Prepared in cooperation with the Commonwealth of Massachusetts
Office of the State Geologist and Executive Office of Energy and Environmental Affairs

Surficial Geologic Map of the Ashby-Lowell-Sterling-Billerica 11-quadrangle area in Northeast-Central Massachusetts

Compiled by Byron D. Stone and Janet R. Stone

Open-File Report 2006-1260-C

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
Dirk Kempthorne, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia 2007

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Stone, B.D., and Stone, J.R., 2007, compilers, Surficial Geologic Map of the Ashby-Lowell-Sterling-Billerica 11-quadrangle area in Northeast-Central Massachusetts: U.S. Geological Survey Open-File Report 2006-1260-C.

Cover figure. A portion of the surficial geologic map of the Ayer quadrangle, shown with semi-transparent shaded relief on a scanned topographic base map.

Contents

Figures

Surficial Geologic Map of the Ashby-Lowell-Sterling-Billerica 11-quadrangle area in Northeast-Central Massachusetts

Compiled by Byron D. Stone and Janet R. Stone

Introduction

The surficial geologic map shows the distribution of nonlithified earth materials at land surface in an area of eleven 7.5-minute quadrangles (total 505 mi^2) in northeast-central Massachusetts (fig. 1). Across Massachusetts, these materials range from a few feet to more than 500 ft in thickness. They overlie bedrock, which crops out in upland hills and in resistant ledges in valley areas. The geologic map differentiates surficial materials of Quaternary age on the basis of their lithologic characteristics (such as grain size and sedimentary structures), constructional geomorphic features, stratigraphic relationships, and age. Surficial materials also are known in engineering classifications as unconsolidated soils, which include coarse-grained soils, fine-grained soils, or organic fine-grained soils. Surficial materials underlie and are the parent materials of modern pedogenic soils, which have developed in them at the land surface. Surficial earth materials significantly affect human use of the land, and an accurate description of their distribution is particularly important for water resources, construction aggregate resources, earth-surface hazards assessments, and land-use decisions.

The mapped distribution of surficial materials that lie between the land surface and the bedrock surface is based on detailed geologic mapping of 7.5-minute topographic quadrangles, as part of a cooperative state-wide mapping program between the U.S. Geological Survey and the Massachusetts Department of Public Works (now Massachusetts Highway Department) (Page, 1967; Stone, 1982), and the Office of the Massachusetts State Geologist. Each published geologic map presents a detailed description of local geologic map units, the genesis of the deposits, and age correlations among units. Regional summaries of these maps and unpublished maps discuss the ages of multiple glaciations, the nature of glaciofluvial, glaciolacustrine, and glaciomarine deposits, and the processes of ice advance and retreat across Massachusetts (Warren and Stone, 1986; Koteff and Pessl, 1981; papers in Larson and Stone, 1982; Oldale and Barlow, 1986; Stone and Borns, 1986).

This compilation of surficial geologic materials is an interim product that defines the areas of exposed bedrock, and the boundaries between glacial till, glacial stratified deposits, and overlying postglacial deposits. This work is part of a comprehensive study to produce a statewide digital map of the surficial geology at a 1:24,000-scale level of accuracy. This map of 11 quadrangles revises previous digital surficial geologic maps (Stone and Beinikis, 1993; MassGIS, 1999) that were compiled on base maps at regional scales of 1:125,000 and 1:250,000. The purpose of this study is to provide fundamental geologic data for the evaluation of natural resources, hazards, and land information within the Commonwealth of Massachusetts.

