SURFICIAL GEOLOGY OF THE SUGAR HILL 7.5-MINUTE QUADRANGLE, GRAFTON COUNTY, NEW HAMPSHIRE

by

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INTRODUCTION

This report describes the surficial geology and Quaternary history of the Sugar Hill 7.5-minute quadrangle in the White Mountains of northern New Hampshire. Surficial earth materials include unconsolidated sediments (sand, gravel, etc.) of glacial and nonglacial origin. Most of these deposits formed during and after the latest episode of glaciation, within the last 25,000 years. Surficial sediments cover the bedrock over much of the quadrangle, and are subject to various land-use considerations. These include sand and gravel extraction, development and protection of ground-water supplies, siting of waste disposal facilities, selection of building sites, and agriculture.

The field work and map compilation for this study were carried out by the author in support of the STATEMAP cooperative between the New Hampshire Geological Survey and the U. S. Geological Survey (USGS).

The geologic map accompanying this report shows the distribution of sedimentary units, and indicates their age, composition, and known or inferred origin. It also includes information on the geologic history of the quadrangle, such as features indicating the flow direction of glacial ice. This map, along with mapping and research done by the author elsewhere in the White Mountains, provides the basis for the discussion of glacial and postglacial history presented here.

Geographic setting. The Sugar Hill quadrangle is located in the western White Mountains. The map area extends in latitude from 44°07'30" to 44°15'00" N, and in longitude from 71°45'00" to 71°52'30" W. It encompasses parts of the towns of Easton, Franconia, Lisbon, Landaff, and Sugar Hill. The southern portion of the quadrangle lies partly within the White Mountain National Forest. Residential development is mainly in the northern part of the map area, in the vicinity of Sugar Hill and Franconia villages.

The quadrangle lies entirely in the Connecticut River drainage basin. The major stream in the map area is Ham Branch, which flows northward through the eastern part of the quadrangle and joins the Gale River in Franconia. Most of the western half of the area drains westward via various brooks to the Ammonoosuc River. A short section the Ammonoosuc crosses the northwest corner of the quadrangle. There are no major lakes and only a few small ponds in the map area, the largest being Pearl Lake in Lisbon.

The topography of the Sugar Hill quadrangle is generally hilly to mountainous. Elevations range from about 600 ft (183 m) above sea level at the Ammonoosuc River to 3300 ft (1006 m) in the southeast corner of the map area. The high peaks of Cannon Mountain and Kinsman Mountain (collectively called the Kinsman Range) are just east of the quadrangle. A few low hills and ridges in the quadrangle have been glacially streamlined in a southerly to south-southeasterly direction.

Bedrock geology. Quaternary sediments cover much of the bedrock at lower elevations in the Sugar Hill quadrangle, but outcrops are common on the hill tops and locally in stream beds and other places. The bedrock includes a complex assortment of metasedimentary and metavolcanic rocks of Ordovician to Devonian age, and intrusive igneous rocks of the Ordovician-age Oliverian Plutonic Suite, and the Devonian-age New Hampshire Plutonic Suite (Lyons *et al*., 1997).

PREVIOUS WORK

No large-scale or detailed surficial geologic mapping has been conducted previously in the Sugar Hill quadrangle. However, a regional aquifer study by Flanagan (1996) provides helpful information on the sand and gravel deposits. The latter report notes the presence of glacial-lake deposits in the Ham Branch valley and cites Lougee (1939) as having assigned these deposits to what he called glacial Lake Franconia. Flanagan also identified potential spillway channels that drained ice-dammed Lake Franconia, first to the south and then to the west.

Detailed surficial mapping of adjacent areas has been carried out by Nelson and Thompson (1998) in the Littleton quadrangle to the north, and by Fowler (2013) in the Franconia quadrangle to the east. Much has been written about the moraines and glacial-lake deposits of the Ammonoosuc River basin in the Littleton-Bethlehem area, which have been studied by many workers since the mid 1800s (Thompson, 1999; Thompson et al., 1999).

The U. S. Department of Agriculture's soil survey of Grafton County (Homer, 1999) provided useful materials information for sites that the present author did not visit in the field. Additional information on glacial and postglacial geomorphology was derived from air photo interpretation and from Lidar imagery that is presently available only in the area of the White Mountain National Forest.

