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Surficial Geology of the Brownfield 7.5-minute Quadrangle, Oxford County, Maine

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INTRODUCTION

This report describes the surficial and Quaternary geology of the Brownfield 7.5-minute quadrangle in southwestern Maine. Surficial materials include unconsolidated sediments of glacial and nonglacial origin that overlie bedrock over much of the quadrangle. Most of these sediments were deposited during or after the most recent episode of glaciation, which spans about the last 25,000 years in Maine. Surficial materials are important for many aspects of economic and environmental geology, including sand and gravel extraction for the aggregate industry, development and protection of ground-water supplies, disposal of wastes in landfills, and agriculture.

Detailed mapping of the surficial geology of the Brownfield 7.5-minute quadrangle was begun by William R. Holland in 1983 for the state/federal Significant Sand and Gravel Aquifer Project and the Maine Geological Survey's (MGS) geologic mapping program. The aquifer map was included in a report by Williams and others (1987), but the geologic map was not completed because of Holland's untimely death in 1989. P. Thompson Davis completed the field mapping of the Brownfield quadrangle in 1994-1995, which is summarized in this report for the STATEMAP program, supported by the MGS and the U.S. Geological Survey.

Two maps accompany this report. The *surficial geologic map* (Davis and Holland, 1997a) shows the distribution of the sedimentary units, whose age, composition, stratigraphic relationships, and origin are discussed here. This map also includes information related to the geologic history of the quadrangle, such as glacial ice-flow directional indicators. In conjunction with similar mapping in adjacent quadrangles, this map provides a basis for discussion of the glacial and postglacial history of the region. The *surficial materials map* (Davis, 1998) shows specific site data used for compiling the surficial geologic map. These data include observations from sand and gravel pits, shovel and auger holes, construction sites, and natural exposures along stream banks. Sand and gravel aquifer studies by the Maine Geological Survey and the U.S. Geological Survey provided additional information on the map area, including seismic logs and depth-to-bedrock data (Willams and others, 1987). Supplemental depth-to-bedrock data were obtained from MGS well inventories.

Field work for this project consisted of driving the road network, including numerous unimproved logging roads not shown on the topographic map base, and hiking across many off-road areas to examine bedrock outcrops, borrow pits, and natural exposures of surficial materials. The authors used a shovel and hand auger to identify near-surface materials in some places where exposures were lacking. The surficial materials map primarily shows specific places where information was obtained from beneath the ground surface. In many places the authors were able to distinguish map units such as eskers and till deposits on the basis of surface indicators such as topography and presence of boulders. In some remote areas, such as the Burnt Meadow Mountains, aerial photographs were used to differentiate map units, such as talus slopes.

Geographic Setting

The Brownfield 7.5-minute quadrangle is located in the White Mountain foothills. Most of the map area is within Oxford County, Maine, except for a narrow corridor in the extreme western part, which is in New Hampshire. The map area extends in latitude from 43°52'30" to 44°00'00" N, and in longitude from 70°52'30" to 71°00'00" W. The quadrangle includes small parts of the towns of Fryeburg and Denmark in the north, a large part

[1]Deceased

of the town of Brownfield in the middle, and small parts of the towns of Porter and Hiram in the south. The principal population center in the quadrangle lies between the villages of Brownfield and East Brownfield along Route 160 in the east-central part of the quadrangle.

The most significant physiographic features in the Brownfield quadrangle are the Burnt Meadow Mountains in the southeast and a meandering part of the Saco River in the northeast. The southern part of Lovewell Pond, which drains into the Saco River, is located in the north-central part of the quadrangle. The highest point in the quadrangle is Stone Mountain (in the Burnt Meadow Mountains) at 1624 ft (495 m), whereas the lowest point is below 360 ft (110 m) on the Saco River (on the eastern boundary of the quadrangle), yielding a relief of 1264 ft (385 m). With the exception of the Saco River valley to the northeast, the terrain over most of the quadrangle is hilly, with many of the larger hills exhibiting steep bedrock cliffs on their south slopes.

Bedrock Geology

The northern part of the Brownfield quadrangle is underlain by Devonian-age binary granite, whereas the central and southern parts are underlain primarily by Devonian granodiorite (Gilman, 1977; Hussey, 1985; Osberg and others, 1985). Small areas of the southeastern and southwestern parts of the quadrangle are underlain by metasedimentary rocks assigned to the lower member of the Rindgemere Formation, which probably is Silurian in age (Hussey, 1985). This member generally consists of high-grade schists and migmatites in the Brownfield quadrangle (Gilman, 1977). The Burnt Meadow Mountains in the central part of the quadrangle owe their relief to underlying rocks of the Triassic to Jurassic-age White Mountain plutonic series, including quartz syenite, syenite, and volcanics. A small area in the southwestern part of the quadrangle is underlain by Conway granite, also of the White Mountain plutonic series (Gilman, 1977). Basaltic and granite pegmatitic dikes locally intrude the above rock units.

PREVIOUS WORK AND ACKNOWLEDGMENTS

Stone (1899) carried out an early reconnaissance of the surficial geology of the Saco Valley region as part of his statewide study of Maine's glacial gravel deposits. Leavitt and Perkins (1935) commented briefly on the area in their "Survey of Road Materials and Glacial Geology of Maine". Prescott (1979) compiled well and test hole data, and conducted preliminary surficial and gravel aquifer mapping (Prescott and others, 1979; Prescott, 1980). Holland compiled a more detailed aquifer map that included the Brownfield quadrangle as part of the Significant Sand and Gravel Aquifer Project sponsored by the Maine Geological Survey, U.S. Geological Survey, and Maine Department of Environmental Protection (Williams and others, 1987). Two field trips for the New England Intercollegiate Geological conference focused on the surrounding area (Thompson, 1986; Thompson and others, 1995).

The authors are grateful to numerous landowners and gravel pit operators who granted access to their properties and often provided us with useful information about the local sand and gravel deposits. In particular, Ronald Barrett provided access in East Brownfield to excellent exposures of lake bottom sediments deposited in glacial Lake Pigwacket; Paul and Donna McGonagle provided access to a pit dug into an esker deposit just south of West Brownfield; and Frank Day of the Brownfield Public Works Department provided access to a town pit dug into deltaic sediments near Burnt Meadow Pond in East Brownfield. Thanks are also due Woody Thompson and Tom Weddle for their detailed reviews of this report.

DESCRIPTION OF GEOLOGIC MAP UNITS

The surficial deposits of the Brownfield quadrangle have been represented on the geologic map as a series of units on the basis of their age and origin. These map units are designated by letter symbols, such as "Pt". The first letter indicates the age of the unit:

"P" = Pleistocene (Ice Age)

"H" = Holocene (postglacial time, i.e. formed during the last 10,000 years)

"Q" = Quaternary (encompasses both the Pleistocene and Holocene epochs)

The Quaternary age is assigned to units that overlap the Pleistocene-Holocene boundary, or whose ages are uncertain. The other letters in the map symbol indicate the origin and/or assigned name of the unit, e.g. "t" for glacial till and "lp" for sediments deposited in Lake Pigwacket. Surficial map units in the Brownfield quadrangle are described below, starting with the older deposits that formed in contact with glacial ice.

Till (Pt)

Till is a glacially deposited sediment consisting of a heterogeneous mixture of silt, sand, gravel, and larger rock debris. Till blankets much of the hilly terrain in the upland parts of the quadrangle where it is the principal surficial material; test borings in other parts of the state show that till commonly underlies younger deposits in valleys. Some till was probably derived from glacial erosion of older surficial sediments (either glacial or non-glacial), whereas much of it was probably freshly eroded from nearby bedrock sources during the most recent glaciation. Well data shown on the materials map indicate that till deposits in the Brownfield quadrangle are up to 150-200 ft (46-61 m) thick.

By definition, till is a poorly sorted sediment (diamicton) in which there is a very wide range of particle sizes. However, the texture and structure of individual till deposits vary depending on their source and how the deposits were formed. In the Brownfield area, till may include a small percentage of clay, but usually has a sandy or silty-sandy matrix as a consequence of having been eroded from coarse-grained bedrock. Till has little or no obvious stratification in some places, but elsewhere is crudely stratified, with discontinuous lenses and laminae of silt, sand, and gravel resulting from sorting by meltwater during the depositional process.

Stones of all sizes are abundant in this unit, and boulders scattered across the ground surface commonly indicate the presence of till. The geologic map shows concentrations of many large boulders; however, these areas may be much more extensive than noted and we may well have missed other boulder concentrations in remote areas. Till stones in the quadrangle consist mainly of coarse-grained igneous and metamorphic rocks, especially lithologies of granitic composition, derived predominantly from local bedrock sources. However, erratic stones from source areas in the White Mountains in New Hampshire are also common. Most till stones are subangular to subrounded, and some have faceted and striated surfaces derived from subglacial erosion. These striated flat surfaces are best developed on dense, fine-grained rocks such as basalt and rhyolite.