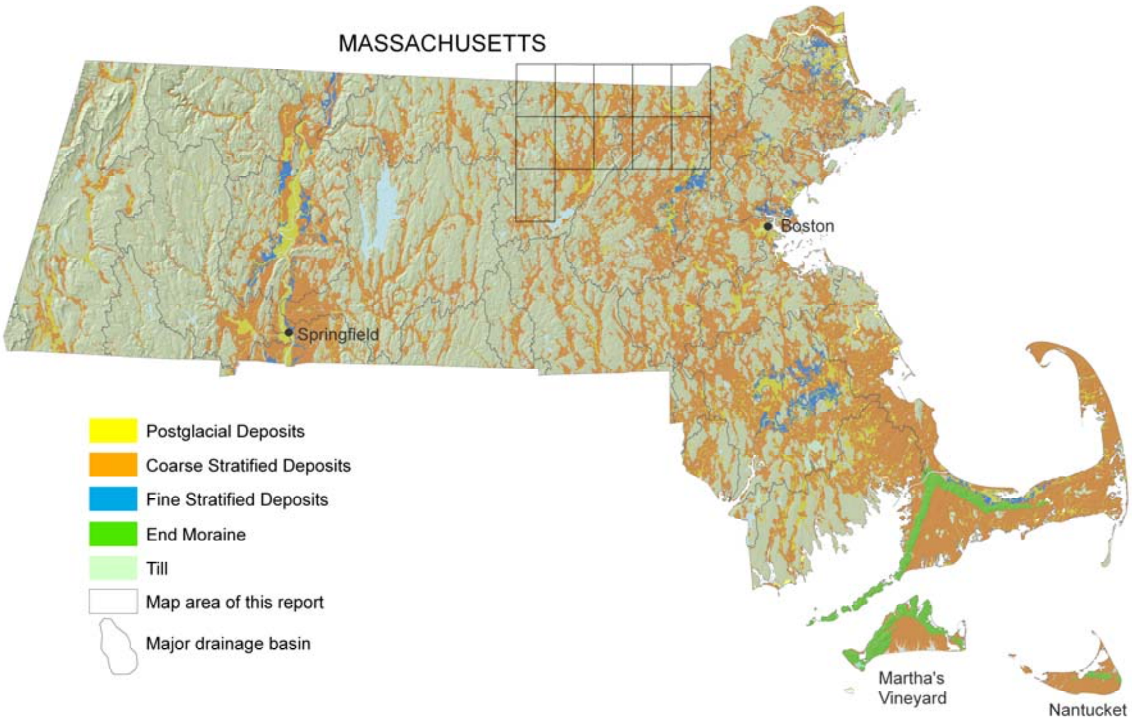


Figure 1. General distribution of glacial and postglacial deposits in Massachusetts (Stone and Beinikis, 1993, MassGIS, 1999) and map area covered by this report.

Surficial Materials in Massachusetts

Most of the surficial materials in Massachusetts are deposits of the last two continental ice sheets that covered all of New England in the latter part of the Pleistocene ice age (Schafer and Hartshorn, 1965; Stone and Borns, 1986; Oldale and others, 1982). The glacial deposits are divided into two broad categories, ***glacial till*** and ***glacial stratified deposits***. Till, the most widespread glacial deposit, was laid down directly by glacier ice. Glacial stratified deposits are concentrated in valleys and lowland areas and were laid down by glacial meltwater in streams, lakes, and the sea in front of the retreating ice margin during the last deglaciation. Postglacial sediments, primarily floodplain alluvium and swamp deposits, make up a lesser proportion of the unconsolidated materials.

Glacial till deposits consist of nonsorted, generally nonstratified mixtures of mineral and rock particles ranging in grain size from clay to large boulders. The matrix of most tills is composed dominantly of fine sand and silt. Boulders within and on the surface of tills range from sparse to abundant. Some tills contain lenses of sorted sand and gravel and less commonly, masses of laminated fine-grained sediments. The color and lithologic characteristics of till deposits vary across Massachusetts, but generally reflect the composition of the local underlying and northerly adjacent bedrock from which the till was derived. Till blankets the bedrock surface in variable thickness, ranging from a few inches to more than 200 ft, and commonly underlies stratified meltwater deposits. Tills deposited during the last two glaciations occur in superposition within Massachusetts (Koteff, 1966; Newton, 1978; Weddle and others, 1989). The upper till was deposited during the last (late Wisconsinan) glaciation; it is the most extensive till and commonly is observed in surface exposures, especially in areas where till thickness is less than 15 ft (thin till unit on the map). The lower till ("old" till) was deposited during an earlier glaciation (probably Illinoian). The lower till has a more limited distribution; it is principally a subsurface deposit that constitutes the bulk of material in drumlins and other hills where till thickness is greater than 15 ft. The distribution of lower till is shown primarily by the thick till unit on the map. The lower till generally is overlain by thin upper till deposits in these areas. In all exposures showing the superposed two tills, the base of the upper till truncates the weathered surface of the old till. The lower part of the upper till commonly displays a zone of shearing, dislocation, and brecciation in which clasts of lower till were mixed and incorporated into the upper till during the last glaciation.

End moraine deposits are composed predominantly of bouldery ablation till, but also locally may include sorted sediments. These deposits were laid down by glacial-melting processes along active ice margins during retreat of the last (late-Wisconsinan) ice sheet. Extensive end moraines on Nantucket and Martha's Vineyard (fig. 1) are related to the terminal position of the late-Wisconsinan ice sheet, and the end moraines on Cape Cod are associated with recessional positions of the last ice sheet. Less extensive end moraines occur locally elsewhere in southeastern Massachusetts, in the Boston area, and in the Gloucester-Rockport area of northeastern Massachusetts.

