.

Block diagrams by R. D. Tucker

BM - Buried moraine
BR - Bedrock ridge
BS - Braided stream
D - Delta
DR - Drumlins
E - Esker
IB - Ice block
K - Kettle
M - Moraine
ML - Marine limit
MS - Marine sediments
OP - Outwash plain
S - Seawater
T - Till
**APPENDIX B**

**ENGLISH - METRIC CONVERSION TABLE FOR MEASURES USED IN THIS REPORT**

<table>
<thead>
<tr>
<th>English System</th>
<th>Metric System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 inch</td>
<td>2.54 centimeters (cm)</td>
</tr>
<tr>
<td>1 foot</td>
<td>0.31 meter (m)</td>
</tr>
<tr>
<td>1 mile</td>
<td>1.61 kilometers (km)</td>
</tr>
<tr>
<td>1 acre</td>
<td>0.40 hectare</td>
</tr>
<tr>
<td>1 gallon</td>
<td>3.79 liters (l)</td>
</tr>
<tr>
<td>1 (short) ton</td>
<td>907.18 kilograms (kg)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metric System</th>
<th>English System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 millimeter (mm)</td>
<td>0.04 inch</td>
</tr>
<tr>
<td>1 centimeter</td>
<td>0.39 inch</td>
</tr>
<tr>
<td>1 meter</td>
<td>3.28 feet</td>
</tr>
<tr>
<td>1 kilometer</td>
<td>0.62 mile</td>
</tr>
<tr>
<td>1 hectare</td>
<td>2.47 acres</td>
</tr>
<tr>
<td>1 liter</td>
<td>0.26 gallon</td>
</tr>
<tr>
<td>1 ton</td>
<td>2204.6 pounds</td>
</tr>
</tbody>
</table>
APPENDIX C

SEDIMENT GRAIN-SIZE CLASSIFICATION
USED IN THIS REPORT
(from Folk, 1968)

<table>
<thead>
<tr>
<th>U. S. Standard Sieve Mesh No.</th>
<th>Grain Diameter in Millimeters</th>
<th>Wentworth Size Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>256</td>
<td>Boulder</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>Cobble</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Pebble</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Granule</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Very Coarse Sand</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Coarse Sand</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>Medium Sand</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>Fine Sand</td>
<td></td>
</tr>
<tr>
<td>230</td>
<td>Very Fine Sand</td>
<td></td>
</tr>
<tr>
<td>0.0039*</td>
<td>Silt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clay</td>
<td></td>
</tr>
</tbody>
</table>

* A silt-clay boundary of 0.002 mm (2 microns) is preferred by many geologists.
APPENDIX D

SUITABILITY OF SOME COMMON SURFICIAL MATERIALS
FOR VARIOUS LAND USES

(Note: These suitability ratings are of necessity very general, and exceptions are common. Actual ratings for a particular deposit are a function of the complex interrelationships of composition, slope, drainage, intended use, and many other features. Consult the text for more information.)

Rating abbreviations are as follows:

G -- good
F -- fair
P -- poor
## APPENDIX D

**SUITABILITY OF SOME COMMON SURFICIAL MATERIALS FOR VARIOUS LAND USES**

<table>
<thead>
<tr>
<th>MATERIAL:</th>
<th>USE:</th>
<th>Source of sand and/or gravel</th>
<th>Source of clay</th>
<th>Source of peat</th>
<th>Water-supply potential (J = domestic only)</th>
<th>Waste disposal potential containment of liquid wastes</th>
<th>Location of highways and underground utility lines</th>
<th>Home sites</th>
<th>Parks and other recreation areas with little development</th>
<th>Farming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal till</td>
<td></td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>F</td>
<td>F-G</td>
<td>G</td>
<td>F-G</td>
<td></td>
</tr>
<tr>
<td>Ablation till</td>
<td></td>
<td>P-F</td>
<td>P</td>
<td>P</td>
<td>P-F</td>
<td>F</td>
<td>F-G</td>
<td>G</td>
<td>F-G</td>
<td></td>
</tr>
<tr>
<td>Mixed sand and gravel (end moraines, glacial-stream deposits, and stream terraces)</td>
<td></td>
<td>G</td>
<td>P</td>
<td>P</td>
<td>F-G</td>
<td>P-F</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>F-G</td>
</tr>
<tr>
<td>Clean, well-washed gravel (end moraines, glacial-stream deposits, and stream terraces)</td>
<td></td>
<td>G</td>
<td>P</td>
<td>P</td>
<td>G</td>
<td>P</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>F-G</td>
</tr>
<tr>
<td>Fine to very coarse sand (glacial-stream deposits, stream terraces, and a few end moraines)</td>
<td></td>
<td>G</td>
<td>P</td>
<td>P</td>
<td>F-G</td>
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<tr>
<td>Clay, silt, and very fine sand (glacial-marine and glacial-lake deposits)</td>
<td></td>
<td>P</td>
<td>(sandy) to G (clay-rich)</td>
<td>P</td>
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<tr>
<td>Swamp and tidal-marsh deposits</td>
<td></td>
<td>P</td>
<td>P</td>
<td>P-G (bogs)</td>
<td>P</td>
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<td>P-G</td>
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<tr>
<td>Flood-plain deposits</td>
<td></td>
<td>P-F</td>
<td>P</td>
<td>P</td>
<td>P-G</td>
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<td>P-F</td>
<td>P</td>
<td>F-G</td>
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