Till deposited under great pressure beneath an ice sheet tends to be more compact and finer-grained than does till formed by ablation processes on the surface of melting glacier ice. Subglacial till facies include lodgement and basal melt-out tills. Lodgement tills are usually very compact ("hardpan") and difficult to excavate, with a platy structure (fissility) evident in their upper, weathered zones. Basal melt-out tills may be difficult to identify with certainty, but typically show a crude stratification inherited from debris bands in the lower part of the glacier. Ablation facies tend to be loose-textured, stony, and contain numerous lenses of water-transported sediment. More than one of these till facies may occur at a single locality. A thin veneer of stony ablation till commonly overlies lodgement till.

Field evidence in the nearby Fryeburg area (Thompson, 1999a), coupled with studies elsewhere in New England (e.g., Koteff and Pessl, 1985; Thompson and Borns, 1985b; Weddle and others, 1989), suggests that till deposits of two glaciations are present in the Oxford Hills region of southwestern Maine. The "upper till" is the product of the most recent (late Wisconsinan) glaciation, which covered southern Maine between about 25,000 and 14,000 radiocarbon years ago. Exposures of this younger till can be seen in many shallow pits, road cuts, and temporary excavations. The upper till is non-oxidized, except for the near-surface zone of Holocene soil formation, and usually is light olive-gray in color. Most till deposits seen by the authors in the Brownfield quadrangle have a sandy, stony texture, and probably are the ablation facies of upper till (**ta** on the materials map).

The "lower till" consists mainly of compact, silty-sandy lodgement deposits. In southwestern Maine, as in other parts of New England, the lower till is likely to occur in smooth, glacially streamlined hills where thick till deposits have accumulated. When present, these thick deposits usually occur on the gentle northwest-facing slopes of hills, whereas steeper, glacially plucked bedrock is commonly exposed on the southeast-facing slopes. The lower till has not been observed in the Brownfield quadrangle.

End Moraines

Bouldery ridges representative of end moraines were not found in the Brownfield quadrangle. However, these features warrant a brief description because they are present in the Hiram and Kezar Falls quadrangles to the east and south (Thompson and Holland, 1999a,b; Davis and Holland,1997b,c), respectively, and may eventually be found in the Brownfield area.

End moraines are ridges of unsorted and unstratified sediment deposited at the margins of glaciers. Moraine ridges may form in many different ways, but generally result from accumulation of sediments derived from the adjacent glacial ice, or are shaped by glacial processes at the glacier margin. Surfaces of end moraines that occur above the zone of late-glacial marine submergence in southwestern Maine are commonly strewn with boulders. Moraine interiors are rarely exposed in this part of the state, but topographic expression and pits suggest that most end moraines are mostly composed of till with locally abundant lenses of sand and gravel.

End moraines, which are useful markers of ice-margin positions, may be difficult to distinguish from areas of "hummocky moraine" or ribbed moraine, both of which also occur in this part of Maine (see descriptions below).

Hummocky Moraine (Phm)

Several areas in the Brownfield quadrangle contain extensive deposits of hummocky moraine. These deposits are distinguished in the field by their knobby topography and abundance of large boulders. The relative scarcity of bedrock outcrops, along with the topographic relief, suggests that hummocky moraine may be typically tens of feet thick. A few exposures indicate that the hummocks of unit Phm vary in composition from till to sand and gravel, with till being the more abundant constituent. However, the composition may vary abruptly, both horizontally and vertically.

Hummocky moraine is generally concentrated in lowland areas, but usually occurs on the sides of valleys at higher elevations than adjacent glacial-lake deposits, which are distinguishable by well sorted and stratified sand and gravel. As proposed by Holland (1986), the location, composition, and topography of unit Phm suggest that it formed during the melting of stagnant debris-rich ice in a late stage of deglaciation. However, it is possible that active ice was present nearby to the north as unit Phm was deposited. In any case, ice-contact outwash heads and numerous series of meltwater channels are common in the Brownfield quadrangle, and these indicate a systematically northward-retreating ice margin, regardless of the degree to which the ice remained active.

An excellent example of the topographic relief expressed by hummocky moraine occurs in the northwestern part of the quadrangle between about 500 and 550 ft in elevation, where boulders are common and small hills express a relief generally less than 20 ft (6 m).

Ribbed Moraine (Prm)

Ribbed moraine consists of groups of till ridges located in the bottoms of valleys that are generally parallel to glacial flow directions (Holland, 1986). There has been much debate about how and where these ridges formed relative to the glacier margin (Davis, in Thompson and others, 1995, p. 46-48). A small area of ribbed moraine was found near the northeast corner of the Brownfield quadrangle, between the Saco River and Pleasant Pond. This map unit is a cluster of low, sub-parallel ridges that trend generally east-west. The deposits appear to be composed of till, but no pit exposures were seen, so it is possible that they also include some sand and gravel.

Eskers (Pge)

Stone (1899, p. 257-258) wrote "The number and height of the hills which the gravels of this region cross are remarkable. Nowhere else in Maine is there anything equal to them. In Brownfield, Porter, and Hiram the glacial rivers flowed up and down over these hills 200 or more feet higher than the valleys to the north of them, and in Parsonsfield and Cornish they crossed several more......... These branching series often reject valleys of favorable slopes to climb hills, and are therefore difficult to map. Delta branches are liable at any point to diverge from the series one is exploring, and constant watchfulness is required."

Eskers are long, sinuous ridges of sand and gravel deposited in tunnels beneath or within glacial ice. As the tunnels became choked with sediment and the surrounding ice melted, the tunnel-filling deposits were left behind with their characteristic ridge shape. Individual esker segments in Maine typically range in length from a few hundred feet to over a mile, and can be up to a hundred feet or more in height. Many eskers are aligned in linear series (esker systems) that can be traced for great distances on regional maps (Thompson and Borns, 1985a).

Most exposures in the Shepards River - Cole Brook esker system, which extends over 7.5 mi (12 km) and nearly the length of the west side of the Brownfield quadrangle, are extremely slumped and no longer useful for study. However, in 1985, Holland and others (Carl Koteff, 1995, oral communication) examined exposures that provided unequivocal paleocurrent data that indicated flow from north to south. Also, this esker climbs over 360 ft (110 m) in elevation, from near 500 ft (150 m) to the north to over 860 ft (260 m) to the south, where a bedrock topographic divide marks the lowest point in the upper Cole Brook drainage. Thus, the esker climbs about 48 ft/ mi (about 9.1 m/km). Holland (1986) noted a lack of collapse features within the core of the esker, which he suggested argued against superposition of the esker on the bed from an englacial position, but rather for formation in a confined subglacial tunnel. He suggested that the esker was formed during an early phase of deglaciation when ice was still thick, whereas other ice-contact stratified deposits in the valley were formed later when the ice was thinner. This two-stage model for deposition of ice-contact stratified drift is similar to one proposed by Goldthwait and Mickelson (1982) for deglaciation of the White Mountains in New Hampshire.

Elsewhere in Maine, Shreve (1985a,b) argued that eskers represent through-flowing systems from end-to-end, with sediments deposited simultaneously within continuously open tunnels. Thus, Shreve (1985a,b) argued that the Katahdin esker system in central Maine could be used to reconstruct hydraulic conditions and ice profiles for the ice sheet, hence ice thickness for any location along a flowline. However, Weddle and others (1994) noted that the Katahdin esker system consists of several distinct segments separated by fans or deltas, thus was not deposited concurrently, but rather was deposited sequentially in segments by retreating active ice. The latter view is consistent with the deposition of morphosequences and end moraines in New England as described by Koteff and Pessl (1981).

The Shepards River - Cole Brook esker is not nearly as large or long as the esker systems in central and eastern Maine and does not appear to exhibit fans or deltas at segment ends. The segmentation of the Shepards River - Cole Brook esker probably is at least partly the result of postglacial stream erosion. With limited exposures, the question concerning whether this esker was formed as one contemporaneous feature or deposited sequentially as individual segments is open to discussion. However, the steep longitudinal gradient of this esker argues that there was a period of time with continuous meltwater flow and thick ice to provide the necessary hydrostatic head for the subglacial stream to climb southward.

Although the large pit about 1.0 mi (1.6 km) due south of West Brownfield is not very active and is severely slumped, the pit extends into the core of the Shepards River - Cole Brook esker and has allowed examination of the coarse sand and gravel bedding typical of esker deposits in Maine.