Glacial stratified deposits consist of layers of well-sorted to poorly sorted gravel, sand, silt, and clay laid down by flowing meltwater in glacial streams, lakes, and marine embayments that occupied the valleys and lowlands of Massachusetts during retreat of the last ice sheet. Textural variations within the meltwater deposits occur both areally and vertically because meltwater-flow regimes were different in glaciofluvial (stream), glaciodeltaic (where a stream entered a lake or the sea), glaciolacustrine (lake bottom), and glaciomarine (marine bottom) depositional environments. Grain-size variations also resulted from meltwater deposition in positions either proximal to or distal from the retreating glacier margin, which was the principal sediment source. A common depositional setting contained a proximal, ice-marginal meltwater stream in which horizontally bedded glaciofluvial gravel and/or sand and gravel were laid down; farther down valley, the stream entered a glacial lake where glaciodeltaic sediments were deposited, consisting of horizontally layered sand and gravel delta-topset beds overlying inclined layers of sand in delta-foreset beds. Farther out in the glacial lake, very fine sand, silt, and clay settled out on the lake bottom in flat-lying, thinly bedded glaciolacustrine layers. Thick sequences having these textural variations commonly are present in the vertical section of meltwater deposits across the State (Stone and others, 1992). Detailed geologic maps can show meltwater sedimentary units within each glacial lake or valley outwash system (Jahns, 1941; 1953; Koteff, 1966). These units, known as *morphosequences* (Koteff, 1974; Koteff and Pessl, 1981), are the smallest mappable stratigraphic units depictable on detailed geologic maps. *Morphosequences* are bodies of stratified meltwater sediments that are contained in a continuum of landforms, grading from ice-contact forms (eskers, kames) to non-ice-contact forms (flat valley terrace, delta plains) that were deposited simultaneously at and beyond the margin of the ice sheet, graded to a specific base level. Each morphosequence consists of a proximal part (head) deposited within or near the ice margin, and a distal part deposited farther away from the ice margin. Both grain size and ice-melt collapse deformation of beds decrease from the proximal to the distal part of each morphosequence. The head of each morphosequence is either ice marginal (ice contact) or near ice marginal. The surface altitude of fluvial sediments in each morphosequence was controlled by a specific base level, either a glacial-lake or marine water plane or a valley knickpoint. Few morphosequences extend distally more than 10 km, and most are less than 2 km in length. In any one basin, individual morphosequences were deposited sequentially as the ice margin retreated systematically northward. Consequently, in many places the distal, finer grained facies of a younger morphosequence stratigraphically overlies the proximal, coarse-grained facies of a preceding morphosequence. Figure 2 shows the variability of sediment types in the subsurface of glacial stratified deposits. The figure schematically shows the relationship between coarse-grained deltaic deposits and extensive fine-grained lake (or marine) deposits in the subsurface. Such coarse- and fine-grained units are common in most of the valleys and lowlands of Massachusetts (Langer, 1979, Stone and others, 1979; Stone and others, 1992; Stone and others, 2005). On this interim map, coarse-grained and fine-grained textural variations within glacial stratified deposits are shown only where they occur at land surface. Subsurface textural variations are not shown.

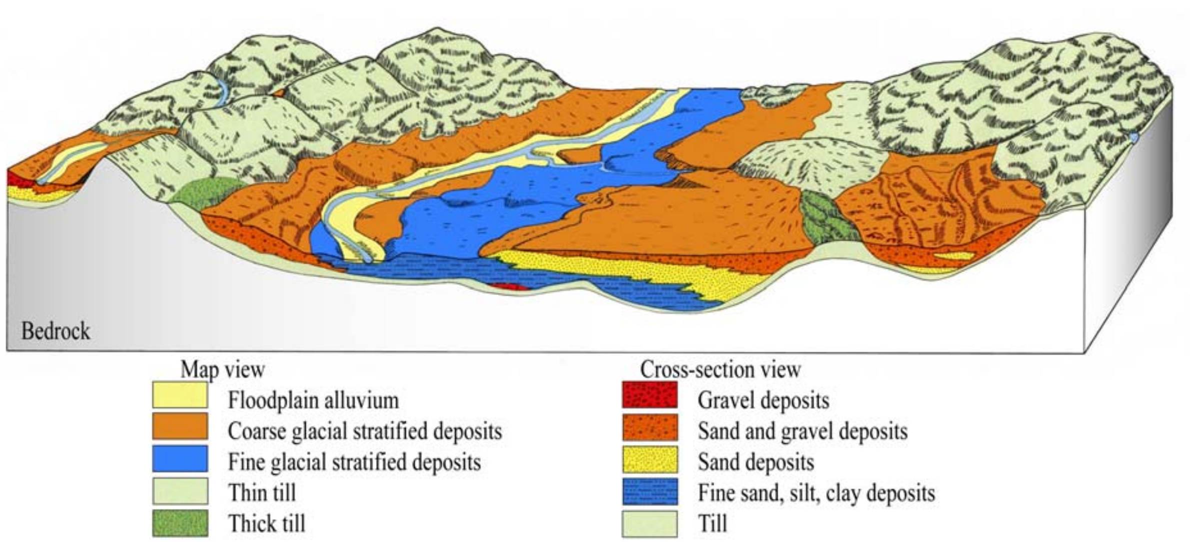


Figure 2. Block diagram illustrating the typical areal and vertical distribution of glacial and postglacial deposits overlying bedrock (modified from Stone and others, 1992).

