

National Cooperative Geologic Mapping Program

Implementation Plan of the National Cooperative Geologic Mapping Program Strategy—Northeast Region of the United States: New York and New England



Open-File Report 2023–1059

Cover. Photograph of the view looking east past Coot Hill in the Adirondack Mountains of New York, across Lake Champlain and the Champlain Valley, to the Green Mountains of Vermont on the horizon. Photograph by Gregory J. Walsh, U.S. Geological Survey.

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By Gregory J. Walsh, Margaret A. Thomas, Robert G. Marvinney,
Stephen B. Mabee, Frederick H. Chormann, Andrew Kozlowski, Marjorie H. Gale,
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The contact information for individuals in the 2020 Northeast Region Working Group is provided in [table 1](#).

Abbreviations

3D	three-dimensional
DEM	digital elevation model
Earth MRI	Earth Mapping Resources Initiative
GIS	geographic information system
km	kilometer
lidar	light detection and ranging
MRP	Mineral Resources Program
NCGMP	National Cooperative Geologic Mapping Program
NESGMC	New England States Geologic Mapping Coalition
NGMDB	National Geologic Map Database
PFAS	per- and polyfluoroalkyl substances
REE	rare earth element
SHRIMP	Sensitive High Resolution Ion Microprobe
SHRIMP–RG	Sensitive High Resolution Ion Microprobe with Reverse Geometry
USGS	U.S. Geological Survey
WMA	Water Resources Mission Area

Implementation Plan of the National Cooperative Geologic Mapping Program Strategy—Northeast Region of the United States: New York and New England

By Gregory J. Walsh,¹ Margaret A. Thomas,² Robert G. Marvinney,³ Stephen B. Mabee,⁴ Frederick H. Chormann,⁵ Andrew Kozlowski,⁶ Marjorie H. Gale,⁷ Jon Kim,⁷ and Brian Savage⁸

Abstract

Complexly deformed igneous, metamorphic, and sedimentary rocks form the bedrock of the Northeast region of the United States. Variably thick unconsolidated sediments deposited by glacial, fluvial, and eolian systems locally cover the bedrock. New geologic mapping focuses on areas lacking modern, detailed studies or syntheses, and contributes to existing framework research. This report addresses plans for the continued development of regionally and nationally consistent geologic maps and map databases, efforts to answer outstanding geologic questions, and societal concerns associated with related geologic topics, such as hazards, geologic and hydrologic resources, and environmental issues.

Introduction

In 2021, the National Cooperative Geologic Mapping Program (NCGMP), authorized by the National Geologic Mapping Act of 1992 (Public Law 102–285 as amended, 106 Stat. 166), published a strategic plan titled “Renewing the National Cooperative Geologic Mapping Program as the Nation’s Authoritative Source for Modern Geologic Knowledge” (Brock and others, 2021). The plan provides a vision, mission, and goals for the program for 2020–2030. The NCGMP developed this implementation plan as a way to promote the goals outlined in the strategic plan.

This implementation plan intends to inform the annual review of projects carried out by U.S. Geological Survey (USGS) staff through FEDMAP—as described in the strategic plan and through the development of the annual FEDMAP prospectus—to ensure effective application of the NCGMP strategy.

This report is part of the implementation plan of the NCGMP strategy. Implementation plans by Langenheim and others (2021) and Merschat and others (2022) guided the development of this current implementation plan. This region-specific report addresses three focal points:

1. continued development of nationally consistent geologic maps and map databases,
2. major unanswered geologic questions within the region, and
3. societal concerns associated with related geologic questions, such as hazards, geologic and hydrologic resources, and environmental matters.

The Northeast region is underlain by glaciated, complexly deformed crystalline igneous and metamorphic rocks and sedimentary rocks; it is variably covered by unconsolidated sediments deposited by continental glaciers, glaciofluvial meltwaters, periglacial conditions, modern fluvial systems, and wind. New geologic mapping focuses on areas lacking detailed or modern maps. New maps contribute to framework studies that help characterize water availability, groundwater behavior and groundwater contaminants in fractured rock and glacial sediments, distribution of mineral and aggregate resources, coastal flooding and natural hazards—such as landslides and river valley evulsion due to extreme weather events—and address outstanding questions about the tectonic evolution of ancient mountain belts. New large-scale geologic maps include detailed fracture information for characterizing the recharge potential of bedrock lithologies and identifying potential pathways for groundwater and contaminant flow. All of these geologic mapping activities are supported by modern geochemistry, geochronology, and paleontology in scientifically appropriate areas.