The author is grateful to the USDA's Natural Resources Conservation Service office in Orford, N.H. for use of their air photos, and to the New Hampshire Geological Survey for cartographic support and supplying the Lidar imagery.

DESCRIPTION OF GEOLOGIC MAP UNITS

The surficial deposits represented on the geologic map have been classified on the basis of their age and origin. 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, i.e. formed during the last 12,000 years);

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

The Quaternary age is assigned to units which 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 "lfe" for the Easton Stage (e) of glacial Lake

Franconia (lf). Surficial map units in the Sugar Hill quadrangle are described below, starting with the older deposits that formed in contact with glacial ice.

Till (map unit Pt)

Till is a glacially deposited sediment consisting of a more-or-less random mixture of sand, silt, and gravel-size rock debris. It may also include numerous boulders. Till is the most widespread surficial deposit in the Sugar Hill quadrangle. It blankets the hills and sides of large mountains in the quadrangle, although parts of it have been disturbed by mass movements and surface water runoff on the steeper slopes. Test borings in other areas of New England show that till commonly extends beneath the younger waterlaid sediments in valleys.

Most exposures of till in the Sugar Hill quadrangle are shallow cuts (3-6 ft) along town roads and logging roads. In a few places, borrow pits and excavations next to woods roads have revealed up to 25 ft of till, and the thickness may be considerably greater beneath some of the lower valley sides. Till is thin or absent on the tops of many hills and mountains in the quadrangle, where bedrock is likely to be exposed. The geologic map indicates areas where bedrock outcrops are common and/or the till thickness is inferred to be less than 10 ft.

Till is, by definition, a poorly sorted sediment (diamicton) in which there is a wide range of rock and mineral particle sizes. However, the texture and structure of individual till deposits vary depending on their source and how they were formed. Till in the Sugar Hill quadrangle may include a small percentage of clay, but it has a dominantly sandy or silty-sandy matrix as a consequence of having been derived from coarse-grained bedrock. Till has little or no obvious stratification in some places. Elsewhere it is crudely stratified, with discontinuous lenses and laminae of silt, sand, and gravel resulting from sorting by meltwater during deposition.

Stones are abundant in this unit, and boulders scattered across the ground surface often indicate the presence of till. Till stones in the quadrangle chiefly consist of igneous and metamorphic rocks that were glacially eroded from local bedrock sources. Most till stones are more-or-less angular, and some have smooth, flat, striated surfaces due to glacial abrasion. These faceted surfaces are best developed on dense, fine-grained rocks such as basalt or slaty metamorphic rocks.

In small exposures, it is often difficult to identify varieties of till and how they formed, but much of the till in the Sugar Hill area is likely to be either lodgement till or ablation till. Lodgement till was deposited under great pressure beneath the ice sheet. It may be very compact and difficult to excavate, with a platy structure (fissility) in the upper, weathered zone. Ablation till was formed during the melting of the ice, in unstable glacial environments where slumping and meltwater action were common. This type of till tends to be loose-textured and stony, with numerous lenses of washed sediment. In places a thin veneer of stony ablation till may overlie finer-grained lodgement till.

Field studies in New England (e.g. Koteff and Pessl, 1985; Thompson and Borns, 1985; Weddle *et al.*, 1989), suggests that till deposits of two glaciations are present in the region. The "upper till" is clearly the product of the most recent, late Wisconsinan glaciations (Laurentide Ice Sheet) which covered northern New Hampshire between about 25,000 and 13,000 years ago. Exposures of upper till can be seen in many shallow pits, road cuts, and temporary excavations. It is not weathered (except in the near-surface zone of modern soil formation) and commonly is light olive-gray to olive in color.

The "lower till" consists of compact, silty-sandy lodgement deposits. This older till is most common in southern New England, where it is distinguished by its thick weathering profile that may extend to a depth of 10 ft or more. Within this weathered zone, the till is oxidized and has an olive-gray to dark olive-gray or dark grayish-brown color. Dark-brown iron/manganese oxide staining coats the surfaces of stones and joints. This till is believed to have been deposited during an earlier glaciation in Illinoian time, prior to 130,000 years ago (Weddle *et al.*, 1989).

Exposures of the lower till are relatively uncommon in northern New England, and none have been found in the Sugar Hill quadrangle. This may be due to the lack of deep excavations, but it is also possible that a greater degree of erosion by the last glacial ice sheet either has removed much of the lower till in the region, or at least has eroded away the diagnostic oxidation zone. The two tills have been observed together at just a few localities, especially in the Nash Stream valley in far northern New Hampshire (Koteff and Pessl, 1985).