Ice-Contact Deposits (Pgi)

As in the adjacent Hiram and Kezar Falls 7.5-minute quadrangles, there are areas of sand and gravel whose origins are not well understood, primarily because of the lack of diagnostic exposures. However, the topographic setting of these sediments indicates deposition in contact with melting glacial ice. These areas are mapped as undifferentiated ice-contact deposits (Pgi).

Excellent examples of ice-contact deposits occur in the headwaters of the West Branch of Tenmile River, east of Pine Hill, and north of Porterfield, in the southeastern part of the quadrangle. Numerous borrow pits have been dug into these deposits, although most were inactive and badly slumped when we visited them.

Glacial Lake Brownfield Deposits ($Plbd_{1-4}$)

During the early stages of glacial retreat from higher elevations in the western part of the quadrangle, a broad tongue of ice in the lower Saco River valley to the east blocked the Shepards River, Linscott Brook, Cole Brook, and Quint Brook valleys. This impoundment of meltwater drainage formed a water body named "glacial Lake Brownfield," which is discussed below in the section on glacial history. The sediments deposited into the four stages of this lake (map units $Plbd_1$, $Plbd_2$, $Plbd_3$, and $Plbd_4$) consist mostly of deltaic and fluvial sands and gravels, although some short eskers and other ice-contact deposits may be included.

The Plbd deposits are grouped into four morphosequences based on their elevations. Unit $Plbd_1$ reaches an elevation of about 870 ft, corresponding to an early high level of glacial Lake Brownfield. Deposits of this stage of the lake occur in the upper reach of Cole Brook valley in the southwestern part of the quadrangle. The larger hills that protrude above $Plbd_1$ lake levels exhibit characteristics of hummocky and bouldery moraine, with extensive areas of thin drift cover. The lake level in $Plbd_1$ time was controlled by a spillway at about 865 ft, located 1.3 mi (2.1 km) south of New Boston on the southern boundary of the quadrangle. Unit $Plbd_1$ is not very extensive because ice retreat quickly opened lower lake spillways to the northeast and northwest.

Unit $Plbd_2$ was graded to an intermediate level of glacial Lake Brownfield. Deltaic deposits of this stage of the lake occur in the middle reaches of Linscott Brook and Cole Brook valleys, and the upper reach of Quint Brook valley. Topographic relief of the erosionally dissected $Plbd_2$ unit is greater (and deposits probably are thicker) than those of unit $Plbd_1$. Gently sloping delta tops at elevations of about 830 ft approximate the water level during this stage of glacial Lake Brownfield. The lower lake level in $Plbd_2$ time was a response to northward ice-margin recession, which caused the lake outlet to shift from the $Plbd_1$ spillway to a spillway at about 830 ft, located 1.2 mi (1.9 km) southeast of New Boston. Soon thereafter, Lake Brownfield probably drained through slightly lower spillways at about 815 and 810 ft near "Sugarloaf." However, any deltaic deposits that may have formed contemporaneously with the 815 or 810-ft water levels are not sufficiently distinct to map separately from unit $Plbd_2$.

Unit $Plbd_3$ corresponds to a lower intermediate level of glacial Lake Brownfield. Deposits of this stage of the lake occur in the Cole, Quint, and Billy Brook valleys, and in the upper part of the Shepards River valley. The lower lake level in $Plbd_3$ time was a response to continued ice recession to the north, which allowed meltwater to drain westward through a spillway at about 730 ft, located at the head of Snow Brook in the eastern part of the Conway (N.H.) 7.5-minute quadrangle (see also Newton, 1974). Deltaic deposits with upper surfaces between about 710 and 730 ft elevations probably mark the former level of this lake stage.

Unit $Plbd_4$ reaches elevations up to about 630 ft, corresponding to the lowest level of glacial Lake Brownfield. Deposits of this stage of the lake occur in the Shepards River valley and lower reaches of Cole and Quint Brook valleys, where there are graded surfaces reaching 620-630 ft elevations. When unit $Plbd_4$ was deposited, the lake drained eastward through a prominent spillway at about the 630-ft elevation (east of Merrill Corner), into the lower reach of present-day Billy Brook valley.

Billy Brook Valley Deposits (Plby)

Unit Plby represents a short-lived, isolated proglacial lake that drained westward through a spillway at about 770 ft elevation, from present-day Billy Brook valley to Quint Brook valley. This small lake existed only as long as glacial ice blocked the northern part of Billy Brook valley to such an extent that the proglacial lake could not yet merge with Lake Brownfield. Drainage from the lake cut a channel into the till-mantled hillside east of Quint Brook and deposited coarse deltaic sand and gravel (exposed near Blake cemetery) into the $Plbd_3$ stage of Lake Brownfield.

Shepards River Valley Deposits (Pgs_{1-2})

Recession of the glacier margin into the northern part of the quadrangle caused glacial Lake Brownfield to drain completely as meltwater escaped eastward down the Shepards River valley. Units Pgs_1 and Pgs_2 were deposited in the Shepards valley, probably when the ice margin stood near Tibbetts Mtn. a short distance to the north. These units consist of sand and gravel deposits that may have formed in two environments. Fluvial outwash could have accumulated where meltwater drained freely down the valley, while local ponding by remnant ice may have led to deposition of lacustrine deltas. The origin of the Pgs deposits is unclear in many places because of limited exposure.

The Pgs_1 deposits were built to levels as high as 550 ft, and probably accumulated among remnant ice masses that still occupied part of the Shepards River valley. Many kettles are seen in the ice-contact Pgs_1 deposits south of Tibbetts Mtn. Subsequently, the Pgs_2 sediments were deposited at elevations of 520 ft and below. Part of this drainage lay to the south of the modern river course, as indicated by the abandoned channels at 510 and 490 ft.

Glacial Lake Marston Deposits (Plmad)

As the ice margin receded northward from Tibbetts Mtn., meltwater was ponded between higher terrain to the west and the ice lobe that remained in the Saco River valley. A glacial lake formed along the west side of the Saco Valley and spilled south through the 495-ft gap just southeast of Tibbetts Mtn. This water body is named glacial Lake Marston, after Marston Cemetery (the only landmark shown in this part of the Brownfield topographic map). Unit Plmad probably consists mainly of deltaic sand and gravel that washed into the ice-marginal lake.

Lake Pigwacket Deposits

Thick deposits of lacustrine sand, gravel, and silt are widespread in the Saco River valley, and extend from Great Falls in the north-central part of the Cornish quadrangle, upvalley through the Brownfield and Fryeburg quadrangles, and into the Conway area of New Hampshire. The large lake, or succession of lakes, in which these sediments were deposited has been named "Lake Pigwacket" by Thompson (1999a,b). The lake was named in honor of the Pigwacket band of Abenaki Indians, who were early inhabitants of the upper Saco River valley (Calloway and Porter, 1989).

Some earlier Lake Pigwacket deposits formed in ice-contact glacial lakes, but the lake system persisted into postglacial time in the Fryeburg area. Plant remains recovered from test borings in lake sediments near Fryeburg village were found to have radiocarbon ages 11,680 to 11,255 yr B.P. (Thompson, 1999a,b). Lake Pigwacket deposits in the Brownfield quadrangle have not been dated, but some of them also may be postglacial in age.

Oak Hill Stage Deposits (Plpo)

Unit Plpo was initially recognized as deposits of sand and gravel banked against the west side of Oak Hill, near the south edge of the Fryeburg quadrangle. Here the deposit reaches an elevation of about 480 ft and forms a hillside terrace, the upper surface of which slopes gently to the west. The unit ranges in texture from sand to boulder gravel, and also includes lenses of silt. Fluvial cross bedding occurs throughout this unit, and suggests deposition by streams flowing in a general southward direction. The morphology and position of the deposit are typical of kame terraces, which are built between hillsides and residual masses of glacial ice in adjacent valleys. Silt lenses also suggest that there was intermittent small-scale ponding of meltwater. Presence of locally collapsed bedding and scattered large stones suggest proximity to glacial ice.

In the Brownfield quadrangle, unit Plpo deposits occur as extensive sand plains between about 440 and 450 ft near the Eastern Slopes Regional Airport west of Lovewell Pond. The unit steadily decreases in elevation to the south, reaching about 410 - 420 ft where it terminates against the slightly lower Saco River flood plain. The uniformly gently sloping topography in this area suggests that stagnant ice masses were less common than in the headward part of unit Plpo in the Fryeburg quadrangle.