The areal distribution of till and stratified deposits is related to the physiography of the State (fig. 1). The thickness of these materials varies considerably within these regions because of such factors as the high relief of the bedrock surface, changing environments of deposition during deglaciation, and various effects of postglacial erosion and removal of glacial sediments. In highland areas, notably in the western and central regions, till is the major surficial material, which is present as a discontinuous mantle of variable thickness over the bedrock surface. Till is thickest in drumlins (reportedly as much as 230 ft thick) and on the northwest slopes of most bedrock hills. Glacial meltwater deposits that average 50 feet in thickness (Stone and Beinikis, 1993) overlie the till in small upland valleys and north-sloping basins between bedrock hills. Glacial stratified deposits are the predominant surficial materials in the Connecticut River valley, the northeastern and southeastern lowlands, and on Cape Cod and the islands. These deposits generally overlie till;

however, well logs indicate that in some places till is not present and the stratified deposits lie directly on bedrock. On Cape Cod and the islands, in the southeastern lowland, and in parts of the Connecticut River valley these deposits completely cover the till-draped bedrock surface.

Postglacial deposits locally overlie the glacial deposits throughout the State. Alluvium underlies the floodplains of most streams and rivers. Swamps occur in low-lying, poorly drained areas in upland and lowland settings, but swamp deposits are shown only where they are estimated to be at least 3 ft thick. Salt-marsh and estuarine deposits are present mainly along the tidal portions of streams and rivers entering the offshore areas. Beach deposits occur along the shoreline.

Description of Map Units

Postglacial Deposits

Artificial fill—Earth materials and manmade materials that have been artificially emplaced, primarily in highway and railroad embankments, and in dams; may also include landfills, urban development areas, and filled coastal wetlands.

Floodplain alluvium—Sand, gravel, silt, and some organic material, stratified and well sorted to poorly sorted, beneath the floodplains of modern streams. The texture of alluvium commonly varies over short distances both laterally and vertically, and generally is similar to the texture of adjacent glacial deposits. Along smaller streams, alluvium is commonly less than 5 ft thick. The most extensive deposits of alluvium on the map are along the Nashua, Squannacook, and Nissitissit Rivers where the texture is predominantly sand, fine gravel, and silt, and total thickness is as much as 25 ft. Alluvium typically overlies thicker glacial stratified deposits.

Swamp deposits—Organic muck and peat that contain minor amounts of sand, silt, and clay, stratified and poorly sorted, in kettle depressions or poorly drained areas. Most swamp deposits are less than about 10 ft thick. Swamp deposits overlie glacial deposits or bedrock. They locally overlie glacial till even where they occur within thin glacial meltwater deposits.

Early postglacial inland dune deposits—Fine to medium, well-sorted sand, in transverse, parabolic, and hummocky dunes as much as 30 ft thick. Occur most commonly in large glacial lake basins where sand was derived from extensive glacial-lake deltas that were not yet vegetated and deposited in dune forms by early postglacial winds. Dune sand is now fixed by vegetation except where disturbed by human activities.

Glacial Stratified Deposits

Sorted and stratified sediments composed of gravel, sand, silt, and clay (as defined in particle size diagram, fig. 3) deposited in layers by glacial meltwater. These sediments occur as four basic textural units—gravel deposits, sand and gravel deposits, sand deposits, and fine deposits. On this interim map, gravel, sand and gravel, and sand deposits are not differentiated and are shown as *Coarse Deposits* where they occur at land surface. *Fine Deposits* also are shown where they occur at land surface. **Textural changes occur both areally and vertically (fig. 2), however subsurface textural variations are not shown on this interim map.**

PARTICLE DIAMETER											
in.	10	2.5	0.16	0.08	0.04	0.02	0.01	0.005	0.0025	0.00015	
mm	256	64	4	2	1	0.5	0.25	0.125	0.063	0.004	
	Boulders	Cobbles	Pebbles	Granules	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
	GRAVEL PARTICLES				SAND PARTICLES				FINE PARTICLES		

Figure 3. Grain-size classification used in this report, modified from Wentworth (1922).

.

Coarse deposits include: *Gravel deposits* composed of at least 50 percent gravel-sized clasts; cobbles and boulders predominate; minor amounts of sand within gravel beds, and sand comprises few separate layers. Gravel layers generally are poorly sorted and bedding commonly is distorted and faulted due to postdepositional collapse related to melting of ice. *Sand and gravel deposits* composed of mixtures of gravel and sand within individual layers and as alternating layers. Sand and gravel layers generally range from 25 to 50 percent gravel particles and from 50 to 75 percent sand particles. Layers are well to poorly sorted; bedding may be distorted and faulted due to postdepositional collapse. *Sand deposits* composed mainly of very coarse to fine sand, commonly in well-sorted layers. Coarser layers may contain up to 25 percent gravel particles, generally granules and pebbles; finer layers may contain some very fine sand, silt, and clay.