Esker deposits (unit Pge)

Eskers are ridges of gravel and sand that accumulated in ice-walled tunnels at the base of a glacier. A prominent esker ridge is seen in the Ham Branch valley near the eastern border of the Sugar Hill quadrangle. Several gravel pits have been opened in this ridge, which is about 60 ft high.

The subglacial stream that formed the Ham Branch esker presumably flowed southward along the valley, toward where the ice margin stood. This esker originally may have been longer, with parts of it having been buried by glacial-lake sediments or removed by postglacial erosion. The tunnel system certainly continued up the Ham Branch valley and into the Mount Moosilauke quadrangle, because the author found another esker segment along the same trend, south of Mud Pond in the latter quad.

Ice-contact deposits (unit Pgi)

Small gravel deposits are perched on the side of the Ham Branch valley, where they reach elevations of 1320-1380 ft. These gravels were laid down by glacial meltwater streams flowing southward between the valley walls and a retreating ice tongue in the valley. An excellent pit exposure on the east side of the valley – just north of the Easton-Franconia town line – showed the contact between the glaciofluvial Pgi gravel and underlying till.

Glacial-lake deposits

Lake Franconia deposits (units Plfe and Plf). The drainages of both glacial and non-glacial streams were temporarily impounded by the retreating ice margin in north-sloping valleys of the White Mountains, causing sediments to accumulate in a series of ice-dammed glacial lakes. Glacial Lake Franconia was one such lake, which existed in the Ham Branch and Gale River valleys.

A substantial deposit of sand and gravel (unit Plfe) was laid down in Lake Franconia on the east side of Route 116 in Easton. This deposit has been dissected by Ham Branch and several brooks draining the high mountains to the east, but small remnants of the upper surface of unit Plfe reach elevations of about 1320-1340 ft. The deposit is inferred to be a delta that built up to the surface of Lake Franconia during its earliest and highest phase, which is here called the Easton Stage. The outlet (spillway) for the Easton Stage was a narrow bedrock ravine whose floor stands at about 1320 ft, located immediately east of Mud Pond in the Mount Moosilauke quadrangle.

Bottom deposits of Lake Franconia occur beneath younger fan and alluvial sediments on the floor of Ham Branch valley. For example, in her description of the Ham Branch aquifer, Flanagan (1996) reported that a USGS observation well in Easton penetrated a total of 68 ft of lake-bottom deposits beneath coarser sediments. The deeper part of the lake sediments consisted of clay, silt, and very fine sand.

Other Lake Franconia deposits in the Sugar Hill quadrangle have been tentatively mapped along the west side of the Ham Branch valley. It is uncertain whether they formed entirely during the Easton Stage or overlapped with the younger Sugar Hill Stage, so they are designated simply as unit Plf.

Uncorrelated lake deposits (unit Pl). Unit Pl consists of poorly exposed sand and gravel deposits in the Salmon Hole Brook valley, whose elevations suggest they formed in ponded areas during the brief time that the glacier margin was retreating down this valley and blocking its drainage. Lack of exposure and access prevented a close examination of these deposits.

Glacial Lake Hitchcock deposits (unit Plh). Lake Hitchcock was a very large and long-lived glacial lake that occupied the Connecticut River valley and its tributaries. This lake extended up the Ammonoosuc River valley to Littleton and south to central Connecticut (Eusden *et al.*, 2013). Thick deposits of deltaic sand and gravel accumulated in many parts of Lake Hitchcock, including the Ammonoosuc Valley in the northwest corner of the Sugar Hill quadrangle (unit Plh).

The Lake Hitchcock deltaic sediments at the lower end of Salmon Hole Brook have a flat upper surface at an elevation of about 820 ft. This is believed to be a remnant of the original delta top. The actual elevation of the lake surface would have been slightly lower, probably around 800-810 ft. The delta likely was supplied by a combination of sediments coming from ice in the Ammonoosuc Valley and from scouring of the Salmon Hole Brook valley during sudden drainage of Lake Franconia.

Koteff and Larsen (1989) called this deposit the Salmon Hole Brook delta. They measured the elevation of the contact between the delta topset and foreset beds, which indicated a lake level of 239.9 m (787 ft). However, this is probably a minimum elevation, given the somewhat higher delta top noted above. Examination of local gravel pits and the topographic map contours indicates that the delta was trimmed down by ancestral Salmon Hole Brook as the level of Lake Hitchcock dropped.