Deposits of the Oak Hill stage are a fine example of a "morphosequence" (Koteff and Pessl, 1981), which is a contemporaneous set of water-laid glacial sediments that originated at or near the glacier margin and were transported by meltwater streams controlled by a common base level, such as the sea or a lake. Unit Plpo includes a "head of outwash" at the near-ice end, which marks a temporary position of the retreating glacier margin in the valley west of Oak Hill near the south border of the Fryeburg quadrangle (Thompson, 1999a,b). The streams that deposited this morphosequence flowed into Lake Pigwacket in the Saco River valley southeast of Lovewell Pond. Thus, Thompson (1999a,b) correlated this unit with the Oak Hill stage of Lake Pigwacket, although the headward part of the unit was deposited upstream from the lake.

Undifferentiated Lake Pigwacket Deposits (Plp)

Many Lake Pigwacket deposits in the Brownfield quadrangle have flat upper surfaces at elevations between about 400 and 420 ft (Unit Plp). The Pine Grove Cemetery just east of Brownfield village offers a fine view of at least two, and perhaps three, terraces of a large delta deposited into glacial Lake Pigwacket. This glaciolacustrine delta extends almost 2 mi (3.2 km) southwest from the Saco River between Shepards River and Burnt Meadow Brook. The delta generally lies above the 400 ft contour, but terraces at the cemetery occur between about 420 and 435 ft, whereas a terrace along the Saco River to the northeast lies at about 380 ft. The elevations of stream-graded surfaces in this area suggest that meltwater flowed from west to east.

On the west side of Route 160, about 0.2 mi (0.3 km) north of Burnt Meadow Pond, the town of Brownfield owns an active gravel pit. During October, 1994, excellent exposures at the south end of the pit exhibited about a 20 ft (6 m) thickness of foreset beds of coarse sand and gravel with dips of about 20^{o} in a generally southeastward direction. About a 3 ft (1 m) thickness of topset beds composed of pebble-cobble gravel were exhibited in other parts of the pit. The elevation of the topset-foreset contact was about 420 ft, though this contact was not clearly exposed. During early April, 1995, all exposures were very slumped, thus foreset beds were barely visible. Nevertheless, the pit is believed to exhibit sediments of an upper delta facies, following the nomenclature of Ashley and others (1982, 1985), that were deposited into glacial Lake Pigwacket.

A former lake level of about 420 to 430 ft, as indicated by the terraces at the cemetery and the exposures of deltaic sediments in the Brownfield town pit, is lower than the lake level indicated by deposits from the Pleasant Mountain stage of Lake Pigwacket to the northeast of here (Thompson, 1999c,d), and probably reflects a drop in lake surface when ice obstructions melted in the Saco River valley and/or the drift dam at Hiram Fall was downcut.

Lake-Bottom Deposits (Plpb)

Fine-grained, silty to sandy deposits of Lake Pigwacket were exposed in the Barrett pit on the east side of Route 5/113, about 0.4 mi (0.6 km) north of the major junction at East Brownfield. This pit has been partly backfilled, but excellent exposures of mid-delta and lower-delta foresets, following the nomenclature of Ashley and others (1982, 1985), may still be seen in the remaining 10-ft (3 m) high exposure on the north side of the pit. The top of this section (original ground surface) has an elevation of about 380 ft. The exposure along the north wall of the pit exhibits all three types of climbing ripple-drift described by Ashley and others (1982, 1985) as indicative of mid-delta and lower delta facies.

Type A ripples exhibit stoss-side laminae that have been eroded by rapidly migrating ripples with low vertical aggradation, whereas Type B ripples exhibit stoss-lee laminae that are preserved from slowly migrating ripples with high vertical aggradation during a waning flow. Draped laminations are formed when ripple migration ceases and finer-grained sediment falls from suspension. The sediments in the Barrett pit mostly consist of fine sand and silt, although coarser sand and clay layers are also present. The variety of ripple types suggests variable meltwater discharge into a lake. Flume experiments by Ashley and others (1982) suggest that such ripple sequences may form very rapidly (i.e., in a few hours), thus many flow events are possible within one season. The direction of ripple climb is about N45E to about N55E, so the flow into glacial Lake Pigwacket at this location was from the southwest. Loading and dewatering structures are also common in the pit exposures.

Glacial Lake Tenmile Deposits (Plt_{1-2})

Tenmile River originates at Clemons Pond and flows north in the southeasternmost part of the Brownfield quadrangle. During the early stages of glacial retreat from this area, a broad tongue of ice receding northward in the Saco River valley initially blocked the lower part of the Tenmile River valley in the southwestern part of the adjacent Hiram quadrangle. This impoundment of meltwater drainage formed a water body named "glacial Lake Tenmile" (Thompson and Holland, 1999a,b), which is discussed below in the section on glacial history.

The sediments deposited into the two stages of Lake Tenmile (map units Plt_1 and Plt_2) mostly consist of deltaic sand and gravel, although some short eskers and other fluvial deposits may be included. Unit Plt formed in contact with decaying ice masses, as shown by numerous swamps, kettles, ice-contact slopes, and knobby topography. Some of the larger hills that protrude above the glacial Lake Tenmile deposits exhibit characteristics of hummocky moraine. Topographic relief of the Plt deposits indicates that the lake sediments are up to about 50 ft (15 m) thick.

The Plt deposits are grouped into two morphosequences based on their elevations. Unit Plt_1 reaches elevations up to about 480 ft, corresponding to an early high level of glacial Lake Tenmile. Deposits of this stage of the lake extend from the northeastern part of the Kezar Falls quadrangle, across the southeastern part of the Brownfield quadrangle, and east into the Hiram quadrangle. The lake level in Plt_1 time was controlled by a spillway through a rock-walled ravine on the drainage divide between Little Clemons Pond and Jaybird Pond in the northeastern part of the Kezar Falls quadrangle.

Unit Plt_2 deposits have upper surfaces that reach about 440 ft, indicating a lower lake level than that for unit Plt_1. The water level fell to this elevation when ice retreat opened a lower spillway for glacial Lake Tenmile. The probable new outlet was the meltwater channel in the gap trending east-west, located 1.0 mi (1.6 km) south of Pequawket Pond in the Hiram quadrangle (Thompson and Holland, 1999a,b). Exposures of deltas built into the low stage of the Lake Tenmile can be seen in gravel pits in Unit Plt_2 adjacent to Route 5/113 in the Hiram quadrangle.

Stream Terrace Deposits

Lake Pigwacket sediments have been partly eroded as the postglacial Saco River cut down to its present level. This downcutting produced terraces along the river at intermediate elevations between the original glaciolacustrine delta tops and the modern flood plain. The material underlying the terraces consists of sand and gravel. At depth these sediments may be largely the remains of Lake Pigwacket deposits, but they are capped by postglacial river alluvium. The Saco River terraces are not morphologically very distinct from the Lake Pigwacket deposits, and thus have not been mapped separately here, but it is likely that at least some of the Plp surfaces between 370 and 390 ft in the East Brownfield area have been terraced by the Saco River.

Eolian Deposits (Qe)

Near the northwest corner of the quadrangle, there are deposits of eolian (windblown) sand (unit Qe). This sand was derived from the nearby Saco River valley, having been blown up onto the downwind (southeast) side of the valley in late-glacial and/or postglacial time. Extensive dunes and sheet deposits of eolian sand occur in the adjacent Fryeburg quadrangle to the north of here (Thompson, 1999a,b). Patchy deposits of this unit probably occur elsewhere in the Brownfield quadrangle, but they may not be easily distinguished from associated water-laid sands.

Talus Deposits (Qta)

Rock fragments found at the foot of steep slopes and cliffs are known as talus deposits (unit Qta). Angular blocks found at the foot of bedrock cliffs suggest a rockfall origin, commonly the result of freeze-thaw processes or heavy rainstorms that release the blocks. Numerous talus deposits occur on south-facing slopes beneath bedrock cliffs in the Burnt Meadow Mountains in the southeastern part of the Brownfield quadrangle.

Beach Deposits

Sandy to gravelly beaches on modern Maine lakes generally are formed by waves and currents that rework nearby glacial deposits, which provide a source for easily eroded sediment to nourish the beaches. These beaches are not always differentiated on surficial geologic maps, because they may be very small or grouped with adjacent sand and gravel deposits of glacial origin. Beach deposits are found bordering Plp deposits along the southwest shoreline of Lovewell Pond, but they are too small to show separately on the geologic map.