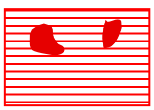
Fine deposits include very fine sand, silt, and clay that occurs as well-sorted, thin layers of alternating silt and clay, or thicker layers of very fine sand and silt. Very fine sand commonly occurs at the surface and grades downward into rhythmically bedded silt and clay varves. Locally, this map unit may include areas underlain by fine sand.

Glacial Till Deposits

Thin till—Nonsorted, nonstratified matrix of sand, some silt, and little clay containing scattered gravel clasts and few large boulders; in areas where till is generally less than 10-15 ft thick and including areas of bedrock outcrop where till is absent. Predominantly upper till of the last glaciation; loose to moderately compact, generally sandy, commonly stony. Two facies are present in some places; a looser, coarser-grained ablation facies, melted out from supraglacial position; and an underlying more compact, finer-grained lodgement facies deposited subglacially. In general, both ablation and lodgement facies of upper till derived from fine-grained bedrock are finer grained, more compact, less stony and have fewer surface boulders than upper till derived from coarser grained crystalline rocks. Fine-grained bedrock sources include the red Mesozoic sedimentary rocks of the Connecticut River lowland, marble in the western river valleys, and fine-grained schists in upland areas.

Thick till—Nonsorted, nonstratified matrix of sand, some silt, and little clay containing scattered gravel clasts and few large boulders at the surface; in the shallow subsurface, compact, nonsorted matrix of silt, very fine sand, and some clay containing scattered small gravel clasts in areas where till is greater than 10-15 ft thick, chiefly in drumlin landforms in which till thickness commonly exceeds 100 ft (maximum recorded thickness is 230 ft). Although upper till is the surface deposit, the lower till constitutes the bulk of the material in these areas. Lower till is moderately to very compact, and is commonly finer grained and less stony than upper till. An oxidized zone, the lower part of a soil profile formed during a period of interglacial weathering, is generally present in the upper part of the lower till. This zone commonly shows closely spaced joints that are stained with iron and manganese oxides.

Bedrock Areas



Bedrock outcrops and areas of abundant outcrop or shallow bedrock— Solid color shows extent of individual bedrock outcrops; line pattern indicates areas of shallow bedrock or areas where small outcrops are too numerous to map individually; in areas of shallow bedrock, surficial materials are less than 5-10 ft thick.

Map Compilation

This compilation is the third in a series of interim products showing surficial geology in eleven 7.5-minute quadrangles in east-central Massachusetts: Ashby, Townsend, Pepperell, Nashua South, Lowell, Fitchburg, Shirley, Ayer, Westford, Billerica, and Sterling (fig. 4, fig 5 area C). Figure 5 shows all of the compilation areas for surficial geology in Massachusetts. These maps will be produced sequentially by letter designation.

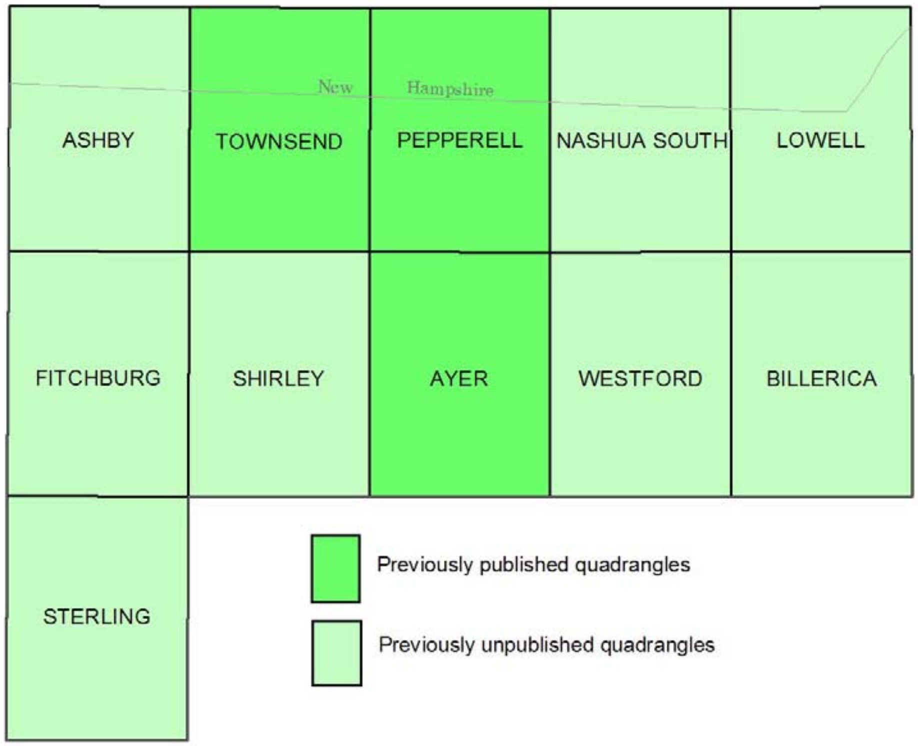


Figure 4. 7.5-minute quadrangles in this compilation.