Alluvial fan deposits (units Qf, Qfsb)

Alluvial fans often form in mountainous areas where steep upland streams discharge into larger valleys. The abrupt decrease in stream gradient at the mouths of these streams causes at least the coarsest part of their sediment loads to be deposited. Many alluvial fans accumulated at the mouths of tributary brooks in the White Mountains. They commonly consist of very coarse gravel, though diamicts may also be present locally due to deposition of debris flows.

The fans are believed to have formed in large part soon after deglaciation, when the barren, freshly-exposed mountain slopes would have been vulnerable to rapid erosion during torrential rain storms. Rare deluges probably contributed to fan growth in postglacial time, so these deposits are assigned a general Quaternary age.

Unit Qf includes two groups of coalescing alluvial fans deposited by brooks on the east side of Ham Branch valley. There has been a lot of runoff and erosion in this area, as the brooks flowed down the steep west side of the Kinsman Range. The slope of the fan surfaces can be seen in large fields along Route 116, in contrast to the flat horizontal surface of the flood plain on the lowest part of the valley floor.

A higher, steeply sloping fan (unit Qfsb) has been mapped separately in the vicinity of Slide Brook, near the south edge of the quadrangle. The deposit is poorly exposed, but shallow excavations on Slide Brook Road showed poorly sorted, angular to subrounded, pebble to boulder gravel. Scattered boulders in this area, and near Kinsman Cemetery, suggest that powerful debris flows likely contributed to the growth of the Slide Brook fan. The name of the brook likewise suggests a history of landslide activity in this part of the Sugar Hill quadrangle.

Stream terrace deposits (unit Qst)

Stream terraces in the Sugar Hill quadrangle are remnants of past flood plains that have been left “high and dry” as streams eroded down to their modern levels. These flat-topped deposits consist mostly of sand and gravel that was reworked from older glacial sediments. A very prominent stream terrace occurs along Ham Branch and the Gale River in Franconia.

Wetland deposits (unit Hw)

Unit Hw consists of fine-grained and organic-rich sediments deposited in low, flat, poorly drained areas. In the Sugar Hill quadrangle this unit occurs in a few small upland areas, and along the upper part of Ham Branch. Only the major wetlands have been shown here, based mostly on air photo interpretation. Thin unmapped wetland areas may be expected in other places as well. The surficial geology map should not be interpreted a definitive wetlands map for purposes of land-use planning and regulation.

Stream alluvium (unit Ha)

Unit Ha consists of alluvial sand, gravel, silt and organic material deposited by late-glacial to modern streams. Sediment textures vary widely depending on the local depositional environment.

GLACIAL AND POSTGLACIAL GEOLOGIC HISTORY

The following reconstruction of the Quaternary history of the Sugar Hill quadrangle is based on the author's interpretations of surficial earth materials described in this report, as well as topographic features in the study area, and the sequence and chronology of deglaciation recorded in neighboring quadrangles to the north and east.

The most recent (late Wisconsinan) glaciation began about 25,000 years ago, when the Laurentide Ice Sheet in Canada spread southward across New England (Stone and Borns, 1986). It produced the stony till deposits that blanket large areas of the quadrangle. Rocks torn from the hills were scattered in the direction of glacial transport.

Abrasion by rock debris dragged at the base of the glacier polished and striated the bedrock surface. In many places striations are not evident because they are either concealed beneath surficial sediments or have been destroyed by weathering at the ground surface. The geologic map shows sites in the quadrangle where striation trends have been recorded. Most data came from ledges along road sides and power lines. Some of these occurrences are limited to very small remnants of glacially polished surfaces on otherwise weathered ledges, and the striations in such cases may be visible only after rubbing a pencil across the rock surface. Glacial striations and grooves also can be seen more easily on wet surfaces.

Striation data from the Sugar Hill quadrangle usually indicate glacial flow toward the south-southeast. This flow probably occurred during the maximum phase of late Wisconsinan glaciation, when glacially streamlined hills in the area were sculpted with the same orientation. However, superposed striation sets at a site near the north edge of the map record a younger flow toward the south-southwest. This shift probably occurred in late-glacial time, when a glacial readvance in the nearby Littleton-Bethlehem area was accompanied by a similar change in ice-flow direction (Thompson *et al.*, 1999).