Wetland Deposits (Hw)

Unit Hw consists of fine-grained and organic-rich sediments deposited in low, flat, poorly drained areas. In the Brownfield quadrangle this unit occurs along streams and in small upland basins. The boundaries of unit Hw were mapped primarily from aerial photographs, thus are only approximately located and should not be used rigorously for land-use zoning. The distinction between "wetland" and "stream alluvium" in the Saco River valley is usually subtle and arbitrary. Therefore, the Saco River flood plain is shown almost entirely as alluvium (unit Ha) on the geologic map, because it is presumed to be underlain largely by inorganic sediments deposited by floods. However, large parts of the alluvial unit are poorly drained and may have vegetation typical of wetlands, as suggested by the marsh-grass pattern printed on the topographic map.

Stream Alluvium (Ha)

Extensive alluvial deposits (Unit Ha) have accumulated during postglacial time on the flood plains of the Saco River and its tributaries. Most of these deposits consist of fine-grained sediments and organic material that have been carried by floods onto the low, flat areas next to stream channels. Numerous test borings in the Saco River flood plain near Fryeburg show that the alluvium is commonly up to 20 ft (6 m) thick (Thompson, 1999a,b), so deposits of comparable thickness are presumed to exist in the Brownfield quadrangle.

Along the Saco River, the alluvium forms sizable ridges (natural levees) where sediment has piled up adjacent to the riverbanks. Excellent examples of such levees occur southeast of Route 160 in the northeast part of the quadrangle. In the extensive flood plain of the Saco River south of Lovewell Pond, there are also numerous oxbow lakes of various shapes and sizes, commonly exhibiting intervening levees. A classic "lake-outlet delta," described by Caldwell and others (1989), is located at the south end of Lovewell Pond. This delta is the result of repeated flooding of the Saco River, during which the flood waters back up into Lovewell Pond and alluvial sediment discharges into the pond at what is normally its outlet! Water levels in Lovewell Pond fluctuate greatly during flood periods.

GLACIAL AND POSTGLACIAL GEOLOGIC HISTORY

The following reconstruction of the Quaternary history of the Brownfield quadrangle is based on the interpretations of surficial earth materials described in this report, as well as reports for adjacent quadrangles, together with glacial landforms and ice-flow indicators. Thus, our understanding of the glacial history of this part of Maine continues to improve as additional quadrangle maps are completed.

Glaciation History

We do not know how many episodes of glaciation have affected the Brownfield area during the Quaternary. However, the record preserved in deep-sea sediment cores and polar ice cores suggest that the world has undergone numerous glacial and interglacial cycles over the past 2.5 million years. Till deposits in southwestern Maine record the most recent (late Wisconsinan) glaciation, and probably also one earlier glacial event. A deeply weathered till found elsewhere in central and southern New England also has been recognized in southern and central Maine (Thompson and Borns, 1985b; Weddle and others, 1989; Weddle, 1992).

Data summarized by Stone and Borns (1986) indicate that the late Wisconsinan Laurentide Ice Sheet expanded south from Canada and spread across Maine about 25,000 years ago. Over the next 10,000 years, the ice sheet continued to flow across the state and reshape the landscape by eroding, transporting, and depositing tremendous quantities of sediment and rock debris. The combined effects of erosion and deposition have provided a streamlined shape to many hills. Hills in southwestern Maine typically have long axes parallel to the south-southeastward flow of the ice. This "landscape fabric" is evident in the shape of hills throughout the Brownfield quadrangle. Also, glacial plucking on the summits and lee sides of many hills formed steep southeast-facing slopes and cliffs. Examples include the Whales Back in the southwest; Burnt Meadow Mountain in the southeast; Tibbetts, Peary, and Frost Mountains in the middle; and Bald Peak in the northwest part of the quadrangle. The late Wisconsinan glaciation not only produced the stony till deposits that blanket the upland areas of the quadrangle, but also scattered boulders in the direction of glacial transport, with many dumped in areas of hummocky moraine (Phm) when the ice melted.

Rock debris dragged at the base of the ice sheet polished and striated the underlying bedrock surfaces. Striations are not easily recognized in the Brownfield quadrangle because they are either concealed beneath surficial sediment cover, or commonly have been destroyed by weathering where the coarse-grained bedrock is exposed at the ground surface, or were not formed in the first place because of the coarseness or hardness of the bedrock. The best places to find striations are on ledge surfaces where the sediment cover only recently has been scraped off, such as along logging roads or where other excavations have reached bedrock. On glacially smoothed outcrops of coarse granite (e.g. pegmatite), fine striations may be revealed by rubbing a soft pencil across the rock surface perpendicular to the general iceflow direction.

Striations were found at only two locations in the Brownfield quadrangle. A 166^o direction was measured from microstriations on a quartz vein in a bedrock outcrop on the east side of Route 160 and Durgin Brook, opposite the 424-ft benchmark in the southeastern part of the quadrangle. On the top of Long Hill in the northwestern part of the quadrangle, a 155^o striation direction was measured by pencil rubbings of quartz blebs in pegmatitic granite. These two measurements are in general agreement with striation trends in adjacent quadrangles, where ice-flow directions ranging from southeast to south-southwest have been recorded.

Azimuths in the range of 145-165^o in southwestern Maine, together with streamlined hills having a similar trend, are presumed to be the product of the main phase of the most recent (late Wisconsinan) glaciation. Where multiple striation sets have been recorded, and where their relative ages can be determined, the more southerly striations (170-190^o) usually are younger than the 145-165^o striations. This later southward ice flow is believed to have been a late-glacial event resulting from reorganization of ice divides as the ice sheet thinned and receded across southwestern Maine (Thompson, 1991, 1995).

Because of the hydrostatic head required to maintain the Shepards River - Cole Brook esker system, which extends over 7.5 mi (12 km) and nearly the length of the west side of the Brownfield quadrangle, this esker was probably formed during an early phase of deglaciation when ice was still thick. Elsewhere in the quadrangle, smaller eskers and other ice-contact stratified deposits in valleys were probably formed later when ice had thinned. This two-stage model for deposition of ice-contact stratified drift is similar to one proposed by Goldthwait and Mickelson (1982) for deglaciation of the White Mountains in New Hampshire, although they did not recognize morphosequences as indicators of systematic recession of the ice margin.

Recession of the Last Ice Sheet

Radiocarbon ages from fossil mollusks in glaciomarine sediments in Maine indicate that during the waning phase of the late Wisconsinan ice sheet, the ice margin receded into central Maine by about 13,000 ^{14}C years ago (Thompson and Borns, 1985a,b; Anderson and others, 1992). The actual calendar ages for these late-glacial events are perhaps as much as 2000 years older than the radiocarbon ages (Bartlein and others, 1995); however, for the purpose of this report, all ages discussed are in radiocarbon years. The Brownfield quadrangle was probably deglaciated about 13,500 ^{14}C years ago, although isolated masses of stagnant ice may have lingered in valleys. The Saco River valley was certainly ice-free by 12,000 ^{14}C years ago, based on dated plant remains obtained from borings in Lake Pigwacket sediments in Fryeburg (Thompson, 1999a,b). A site with potential for future sediment coring to provide minimum-limiting radiocarbon ages for deglaciation in the area would be Clemons Pond, at an elevation of 401 ft, in the Tenmile River valley in the southeast corner of the quadrangle.

In coastal Maine, it is possible to trace ice sheet retreat in detail because there are hundreds of end moraine segments, submarine fans, and deltas that were deposited at the margin of the ice sheet during recession in a marine environment. End moraines are relatively uncommon in the interior of southwestern Maine, but the few that have been found in quadrangles adjacent to the Brownfield quadrangle are useful in reconstructing the pattern of deglaciation. The ice-contact sand and gravel deposits left by meltwater steams flowing into glacial lakes provide further clues to the history of ice retreat from the study area. Also, ice-marginal meltwater channels, which are common in the Brownfield and adjacent quadrangles, are useful for locating former positions of the receding glacier margin. These types of evidence were used to infer the ice-margin positions shown on the geologic map.

As the ice sheet began to thin and recede from the western part of the Brownfield quadrangle, a series of ice-marginal lakes formed in the Shepards River, Cole Brook, Quint Brook, and Paine Brook valleys. The stages of these lakes, including glacial Lake Brownfield, were controlled by a series of spillways that formed as the ice sheet receded from the area. Glacial Lake Brownfield initially drained to the south, then westward, and finally to the east through a series of spillways west and north of the Burnt Meadow Mountains in the southwestern part of the quadrangle.

When glacial Lake Brownfield was at its highest level (about 865 ft) the ice margin probably stood briefly at the $Plbd_1$ position shown on the geologic map, and the lake drained through the spillway at the south edge of the quadrangle. Subsequent retreat of the ice margin to about the $Plbd_2$ position allowed this lake to drain to the southeast, initially through the 830-ft spillway southeast of New Boston, and later through the spillways at about 815 and 810 ft near the hill called Sugarloaf. There is evidence of torrential meltwater drainage through the 810-ft outlet. One of the authors of this report (W. R. Holland) discovered a relict plunge pool at the east end of this spillway, marking the former location of a powerful waterfall.