This map was compiled in several steps: 1) Paper copies of the published surficial geologic maps for three quadrangles were scanned and georeferenced by MASSGIS. 2) The Office of the Massachusetts State Geologist vectorized the georeferenced images in order to digitally retain the original line work of the published maps (Mabee and others, 2004). 3) Digital geologic map units were compiled and grouped into ten basic units in four broader categories: *Postglacial deposits* including artificial fill, swamp deposits, floodplain alluvium, and inland dune deposits; *glacial stratified deposits* including coarse-grained and fine-grained deposits; *glacial till* including thin till and thick till (drumlins); and *bedrock areas* including outcrops and areas of shallow bedrock). The distribution of glacial stratified deposits beneath adjacent overlying postglacial deposits and water bodies was inferred by the compilers. 4) The same basic units for eight unpublished quadrangles were compiled and digitized from scanned field maps by U.S. Geological Survey personnel. 5) The 11 individual quadrangles were joined and edge-matched in order to form a seamless geologic map. Discrepancies along quadrangle boundaries were resolved, and thick till areas were added by the compilers in quadrangles where this unit was not previously mapped.

All geologic mapping was completed at 1:24,000 scale; however the browse graphic is presented at 1:50,000 scale with shaded relief base. The 1:24,000-scale, 10-ft contour interval topographic base maps used for this mapping effort are included as part of the digital data package in the 24k_basemaps folder. The GIS folder included with this report contains 3 ARCGIS shapefiles which are geologic units that cover the entire map area, and are intended for use at quadrangle scale; the shapefiles can be clipped by quadrangle or town boundaries. Unlike conventional geologic maps, the digital mapping is arranged in layers according to superposition.

The till-bedrock shapefile should be placed on the bottom, and overlain by the stratified deposits shapefile; these materials are shown everywhere that they occur including beneath postglacial deposits, such as swamp deposits, floodplain alluvium, and water bodies. The postglacial shapefile should be placed on top because these materials overlie the other two layers. Instructions for using the digital files are included in the README file and metadata.

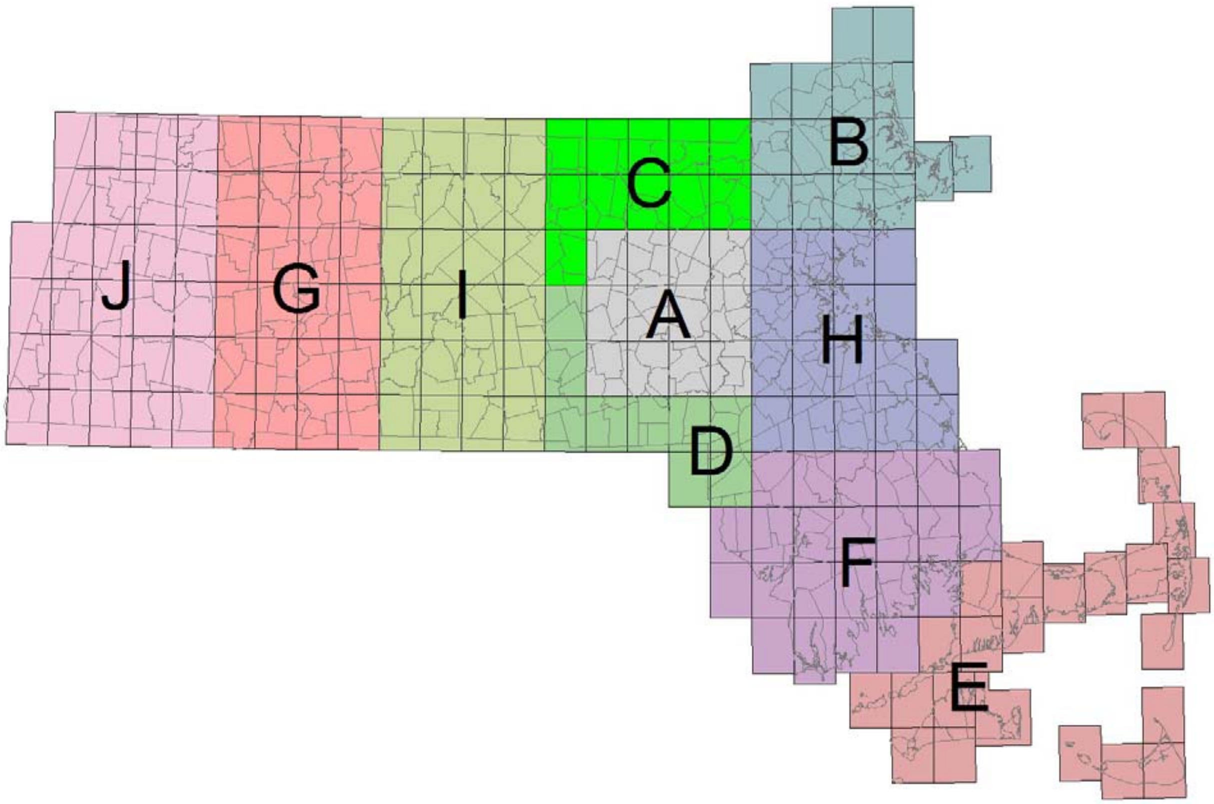


Figure 5. Compilation areas in Massachusetts.