The time of glacial retreat from the Sugar Hill quadrangle can be estimated from radiocarbon dating and correlation of sequences of annual clay layers (varves) deposited in glacial Lake Hitchcock in the Connecticut River valley (Ridge *et al.*, 2012). The Lake Hitchcock varve chronology shows that the glacier receded from the study area shortly before 14,000 years ago.

Melting of the Laurentide Ice Sheet would have simultaneously produced thinning of the ice sheet and recession of its margin. In the rugged terrain of the White Mountains, the configuration of the ice margin probably was very irregular, with tongues of still-active ice in some of the valleys when nearby mountain peaks had already emerged from the ice sheet.

The lack of end moraines in the Sugar Hill quadrangle hinders detailed reconstruction of the pattern of deglaciation. However, the locations and slopes of meltwater channels carved on hillsides by glacial streams generally support a northward recession of the ice margin. Additional evidence of northward retreat is provided by the distribution and topography of glacial Lake Franconia deposits, and the progressively lower spillway channels that drained the stages of this lake as ice recession opened these new outlets.

The deglaciation history of the Sugar Hill quadrangle is closely tied to ice recession in the Franconia quadrangle and other nearby areas to the east. These developments included a complex chain of drainage events in the upper Gale River valley, which in turn were related to drainage of glacial Lake Ammonoosuc waters from the Bethlehem-Twin Mountain area to the north. In the following section the author has attempted to reconstruct the deglaciation sequence and history of Lake Franconia from various lines of field of evidence. Discussions with mappers in the neighboring quadrangles – Brian Fowler in Franconia and Carol Hildreth in South Twin Mountain – were very helpful in this process.

Deglacial history, landscape changes, and evolution of glacial Lake Franconia (Sugar Hill and Franconia quadrangles)

1) The ice margin retreated north from the Ham Branch valley in Easton, initiating the Easton Stage of Lake Franconia. This lake stage drained south through spillway at ~1320 ft (402m) in the northern part of the adjacent Mount Moosilauke quadrangle.

2) Continued ice retreat allowed the Easton stage to expand northward, while also spreading east into Meadow Brook valley in Franconia and west into Salmon Hole Brook valley in Sugar Hill.

3) The latest Easton Stage ice margin reached Franconia village. The upper Gale River valley opened in the Franconia quad, and ice retreat also caused glacial Lake Ammonoosuc (in Bethlehem) to drop as a succession of progressively lower spillways enabled the latter lake to drain into the head of the Gale River valley. Floods of Lake Ammonoosuc water scoured sediments from the spillway channel along U.S. Route 3 west of Twin Mountain village. These sediments, coupled with alluvial fan sediments coming out of the mountains to the SE, filled a small water body (glacial Lake Gale) in the Five Corners area (NE corner of Franconia quad and adjacent part of South Twin Mountain quad).   Till terraces reported by B. K. Fowler (pers.comm., 2014) would have started to form in the upper Gale River valley NE of Franconia due to the catastrophic releases of water from Lake Ammonoosuc.

4) Slight additional ice retreat resulted in cutting of a deep bedrock gorge called "The Gulf" in the NW corner of Sugar Hill quad. The elevation of the gorge floor is at ~ 1110 ft (338 m). Opening of The Gulf emptied the arm of Lake Franconia in Salmon Hole Brook valley as the lake fell to the Sugar Hill stage. The new spillway was at ~1290 ft (393 m) on west side of Ham Branch valley. After this lowering of base level, a 1300-ft terrace and/or delta formed in the upper Gale River valley as Lake Franconia expanded into that area. At about the same time, the lowest Lake Ammonoosuc spillway (1320 ft) opened up in the Five Corners area. Water/sediment were still coming down the alluvial fans SE of Five Corners and probably contributing to Lake Franconia deposits.

5) Slight additional ice retreat opened a drainage channel at 850 ft (259 m) at the north edge of Sugar Hill quad. This channel completely drained and terminated Lake Franconia. The catastrophic 260-ft lowering of base level initiated carving of the deep stretch of the upper Gale River valley NE of Franconia village. Deepening of the lower Salmon Hole Brook valley was also promoted at this time.