Further retreat of the ice margin to the $Plbd_3$ position allowed Lake Brownfield to drain westward through a spillway at about 730 ft in the Conway, New Hampshire quadrangle. The final stage of Lake Brownfield was dammed by the $Plbd_4$ ice margin, which resulted in eastward drainage through the 630 ft spillway near Merrill Corner.

When the ice sheet margin receded to approximately the Pgs position in the northern part of the Brownfield quadrangle, meltwater probably drained south through gaps in the hills in the Tibbetts Mtn. area and thence down the Shepards River valley. This drainage formed the Pgs_{1-2} sediments in the Shepards valley. A short time later, meltwater was ponded against the Plmad ice margin on the west side of the Saco River valley, forming glacial Lake Marston, and the deltaic Plmad unit was deposited into this small water body.

While the above sequence of sand and gravel deposits was forming in the western half of the quandrangle, Lake Pigwacket was expanding up the Saco River valley as the glacier receded. This lake system ultimately reached far up the valley to Bartlett, New Hampshire. The lake was impounded behind a thick accumulation of glacial debris, mostly sand and gravel, that plugged the narrow part of the valley near Great Falls in the north-central part of the Cornish quadrangle to the east. Much glaciolacustrine deltaic sediment (Unit Plp) was deposited into Lake Pigwacket in the Brownfield quadrangle, and one spectacularly large delta occurs in a triangular area between Brownfield, East Brownfield, and Burnt Meadow Pond.

At the same time that Lake Pigwacket was expanding up the Saco River valley in contact with the receding ice sheet, a smaller glacial lake developed in the Tenmile River valley (a tributary to the Saco valley), in the southeastern part of the quadrangle. Glacial Lake Tenmile was ponded against the western part of an ice tongue that occupied the Saco valley. The lake initially drained southwestward through a spillway in the northeastern part of the Kezar Falls quadrangle, with the outflow reaching the Ossipee River at South Hiram. At this time, the ice margin that held the lake at the higher (480 ft) level probably stood at the Plt_1 position shown on both the Brownfield and Hiram surficial geologic maps (Thompson and Holland, 1999a,b). Subsequent retreat of the ice margin to the Plt_2 position allowed glacial Lake Tenmile to drain eastward into the Saco River valley at a level of about 440 ft, an elevation only slightly higher than Lake Pigwacket. Thus, these two lakes soon merged when the ice margin withdrew from the Plt_2 position.

Postglacial History

At some point during late-glacial or early postglacial time, the part of Lake Pigwacket in the Brownfield and Hiram quadrangles either completely filled with sediment and/or drained in response to erosion of the drift dam at Great Falls. The Saco River valley is relatively wide in the Brownfield and Fryeburg quadrangles compared to its narrow width in the Hiram quadrangle. Quite likely the part of Lake Pigwacket in the Brownfield area remained open water as the valley became choked with glacial meltwater sediments in the Hiram quadrangle.

Breaching of the Great Falls debris dam, together with crustal uplift in response to deglaciation, helped establish the postglacial Saco River on the former bed of Lake Pigwacket. This erosional process is recorded by stream terraces that were carved in the Lake Pigwacket deposits as the river cut down through them. There is also a clear record of lowering base level in the form of channels and terraces cut into the broad Lake Pigwacket delta in the east-central part of the Brownfield quadrangle.

Sedimentation continues today on the flood plains of modern streams. Organic-rich deposits have accumulated in wetlands and on lake bottoms throughout postglacial time.

Economic Geology

Sand and gravel deposits are abundant in the Brownfield quadrangle. The largest volumes of sand and gravel are concentrated in lowland areas, including the Tenmile River and Burnt Meadow Brook valleys in the east, the Shepards River valley across the central portion of the quadrangle (especially between Brownfield and East Brownfield), the sand plains between Lovewell Pond and Peary Mountain in the north-central portion of the quadrangle, and the esker system and glacial Lake Brownfield deposits in the Cole Brook valley and its tributaries. Numerous borrow pits already exist in these areas; however, many of them were inactive when the quadrangle was mapped.

Gravel is most likely to be found in the cores of esker ridges (map unit Pge), the upper and northern parts of glaciolacustrine deltas (units Plbd, Plmad, Plt, and Plp), and ice-contact deposits (units Pgi and Pgs). The bulk of the deltas, beneath the usual surface layer of fluvial gravel, is most likely to consist of large amounts of sand. Some of the loose, sandy till deposits (unit Pt) compact well, and are good fill material. Given proper drainage conditions, till deposits in the quadrangle should be suitable for domestic leach fields.

Most surficial materials in the quadrangle should be fairly easy to excavate, except for areas with numerous large boulders (unit Phm and some Pt deposits) or occurrences of dense lodge-ment till ("hardpan"). Areas indicated with the thin-drift pattern on the geologic map generally have much bedrock exposure and commonly only a thin cover of surficial sediments on top of the bedrock, which could be problematic for drainage and domestic leach fields.

The extensive, relatively flat sand plains to the south of the Eastern Slope Regional Airport in the north-central portion of the quadrangle would be suitable for development of a larger airport to serve the North Conway area in New Hampshire. However, the extensive wetlands surrounding the Saco River south of Lovewell Pond to the east provide excellent wildlife habitat, especially for birds, which might be incompatible with airport expansion.

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APPENDIX A: GLOSSARY OF GEOLOGIC TERMS THAT MAY APPEAR IN THIS REPORT.

Ablation till: till deposit formed by release of debris from melting glacial ice, accompanied by variable amounts of slumping and meltwater action. May be loose and stony, and contain lenses of washed sand and gravel.

Basal melt-out till: till deposit resulting from melting of debris-rich ice in the bottom part of a glacier. Generally shows crude stratification from included sand and gravel lenses.

Clast: pebble-, cobble-, or boulder-size fragment of rock or other material in a finer-grained matrix (q.v.). Commonly refers to stones in glacial till or coarse-grained water-laid sediments.

Clast-supported: refers to sediment that consists mostly or entirely of clasts, generally with more than 40% clasts. Usually the clasts are in contact with one another. For example, a well-sorted cobble gravel.

Delta: a body of sand and gravel deposited where a stream enters a lake or ocean and drops its sediment load. Glacially deposited deltas in Maine usually consist of two parts: (1) coarse, horizontal, usually gravelly topset beds deposited in stream channels on the flat delta top, and (2) underlying, finer-grained, inclined foreset beds deposited on the advancing delta front.

Deposit: general term for any accumulation of sediment, rocks, or other earth materials.

Diamicton: any poorly-sorted sediment, containing a wide range of particle sizes.

Drumlin: an oval-shaped hill, often composed of glacial sediments, that has been shaped by the flow of glacial ice, such that its long axis is parallel to the direction of ice flow.

End moraine: a ridge of sediment deposited at the margin of a glacier. Usually consists of till and/or sand and gravel in various proportions.

Englacial: occurring or formed within glacial ice.

Eolian: formed by wind action, such as a sand dune.

Esker: a ridge of sand and gravel deposited by meltwater streams in a tunnel within or beneath glacial ice.

Fluvial: Formed by running water, for example by meltwater streams discharging from a glacier.

Glaciolacustrine: refers to sediments or processes involving a lake that received meltwater from glacial ice.

Glaciomarine: refers to sediments and processes related to the environment where marine water and glacial ice are in contact.

Holocene: term for the time period from 10,000 years ago to the present. It is often used synonymously with “postglacial” because most of New England has been free of glacial ice since that time.

Ice-contact: refers to any sedimentary deposit or other feature that formed adjacent to glacial ice. Many such deposits show irregular topography due to melting of the ice against which they were laid down, and resulting collapse.

Kettle: a depression on the ground surface, ranging in outline from circular to very irregular, left by the melting of a mass of glacial ice that had been surrounded by glacial sediments. Many kettles now contain ponds or wetlands.

Lacustrine: pertaining to a lake.

Late glacial: refers to the time when the most recent continental ice sheet was receding from Maine, approximately 15,000-10,000 years ago.

Late Wisconsinan: the most recent part of Pleistocene time, during which the latest continental ice sheet covered all or portions of New England (approx. 25,000 - l0,000 years ago).

Lodgement till: very dense variety of till, deposited beneath flowing glacial ice. May be known locally as “hardpan.”

Matrix: the fine-grained material, generally silt and sand, which comprises the bulk of many sediments and may contain clasts (q.v.).

Matrix-supported: refers to any sediment that consists mostly or entirely of a fine-grained component such as silt or sand. Generally contains less than 20-30% clasts, which are not in contact with one another. For example, a fine sand with scattered pebbles.