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Geologic Setting

The Northeast region, in this report, includes New York and the six New England States (fig. 1). The physiography primarily includes the Adirondack Mountains and the New England section of the northern Appalachian Highlands but also includes the St. Lawrence and Champlain Valleys (fig. 2). In New York, the region overlaps with the Appalachian Plateau and Valley and Ridge provinces and the Great Lakes-Central Lowland provinces.

The oldest bedrock (circa 1.4–0.9 Ga, giga annum, or billion years ago) is underlain by highly deformed crystalline metamorphic and igneous basement rocks of the Grenville province exposed in massifs of the Adirondack Mountains, Green Mountains, Berkshire Hills (or Berkshires), and Housatonic and Hudson Highlands (as in Walsh and others, 2004 and Ratcliffe and others, 2011). Neoproterozoic to Paleozoic metamorphic rocks of different terrane affinities and sedimentary rocks derived from the Appalachian Highlands (Hibbard and others, 2006) underlie the New England, Valley and Ridge, Appalachian Plateau, and St. Lawrence Valley provinces of Fenneman (1970).

Multiple orogenic events from the Mesoproterozoic to the Late Paleozoic deformed the bedrock of the Appalachian Mountains, which extends from Georgia to Maine and into Canada, and once extended to the United Kingdom, Western Europe, and Western Africa (as explained in Murphy and others, 2010, and van Staal and others, 2012). Middle to Late Paleozoic plutonic rocks are widespread, and Mesozoic rift basins and magmatic rocks are related to the formation of the Atlantic Basin and mantle plumes (Eby, 1987; Foland and Allen, 1991). The Appalachian Highlands disappear beneath the Cenozoic sedimentary rocks and unconsolidated deposits of the Atlantic Coastal Plain, which, in the Northeast region, occur only in coastal southern New York and southern New England. Excepting a small area of southwestern New York along the Pennsylvania border (Soller, 1993; Crowl and Sevon, 2002), the entire Northeast region was buried by Pleistocene continental ice sheets, the last of which created the terminal deposits from Long Island to Cape Cod during Wisconsinan glaciation (Stone and others, 2005).

Status of Geologic, Topographic, and Geophysical Mapping

Over the last two decades, geologic mapping in the Northeast region focused on framework mapping at the scale most relevant to societal applications (1:24,000, as discussed in Bhagwat and Ipe, 2000; Fortier and others, 2019; and New England States Geologic Mapping Coalition [NESGMC], 2021). This is especially true for forested terrain underlain by the complex geology of the Northeast region. Map compilations at 1:100,000-scale are the current standard for synthesizing the detailed bedrock mapping of the region (Ratcliffe and others, 2011; Hussey and others, 2016). Map compilations at 1:24,000- to 1:125,00-scale are the current standard for synthesizing detailed surficial mapping in the region (see Stone and others, 2005, 2018).

These map compilations provide multiple benefits, such as improving upon the geologic framework mapping for a region or State, solving edge-match problems, superseding maps that are decades old, providing new maps that are more detailed than older maps (1:250,000 to 1:500,000), providing maps widely used in regional- and national-scale studies, and creating significant educational value. In many cases, regional syntheses were made possible by 1:24,000-scale mapping (see Cobb, 2002, and Ratcliffe and others, 2011).

The continued acquisition of new data from field observations is a requirement for any geologic mapping program, and the continuation of the practice has clear societal and economic value (Bernknopf and others, 1993; Bhagwat and Ipe, 2000; Cobb, 2002; Thomas, 2004; Hornberger and others, 2006; Häggquist and Söderholm, 2015; Indiana University, 2017). For this reason, it is the consensus of the working group that detailed mapping remains a crucial component of future work in the region.