Postglacial events

During and after deglaciation of the Sugar Hill quadrangle, nonglacial streams began to establish their modern drainage patterns. Water emptied from the glacial lakes upon melting of their ice dams, and the lake deposits in the Ham Branch valley were deeply eroded by brooks draining the high mountains of the Kinsman Range. As soon as the ice retreated from the sides of these mountains, the freshly deposited glacial sediments were very susceptible to erosion until a vegetation cover was established. Much of the alluvial gravel and sand in the fan deposits probably formed at this time, along with the early stream alluvium between Easton and Franconia village.

The older Ham Branch alluvium forms the prominent river terrace (unit Qst) that stands higher than the present-day flood plain along this river. Similar terraces likewise formed along the Gale and Ammonoosuc Rivers.

Deposits of recent flood-plain alluvium (unit Ha) continue to accumulate along modern streams in the Sugar Hill quadrangle, and organic-rich sediments (unit Hw) are being deposited in small wetlands. Most of the alluvial sand and gravel transport along streams in the area presumably occurs when water levels are high during spring runoff and floods.

ECONOMIC GEOLOGY

Sand and gravel resources are found mainly in valley areas of the quadrangle, where they have been concentrated by glacial and postglacial deposition. Major pit operations occur in the glacial Lake Hitchcock deposits and adjacent stream terraces along the Ammonoosuc River in the northwest corner of the map area. Other scattered pits have been worked in esker, glacial lake, alluvial fan, and steam terrace deposits along the Ham Branch and Salmon Hole Brook valleys. Extensive gravel deposits remain in the alluvial fans of this area. Much of the sandy till in the quadrangle has a silty-sandy matrix that compacts well in applications where fill is needed.

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GLOSSARY OF TERMS

(updated and expanded from glossary originally compiled by John Gosse and Woodrow Thompson for the Maine Geological Survey mapping program)

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

Alluvial: refers to sediments or processes resulting from the action of running water, such as the alluvium found on river flood plains.

Alluvial fan: an accumulation of sediment typically deposited where a relatively steep upland stream enters a valley and the sudden decrease in stream gradient causes much of its load to be deposited. Often develops a fan-shaped outline as it spreads into the valley. Usually has a noticeable (gentle to moderately steep) surface slope and coarse gravelly sediments.

Clast: pebble-, cobble-, or boulder-size fragment of rock or other material in a finer-grained matrix. Often refers to stones in glacial till or gravel.

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 each other. For example, a well-sorted cobble gravel.

Colluvium: sedimentary debris on the lower slopes of hills and mountains. Results from slow downslope movement due to gravity, freeze-thaw action, etc., acting upon preexisting surficial sediments (derived from till in many cases, from which it may be hard to distinguish).

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 New England usually consist of two parts: (1) coarse, horizontal, often 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, e.g. glacial till.

Drumlin: an elongate 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. Often simply called a “moraine”.

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 at least partly by meltwater flowing in a tunnel within or beneath glacial ice. Many ridges mapped as eskers include variable amounts of sediment deposited in narrow open channels or at the mouths of ice tunnels.

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

Glaciolacustrine / glacial-lacustrine: refers to sediments or processes involving a lake which received meltwater from glacial ice.

Glaciomarine / glacial-marine: refers to sediments and processes related to environments where marine water and glacial ice were in contact.

Head of outwash: same as outwash head.

Holocene: term for the time period from 12,000 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 age: see Pleistocene.

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.

Kettle hole: same as kettle.

Lacustrine: pertaining to a lake.

Late-glacial: refers to the time when the most recent glacial ice sheet was receding from New England, approximately 20,000-12,000 years ago.

Laurentide ice sheet: the most recent continental ice sheet that covered New England, in Late Wisconsinan time.

Late Wisconsinan: the most recent part of Pleistocene time, during which the latest continental ice sheet covered New England (approx. 25,000-12,000 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.

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”.

Outwash: sediment derived from melting glacial ice, and deposited by meltwater streams in front of a glacier.

Outwash head: the end of an outwash deposit that was closest to the glacier margin from which it originated. Ice-contact outwash heads typically show steep slopes, kettles and hummocks, and/or boulders dumped off the ice. These features help define former positions of a retreating glacier margin, especially where end moraines are absent.

Pleistocene: term for the time period between 2.6 million years ago and 12,000 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 era between 2.6 million years ago and the present. Includes both the Pleistocene and Holocene.