References

Allmendinger, R.W., and Schneider, W.D., 1976, Interim surficial geologic map of the Shirley quadrangle, Massachusetts, U.S. Geolgical Survey Open-file Map 76-388 (assisted by S.L. Russel and P.C. Weigel).

Castle, R.O., 1950, Surficial geologic map of parts of Billerica, Wilmington, and Lexington quadrangles, U.S. Geological Survey Open-file map 50-31, 1:31,680 scale.

Holland, W.R., 1980, The surficial geology of the Billerica quadrangle, Middlesex County, Massachusetts; unpublished A.M. Thesis, 172 pp., 5 plates, Boston University, Boston, Massachusetts.

Jahns, R.H, 1941, Outwash chronology in northeastern Massachusetts (abs.): Geological Society of America Bulletin, v. 52, no. 12, pt. 2, p. 1910.

Jahns, R.H, 1953, Surficial geology of the Ayer quadrangle, Mass: U.S. Geological Survey Geologic Quadrangle Map GQ-21, scale 1:31,680.

Jahns, R.H., Willard, M.E., White, W.S., Currier, L.W., and White, S.E., 1946, Overlay map of the Glacial Geology of parts of the Tyngsboro and Westford, Massachusetts Quadrangles: Friends of the Pleistocene Glacial Geology Field Meeting, June 1 and 2, 1946, scale 1:31,680.

Koteff, Carl, 1966, Surficial geologic map of the Clinton quadrangle, Worcester County, Massachusetts: U.S. Geological Survey Geologic Quadrangle Map GQ-567, scale 1:24,000.

Koteff, Carl, 1974, The morphologic sequence concept and deglaciation of southern New England, in Coates, D.R., ed., Glacial geomorphology: Binghamton, N.Y., State University of New York, Publications in Geomorphology, p. 121-144.

Koteff, Carl, and Pessl, Fred, Jr., 1981, Systematic ice retreat in New England: U.S. Geological Survey Professional Paper 1179, 20 p.

Koteff, Carl, and Stone, B.D., 1990, Surficial geologic map of the Townsend quadrangle, Middlesex and Worcester Counties, Massachusetts, and Hillsborough County, New Hampshire: U.S. Geological Survey Geologic Quadrangle Map GQ-1677, scale 1:24,000.

Koteff, Carl, and Volckmann, R.P., 1973, Surficial geology of the Pepperell quadrangle, Middlesex County, Massachusetts, and Hillsborough County, New Hampshire: U.S. Geological Survey Geologic Quadrangle Map GQ-1118, scale 1:24,000.

Langer, W.H., 1979, Map showing distribution and thickness of the principal fine-grained deposits, Connecticut Valley urban area, central New England: U.S. Geological Survey Miscellaneous Investigations Series Map I-1074-C, scale 1:125,000.

Larson, G.J., and Stone, B.D. (eds.), 1982, Late Wisconsinan glaciation of New England: Dubuque, Iowa, Kendall/Hunt, 252 p.

Mabee, S.B., Stone, B.D., and Stone, J.R., 2004, Precise conversion of paper geologic maps to value-added digital products: the Massachusetts method for surficial geology; Geological Society of America Abstracts with Programs v. 36, no. 2, p. 78.

MassGIS, Office of Geographic and Environmental Information, Commonwealth of Massachusetts, Executive Office of Environmental Affairs, 1999, Surficial geology data layer, vector digital data.

Newton, R.M., 1978, Stratigraphy and structure of some New England tills: Amherst, Massachusetts, University of Massachusetts, unpublished Ph.D. thesis, 241 p.

Oldale, R.N., and Barlow, R.A., 1986, Geologic map of Cape Cod and the Islands, Massachusetts; U.S. Geological Survey Miscellaneous Investigations Map I-1763, scale 1:100,000.

Oldale, R.N., Valentine, P.C., Cronin, T.M., Spiker, E.C., Blackwelder, B.W., Belknap, D.F., Wehmiller, J.F., and Szabo, B.J., 1982, Stratigraphy, structure, absolute age, and paleontology of the upper Pleistocene deposits at Sankaty Head, Nantucket Island, Massachusetts: Geology, v. 10, no. 5, p. 246-252.

Page, L.R., 1967, The role of the United States Geological Survey in Massachusetts: in Farquhar, O.C. (ed.), Economic Geology in Massachusetts: University of Massachusetts, p. 9-28.