Moraine: General term for glacially deposited sediment, but often used as short form of "end moraine" (q.v.).

Morphosequence: a group of water-laid glacial deposits (often consisting of sand and gravel) that were deposited more-or-less at the same time by meltwater streams issuing from a particular position of a glacier margin. The depositional pattern of each morphosequence was usually controlled by a local base level, such as a lake level, to which the sediments were transported.

Pleistocene: term for the time period between 2-3 million years ago and 10,000 years ago, during which there were several glaciations. Also called the "Ice Age."

Proglacial: occurring or formed in front of a glacier.

Quaternary: term for the period of time between 2-3 million years ago and the present. Includes both the Pleistocene and Holocene.

Striation: a narrow scratch on bedrock or a stone, produced by the abrasive action of debris-laden glacial ice.

Subaqueous fan: a somewhat fan-shaped deposit of sand and gravel that was formed by meltwater streams entering a lake or ocean at the margin of a glacier. Similar to a delta (q.v.), but was not built up to the water surface.

Subglacial: occurring or formed beneath a glacier.

Till: a heterogeneous, usually non-stratified sediment deposited directly from glacial ice. Particle size may range from clay through silt, sand, and gravel to large boulders.

Topset/foreset contact: the more-or-less horizontal boundary between topset and foreset beds in a delta (q.v.). This boundary closely approximates the water level of the lake or ocean into which the delta was built.

APPENDIX B.
LOGS OF PIT EXPOSURES IN THE BROWNFIELD 7.5-MINUTE QUADRANGLE

These field observations were initially recorded by W. R. Holland during 1983 (dates recorded below), and field checked by P. T. Davis in 1994 and 1995. Many of Holland's paleocurrent measurements listed here could not be replicated in 1994-95 because of slumping and other changes during the intervening years. Refer to (Davis, 1998) for pit locations.

PIT #: B-1
Location: off Rte 113 N of E Brownfield
Date: 7/12/83
Dominant textures: s,st
Water present in pit? slightly, on pit floor
Total exposure thickness: 15'
Is pit active? no; pit backfilled and leveled for warehouse built in 1994-95
Landform exposed: terrace
Stratigraphy: 8' uniform f-med sands, 6' beds/interbedded fine sands and laminated silts
Bedforms: climbing ripple drift in sand units, lamination in silts
Paleocurrents: angle of ripples climb = 12S45E; 10S54E
Environment of deposition: shallow lacustrine or very deep fluvial
Structures: none seen
Dominant cobble lithology: na
Permeability of deposits: low to very low

PIT #: B-2
Location: E of Clemons Pond Rd, N of Clemons Pond
Date: 7/23/83
Dominant textures: s,p,c
Water present in pit? no
Total exposure thickness: 8'
Is pit active? no
Landform exposed: terrace, either valley train or deltaic
Stratigraphy: 2' pbly gr (fluvial trough x-sets)/ 6' sand; appears to be a delta but exposure insufficient to substantiate
Bedforms: gravels troughed; sands planar
Paleocurrents: 25N62E
Environment of deposition: deltaic; either shallow lacustrine or deep water fluvial; mod. close to ice
Structures: none seen
Dominant cobble lithology: granite, schist
Permeability of deposits: moderate

PIT #: B-3
Location: just N of B-2
Date: 7/23/83
Dominant textures: s,p,c
Water present in pit? no
Total exposure thickness: 15'
Is pit active? no
Landform exposed: 440' terrace or delta
Stratigraphy: 3' pbly-cbly sand (fluvial)/12' sand
Bedforms: sand beds tabular, minor x-beds (lobation cut and fill?)
Paleocurrents: none measured
Environment of deposition: deltaic; shallow lake or deep water fluvial
Structures: none seen
Dominant cobble lithology: granite, schist, sandstone(?)
Permeability of deposits: moderate to high

PIT #: B-4
Location: off Porterfield Rd, N of W Branch, Tenmile River
Date: 7/23/83
Dominant textures: s,p
Water present in pit? no
Total exposure thickness: 10'
Is pit active? no
Landform exposed: 480' terrace
Stratigraphy: 2' pbly med-crse sand/8' sand
Bedforms: fluvial sands over foresets; but poorly exposed, so entire section may be fluvial
Paleocurrents: none measured
Environment of deposition: shallow lacustrine or deep water fluvial
Structures: none seen
Dominant cobble lithology: na
Permeability of deposits: moderate to high

PIT #: B-5
Location: 0.1 mi N of Porterfield on W Branch Rd
Date: 7/23/83
Dominant textures: s,p,c
Water present in pit? no
Total exposure thickness: 7'
Is pit active? no
Landform exposed: 540+' ice-contact terrace
Stratigraphy: slumped; very bad exposure; appears to be uniform gr sand
Bedforms: none seen

Paleocurrents: none measured
Environment of deposition: presumably fluvial
Structures: none seen
Dominant cobble lithology: granite, Littleton schist
Permeability of deposits: moderate to high

PIT #: B-6
Location: behind Wally's General Store, at jct Rtes. 5/113 and 160
Date: 8/4/83
Dominant textures: s,p, minor silt
Water present in pit? no
Total exposure thickness: 11'
Is pit active? yes (no, 10/10/94)
Landform exposed: fluvial plain
Stratigraphy: 3' interbedded sands & pbly gr/8' interbedded pbly sand and sand (c.2" thick); silts interbedded occ. (c.4" thick) at bottom of upper unit
Bedforms: planar set boundaries, thin x sets (c.2" thick), w/ tangential contacts, rhythmically bedded sand and pbly gr
Paleocurrents: 21S30E
Environment of deposition: shallow fluvial (?)
Structures: none seen
Dominant cobble lithology: na
Permeability of deposits: low to moderate

PIT #: B-7
Location: off Peat Pond Rd, S of Bold Brook, near jct. w/ Haley Brook
Date: 8/6/83
Dominant textures: c-b
Water present in pit? no
Total exposure thickness: 16'
Is pit active? yes (no, 10/10/94)
Landform exposed: kame or esker segment
Stratigraphy: very immature cobble to boulder gr; very sharp textural break between materials exposed here and those exposed across road, to E (fine sands)
Bedforms: none seen
Paleocurrents: none measured
Environment of deposition: ice-contact; englacial
Structures: none seen
Dominant cobble lithology: nearly 100% granite
Permeability of deposits: high to very high

PIT #: B-8
Location: N of Tibbetts Mtn, S of Paine Brook
Date: 8/6/83
Dominant textures: s; c-b,s,p
Water present in pit? no
Total exposure thickness: c.17'
Is pit active? yes, in places
Landform exposed: terrace
Stratigraphy: two units exposed, although not adjacent to one another: 1) 7' sand, plane bedded (exposed NE end of pit), 2) c.10' c-b gr (exposed SW end of pit)
Bedforms: sands, tabular, foreset-like beds; gravels too coarse to see bedding
Paleocurrents: 38S29W; 26N87E
Environment of deposition: gravels likely older ice-contact; sands likely subaqueous proglacial
Structures: none seen
Dominant cobble lithology: granite, pegmatite, schist
Permeability of deposits: high

PIT #: B-9
Location: off Brownfield Rd at jct w/ Tibbetts Mtn. Rd
Date: 8/6/83
Dominant textures: s,p, minor c
Water present in pit? no
Total exposure thickness: 24'
Is pit active? no
Landform exposed: kame plateau
Stratigraphy: interbedded med-crse sand; some thin beds of p-c (c.1' thick), near top of section; general fining of textures from Tibbetts Mtn. to here
Bedforms: generally tabular set boundaries, minor long-wave climbing ripples
Paleocurrents: S63E; N90E; S55E
Environment of deposition: deep water fluvial; perhaps shallow lacustrine
Structures: beds appear to be collapsed to E; no faults
Dominant cobble lithology: na
Permeability of deposits: moderate to high

PIT #: B-10
Location: E side of Dugway Rd, 1 mi W of Stone Mtn, 1.5 mi SE of Merrill Corner
Date: 8/7/83
Dominant textures: s,p,c
Water present in pit? no
Total exposure thickness: 8'
Is pit active? yes
Landform exposed: drift tail at distal end of drumlin
Stratigraphy: 2' f-crse sand, thinly laminated/0.8' pea gr/1.5' sand/1' p-c gr/0.5 st-f sand/sand; minor boulders; all stones angular "glacial" shapes
Bedforms: tabular sets, "pseudo-foresets," open-work pea gr