Sorting: the degree to which the rock or mineral particles in a sediment are all the same or similar in size. For example, many glacial tills contain a mixture of rock debris ranging from clay-size to boulders, and thus are very poorly sorted.

Striation: a narrow scratch on bedrock or a stone, produced by the abrasive action of debris-laden glacial ice. Plural form sometimes given as “striae”.

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, 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.

Talus: a pile of rocks at the bottom of a bedrock cliff, formed by falling and sliding of blocks of rock that detached from the cliff.

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

Sugar Hill Quadrangle Figure Captions

from Woody Thompson

Geo-052-024000-SMOF

STATEMAP 2013 Mapped 2014

Figure 1. Glacial striations trending 180° on granite ledge next to North Peak Road in Easton. Red pencil points in direction of former ice flow.

Figure 2. Till exposure on east side of Ham Branch valley, Franconia.

Figure 3. Terraced excavation showing cross-section of esker ridge next to Route 116 in Franconia.

Figure 4. Erosional contact between coarse, poorly-sorted, glacial stream gravel (map unit Pgi) and underlying till, east side of Ham Branch valley in Franconia.

Figure 5. View looking south along power line on east spur of Cole Hill in Easton. Photo shows the upper end of Ham Branch valley (center to center-left) and Mount Moosilauke (top-left). The small dark notch on the ridge in the middle distance (just beyond and to right of power line) is the spillway channel for the Easton Stage of glacial Lake Franconia.

Figure 6. View looking southwest along the swampy floor of The Gulf in Lisbon. This spectacular meltwater channel is difficult to photograph but is cut into bedrock and up to 100 ft deep. The elevation of the channel floor is about 1110 ft.

Figure 7. The 1290-ft spillway for the Sugar Hill Stage of glacial Lake Franconia. This view looks southeast along the broad spillway channel from Toad Hill Road in Sugar Hill.

Figure 8. View looking southeast at the Kinsman Range and east side of Ham Branch valley in Easton. Several ravines can be seen on the mountain sides, where steep brooks have eroded glacial sediments and transported them to alluvial fans on the valley bottom. The prominent Slide Brook ravine is near center of photo.

Figure 9. View looking south, up the gently sloping surface of an alluvial fan deposited in Ham Branch valley by Reel Brook. This fan overlaps the south edge of the quadrangle.

Figure 10. Stream-terrace gravel in early Ammonoosuc River channels. These channels were eroded into the underlying sand that is part of a glacial Lake Hitchcock delta. The pit is just off the NW edge of the map, near Sugar Hill Station in the Lisbon quadrangle.

EXPLANATION

SURFICIAL GEOLOGIC MAP OF THE SUGAR HILL 7.5-MINUTE QUADRANGLE
Grafton County, New Hampshire

By Woodrow B. Thompson
2014

Note: The following letter symbols identify units shown on the geologic map. "H" indicates units of Holocene (postglacial) age. "P" indicates Pleistocene deposits formed during the Ice Age. "Q" designates units of Quaternary age that probably formed during late-glacial to recent time, and thus may range from late Pleistocene through Holocene.

Ha **Stream Alluvium** – Sand, silt, and gravel deposited on the flood plains of Ham Branch, Gale River, and the Ammonoosuc River. Unit may include some wetland areas.

Hw **Wetland deposits** – Peat, muck, silt, and clay. Deposited in poorly drained areas.

Qst **Stream terraces** – Sand and gravel terraces along Ham Branch, Gale River, Salmon Hole Brook, and the Ammonoosuc River. These terraces resulted from erosion of originally higher glacial deposits as stream base levels dropped in response to ice recession and drainage of glacial lakes. Two terrace levels – **Qst$_1$** and **Qst$_2$** are present in the Ammonoosuc Valley.

Qf **Alluvial fan deposits** – Series of coalescent alluvial fans formed at the mouths of streams draining the mountain slopes on the east side of the Ham Branch valley during late-glacial and postglacial time. Composed of gravel (locally very coarse) and sand.

Qfsb Slide Brook fan – Fan deposit in the Slide Brook area on east side of Ham Branch valley. This fan is steeper than the adjacent alluvial fans (Qf) closer to the valley bottom. Surface exposures include coarse gravel, but boulders in some areas suggest that poorly sorted debris-flow deposits also may be present.