Schafer, J.P., and Hartshorn, J.H., 1965, The Quaternary of New England, in Wright, H.E., Jr., and Frey, D.G., eds., The Quaternary of the United States: Princeton, N.J., Princeton University Press, p. 113-128.

Stone, B.D., 1982, The Massachusetts state surficial geology map: in Farguhar, O.C. (ed.), Geotechnology in Massachusetts: Boston, Massachusetts, p. 11-27.

Stone, B.D., and Beinikis, A.I., 1993, Sand and gravel resources of Massachusetts; New England Governors' Conference, Inc., Boston, MA, map, 2 sheets, scale 1:250,000.

Stone, B.D., and Borns, H.W., Jr., 1986, Pleistocene glacial and interglacial stratigraphy of New England, Long Island, and adjacent Georges Bank and Gulf of Maine: in Sibrava, V., Bowen, D.Q., and Richmond, G.M., [eds.], Quaternary Glaciations in the Northern Hemisphere: Oxford, Pergamon Press, p. 39-52.

Stone, J.R., London, E. H., and Langer, W.H., 1979, Map showing textures of unconsolidated materials, Connecticut Valley urban area, central New England: U.S. Geological Survey Miscellaneous Field Studies Map I-1074-B, scale 1:125,000.

Stone, J.R., Schafer, J.P., London, E.H., and Thompson, W.B., 1992, Surficial materials map of Connecticut: U.S. Geological Survey Special Map, scale 1:125,000.

Stone, J.R., Schafer, J.P., London, E.H., Lewis, R.L., DiGiacomo-Cohen, M.L., and Thompson, W.B., 2005, Quaternary geologic map of Connecticut and Long Island Sound Basin: U.S. Geological Survey Scientific Investigations Map SI-2784, 1:125,000 scale, two sheets.

Warren, C.R., and Stone, B.D., 1986, Deglaciation stratigraphy, mode and timing of the eastern flank of the Hudson-Champlain lobe in western Massachusetts, in D.H. Cadwell (ed.), The Wisconsinan Stage of the First Geological District, Eastern New York: New York State Museum Bulletin Number 455, pp. 168-192.

Weddle, T.K., Stone, B.D., Thompson, W.B., Retelle, M.J., Caldwell, D.W., and Clinch, J.M., 1989, Illinoian and Late Wisconsinan Tills in Eastern New England: A transect from Northeastern Massachusetts to West-Central Maine, Trip A-2: in A.W. Berry Jr., [ed.], Guidebook for Field Trips in Southern and West-central Maine, New England Intercollegiate Geological Conference, p. 25-85.

Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments; Journal of Geology, vol. 30, p. 377-392.

Appendix

Sources of Data by 7.5-Minute Quadrangle

Ashby Quadrangle

Stone, B.D., 1982, Unpublished field maps

Townsend Quadrangle

Map units were reproduced from Koteff and Stone (1990). Glacial Stratified Deposits in this quadrangle include deposits of glacial lakes Nashua and Nissitissit and other smaller valley deposits. Thick till areas shown on this map were inferred from photographic-image and topographic analysis, well data, and drumlin symbols shown by Koteff and Stone (1990).

Pepperell Quadrangle

Map units were reproduced from Koteff and Volckmann (1973). Glacial Stratified Deposits in this quadrangle include deposits of glacial lakes Nashua and Nissitissit, and other smaller valley deposits. Fine-grained glacial stratified deposits at land surface include lake-bottom deposits of glacial Lakes Nashua and Nissitissit (units Qnb and Qnib of Koteff and Volckmann 1973); these units have been extended beneath adjacent water bodies and postglacial deposits on this map. Thick till areas shown on this map were inferred from photographic image and topographic analysis and drumlin symbols shown by Koteff and Volckmann (1973).

Nashua South Quadrangle

Unknown compiler, 1980-82, Unpublished field maps

Lowell Quadrangle

Unknown compiler, 1980-82, Unpublished field maps

Fitchburg Quadrangle

Stone, B.D., 1982, Unpublished field maps

Shirley Quadrangle

Primary source of map units was Stone, B.D., 1982, Unpublished field maps; minor contributions from Allmendinger and Schneider (1975).

Ayer Quadrangle

Map units were reproduced from Jahns (1953). Glacial Stratified Deposits in this quadrangle include deposits of glacial Lake Nashua and other smaller valley deposits. Fine-grained glacial stratified deposits at land surface include lake-bottom deposits of glacial Lake Nashua (unit Qnl of Jahns, 1953); these units have been extended beneath adjacent water bodies and postglacial deposits on this map. Drumlin till unit was reproduced from the published map; other areas of thick till were inferred from photographic-image and topographic analysis.

Westford Quadrangle

Unknown compiler, 1980-82, Unpublished field maps

Billerica Quadrangle

Map units reproduced from Holland, W.R. (1980).

Sterling Quadrangle

Stone, B.D., 1982, Unpublished field maps