Paleocurrents: "foresets" = 18N58E
Environment of deposition: may be subglacial, or perhaps meltout till, or ice-contact fluvial
Structures: na
Dominant cobble lithology: nearly 100% granite
Permeability of deposits: moderate to low

PIT #: B-11
Location: behind old Blake Homestead, about 1.3 mi S of Merrill Corner
Date: 8/7/83
Dominant textures: med-crse sand, p-c gr
Water present in pit? no
Total exposure thickness: 30Æ+
Is pit active? yes (not any longer on 10/14/94)
Landform exposed: terrace, perhaps delta
Stratigraphy: 2' pebble to cobble gr/c.28' pbly sand
Bedforms: sand "foresets," gently dipping, tabular
Paleocurrents: foresets = 11S60W; 18S30W
Environment of deposition: appears to be deltaic, although badly slumped
Structures: none seen
Dominant cobble lithology: not determined
Permeability of deposits: moderate to high

PIT #: B-12
Location: W of Rte 160, just NW of Burnt Meadow Pond
Date: 8/17/83
Dominant textures: s,p,c
Water present in pit? no
Total exposure thickness: 23'
Is pit active? yes (by town of Brownfield, 10/10/94)
Landform exposed: 420' valley train, outwash, or delta
Stratigraphy: 3' p-c gr (fluvial)/20' med-crse sl pbly sand (foresets); at SW end of pit, 3' c-b gr/sand; contacts variable
Bedforms: foresets
Paleocurrents: foresets = 19S65E; 17S27E; 15S20E
Environment of deposition: deltaic
Structures: none seen
Dominant cobble lithology: volcanics, granite, schist, sandstone
Permeability of deposits: moderate

PIT #: B-13
Location: S of Rte 160, across from Brownfield Town Hall
Date: 8/17/83
Dominant textures: s,p,c-b
Water present in pit? no
Total exposure thickness: 16'
Is pit active? yes (although no longer main town pit, 10/10/94)
Landform exposed: 460' terrace
Stratigraphy: interbedded p-c gr and sand; some boulders present; gravel clasts are angular and immature
Bedforms: planar sets in sand; pseudo-foresets c.8" thick
Paleocurrents: "pseudo-foresets" = 18S65E
Environment of deposition: near ice fluvial; kame terrace
Structures: apparently collapse along edges; no faults
Dominant cobble lithology: granite, volcanics, schist
Permeability of deposits: moderate to high

PIT #: B-14
Location: E of Linscott Brook, W of Cole Br, about 0.8 mi S of West Brownfield
Date: 8/17/83
Dominant textures: s,p,c-b, minor silt
Water present in pit? no
Total exposure thickness: c.30'
Is pit active? no
Landform exposed: esker
Stratigraphy: interbedded pbly sands (med-crse) and c-b gravel; thinly laminated fine sand-silt found in on place; silts appear to be within the deposit, but not on top of deposit
Bedforms: tabular beds at center of deposit; dipping and planar
Paleocurrents: 13N10W
Environment of deposition: englacial fluvial (lake sediments are likely very local)
Structures: none observed
Dominant cobble lithology: volcanics, granite, schist
Permeability of deposits: high

PIT #: B-15
Location: just S of B-14, woods road access, just off main road
Date: 8/17/83
Dominant textures: s,p-c,b, minor f sand-silt
Water present in pit? no
Total exposure thickness: 16'
Is pit active? no
Landform exposed: esker
Stratigraphy: interbedded bouldery pebble-cobble gravel and med-crse sand; minor fine sand and silt not apparently in place, as in B-14
Bedforms: dipping tabular sand sets at center of deposit
Paleocurrents: sands = 25N45E; 17S36E; 27N63W; 27N31W
Environment of deposition: englacial fluvial
Structures: none seen
Dominant cobble lithology: volcanics, granite, schist, sandstone
Permeability of deposits: high

PIT #: B-16
Location: just W of Merrill Corner (two separate pits)
Date: 8/22/83
Dominant textures: s,p, w/ c,b (may have been dumped?)
Water present in pit? no
Total exposure thickness: 30'
Is pit active? yes (no longer, 10/10/94)
Landform exposed: gently sloping 620' terrace form
Stratigraphy: 4' sandy pebble gravel/c.26' uniform pbly med-crse sand w/ occ. small cobbles; possible delta
Bedforms: "foresets" tabular, planar; "topsets" appear to be troughed, but poorly exposed
Paleocurrents: 21S80E; 20S33E; 29S36E
Environment of deposition: deep water fluvial (no braid bars, but rather small-scale foresets) or shallow lacustrine
Structures: none seen; no kettles on surface
Dominant cobble lithology: quartz monzonite, granite, volcanics
Permeability of deposits: moderate

PIT #: B-17
Location: just S of Eastern Slopes Regional Airport, E of Clays Pond
Date: 8/30/83
Dominant textures: s(med-crse),b, minor p
Water present in pit? no
Total exposure thickness: 10'
Is pit active? no
Landform exposed: 450' ice-contact (?) surface, or outwash plain
Stratigraphy: slumped exposure, but materials appear uniform throughout exposure thickness; bimodal texture, with a few angular boulders on nearby surfaces
Bedforms: none seen; massive fine-med. sands
Paleocurrents: none measured
Environment of deposition: inconclusive, but possible outwash
Structures: none seen
Dominant cobble lithology: most boulders granite and amphibolite
Permeability of deposits: moderate

PIT #: B-18
Location: former Fryeburg landfill
Date: 8/30/83
Dominant textures: s,p-c,st,cy
Water present in pit? some, at contact between sand and cy
Total exposure thickness: 14'
Is pit active? no
Landform exposed: part of 510' kame plateau or kame delta (?)
Stratigraphy: E side of pit: 6' p-c gr/med-crse sand (foresets?), relationships unclear because poorly exposed; W side of pit: uniform pbly sand, cy-st exposed in places on floor, but not in situ Bedforms: none seen; sediments massive
Paleocurrents: none measured
Environment of deposition: deltaic, based on coarsening upward sequences
Structures: none seen
Dominant cobble lithology: granite, volcanics, minor schists
Permeability of deposits: low to high, depending on strata

PIT #: B-19
Location: just N of former Fryeburg landfill
Date: 8/30/83
Dominant textures: s,p,c, w/ minor boulders
Water present in pit? no
Total exposure thickness: c.25'
Is pit active? no
Landform exposed: part of 510' kame plateau (kame delta?)
Stratigraphy: 8' med-crse sand/4' s,p-c gr, w/ minor boulders/med-crse sand
Bedforms: tabular, planar sand sets, graded c.2' thick
Paleocurrents: dips: 21S86W
Environment of deposition: apparently subaqueous; ice-contact pro-delta slope deposits (?)
Structures: none seen
Dominant cobble lithology: granite, volcanics, minor schist
Permeability of deposits: moderate

PIT #: B-20
Location: S shore of Round Pond
Date: 8/30/83
Dominant textures: s,p
Water present in pit? no
Total exposure thickness: 18' (above pond level)
Is pit active? no, some activity 10/14/94
Landform exposed: part of 460' kame plateau, similar to B-17
Stratigraphy: uniform, massive, tabular, med-crse sand, grading to 2-3" thick beds near top of exposure
Bedforms: none seen
Paleocurrents: none measured
Environment of deposition: possibly outwash
Structures: none seen
Dominant cobble lithology: granite
Permeability of deposits: moderate

PIT #: B-21
Location: about 0.3 mi SW of W Brownfield
Date: 8/30/83
Dominant textures: s,p
Water present in pit? no
Total exposure thickness: 14'
Is pit active? no
Landform exposed: large kame plain or kame terrace
Stratigraphy: 1-2' fine sand (eolian cap?)/sandy pebble gravel interbedded with and overlying tabular med sands
Bedforms: tabular, planar sand sets; no climbing ripples
Paleocurrents: S86E; N61W; S65E; S5E; N86E
Environment of deposition: subaqueous, relatively shallow water
Structures: minor normal faults to due E; some dips may be collapsed
Dominant cobble lithology: na
Permeability of deposits: moderate

PIT #: B-22
Location: 0.9 mi E of New Boston, 0.4 mi N of Porter town line
Date: 8/30/83
Dominant textures: s,p,c
Water present in pit? no
Total exposure thickness: c.15'
Is pit active? intermittent
Landform exposed: part of kame assoc w/ 810' kame delta
Stratigraphy: interbedded p-c gravel and med-crse pbly sands
Bedforms: small sandy tabular "foresets" c.8" thick
Paleocurrents: N35E; S15W; S1E; S10E; N15W; S5W
Environment of deposition: ice-contact, fluvial
Structures: none seen
Dominant cobble lithology: granite, volcanics, minor schist
Permeability of deposits: moderate to high