Plh **Glacial Lake Hitchcock deposits** – Sand and gravel deposited as a delta into glacial Lake Hitchcock, a very large lake which extended from Littleton down the Ammonoosuc and Connecticut River valleys to central Connecticut. The top of unit Plh in the Sugar Hill quadrangle, at an elevation of ~ 820 ft, probably marks the approximate level of Lake Hitchcock in this area.

Pl **Glacial lake deposits** – Poorly exposed sand and gravel that probably was deposited in areas of briefly ponded glacial meltwater in the Salmon Hole Brook valley.

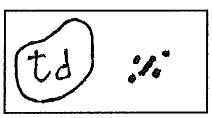
Plf **Glacial Lake Franconia deposits** – Sand, gravel, and silt deposited in an ice-dammed glacial lake in the Ham Branch valley. The higher level of Lake Franconia (Easton Stage – **Plfe**) drained through a spillway at elevation of ~ 1320 ft (402 m), located east-northeast of Mud Pond in the northern part of the Mount Moosilauke quadrangle. The lower lake level (Sugar Hill Stage – **Plfsh**) drained west through the 1290 ft (393 m) spillway south of Ore Hill and thence through a deep rock-walled channel (The Gulf) at

1110 ft (338 m) in Lisbon. Lake Franconia deposits exposed in the Sugar Hill quadrangle include dissected deltaic and possible subaqueous fan sediments (map unit Plfe) formed during the Easton Stage in the upper Ham Branch valley, and undifferentiated Plf deposits on the lower west side of this valley, as well as near Franconia village. Additional Lake Franconia deposits occur beneath younger alluvial fan, river terrace, and flood plain sediments in the Ham Branch valley.

Pgi **Ice-contact deposits** – Small gravel deposits built by glacial meltwater on the east and west walls of the Ham Branch valley. Formed along the sides of the ice lobe that deposited unit Plfe as it receded down the valley toward Franconia.

Pge **Esker** – Ridge of sand and gravel deposited by a south-flowing meltwater stream in a subglacial ice tunnel in the Ham Branch valley. The chevron symbols indicate the axis of the esker and presumed meltwater flow direction when it was deposited. The esker ridge also may include subaqueous fan deposits that discharged from the tunnel mouth into glacial Lake Franconia as the ice margin retreated northward.

Pt **Till** – Loose to very compact, poorly sorted, massive to weakly stratified mixture of sand, silt, and gravel-size rock debris deposited directly from glacial ice. Locally includes lenses of waterlaid sand and gravel.



Bedrock outcrops/Thin-drift areas – "td" indicates areas where outcrops are common and/or surficial sediments are generally less than 10 ft thick (mapped partly from air photos and Lidar imagery). Dots show individual outcrops.

Contact – Boundary between map units. Dashed where inferred.

Scarp – Hachured line shows scarp between adjacent stream terraces in the Ammonoosuc River valley. Hachures point toward the lower terrace.

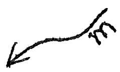
Ice-margin position – Line shows an approximate position of the glacier margin during ice retreat, based on positions of glacial meltwater channels and inferred sequence of major erosion episodes along the Salmon Hole Brook and the upper Gale River valleys. "Plfe" indicates the inferred ice-margin position during the latest Easton Stage of Lake Franconia, and "Plfsh" shows the position during the latest Sugar Hill Stage of the lake.

Glacially streamlined ridge - Symbol shows long axis of streamlined till or bedrock ridge, which is parallel to former glacial ice-flow direction. Most of these features are low, narrow till ridges, collectively known as "fluted ground moraine", and are evident only on Lidar imagery.

Glacial striation locality – Arrow shows ice-flow direction(s) inferred from striations on bedrock. Dot marks point of observation. Number is azimuth (in degrees) of flow direction. Where two striation sets are present and their relative ages could be determined, the flagged direction is older.

Crescentic mark locality – Bedrock outcrop where glacial flow direction (indicated by arrow) was inferred from crescentic fractures on ledge surface.

Glacial Lake Franconia spillway – Channel eroded by outflow from glacial Lake Franconia. Associated number is the approximate spillway elevation in feet. The spillways for the Easton and Sugar Hill stages are shown here, as well as the final drainage channel at 850 ft (near north edge of map) that terminated the lake.



Meltwater channel – Channel eroded by glacial meltwater stream. Arrow shows inferred direction of former stream flow.

Postglacial stream channel – Channel eroded by former or ephemeral brook that has carried sediments to alluvial fan network in the Ham Branch valley.