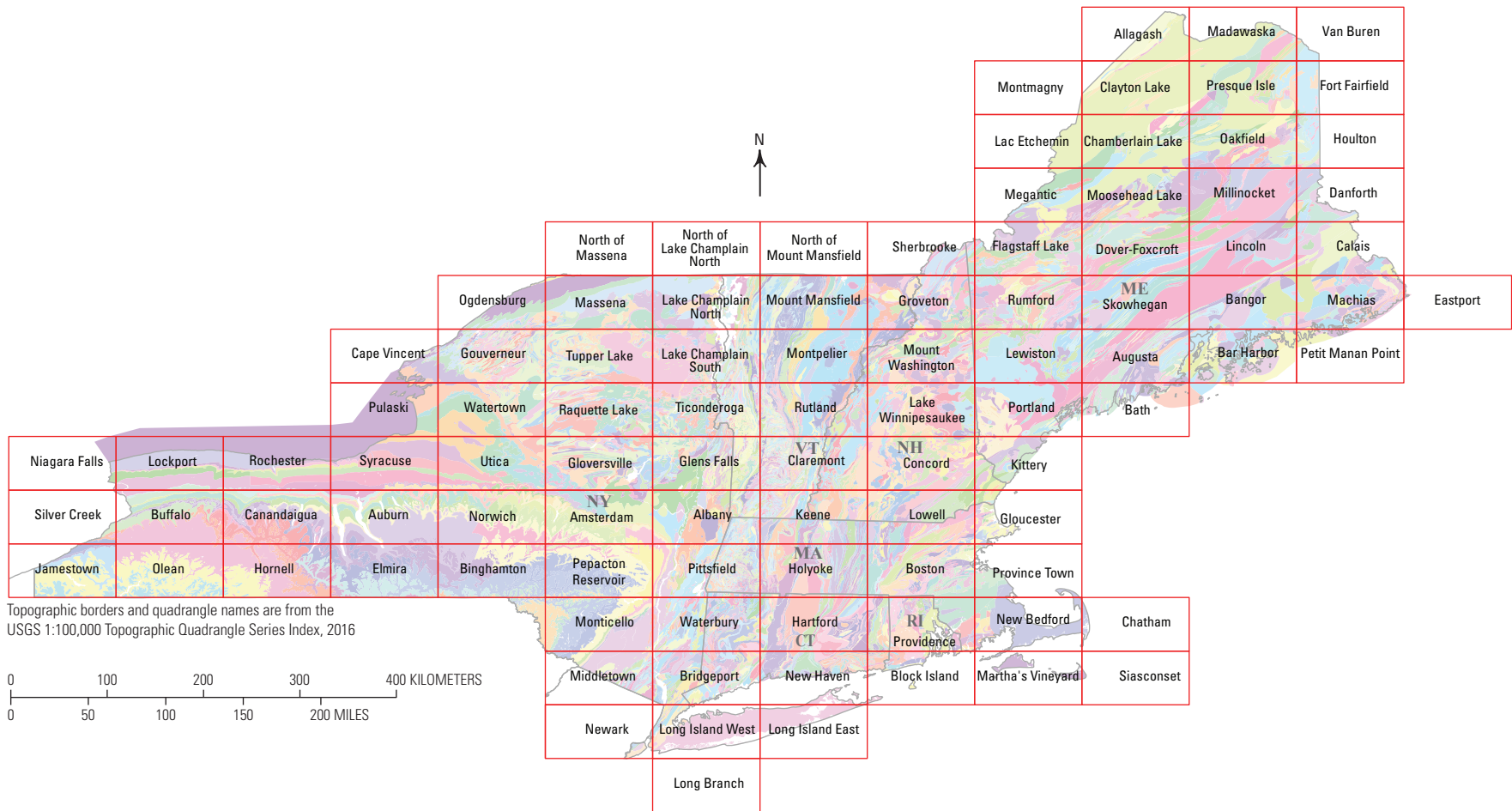


Figure 1. Bedrock geologic map of the Northeast region of the United States including New York and the six New England States showing the bedrock geology compiled from the State geologic maps and index to 30- x 60-minute quadrangles. Geology from Fisher and others (1970), Zen and others (1983), Osberg and others (1985), Rodgers (1985), Hermes and others (1994), Lyons and others (1997), and Ratcliffe and others (2011), compiled from the digital files available from the U.S. Geological Survey Mineral Resources On-Line Spatial Data website (<https://mrdata.usgs.gov/geology/state/>).

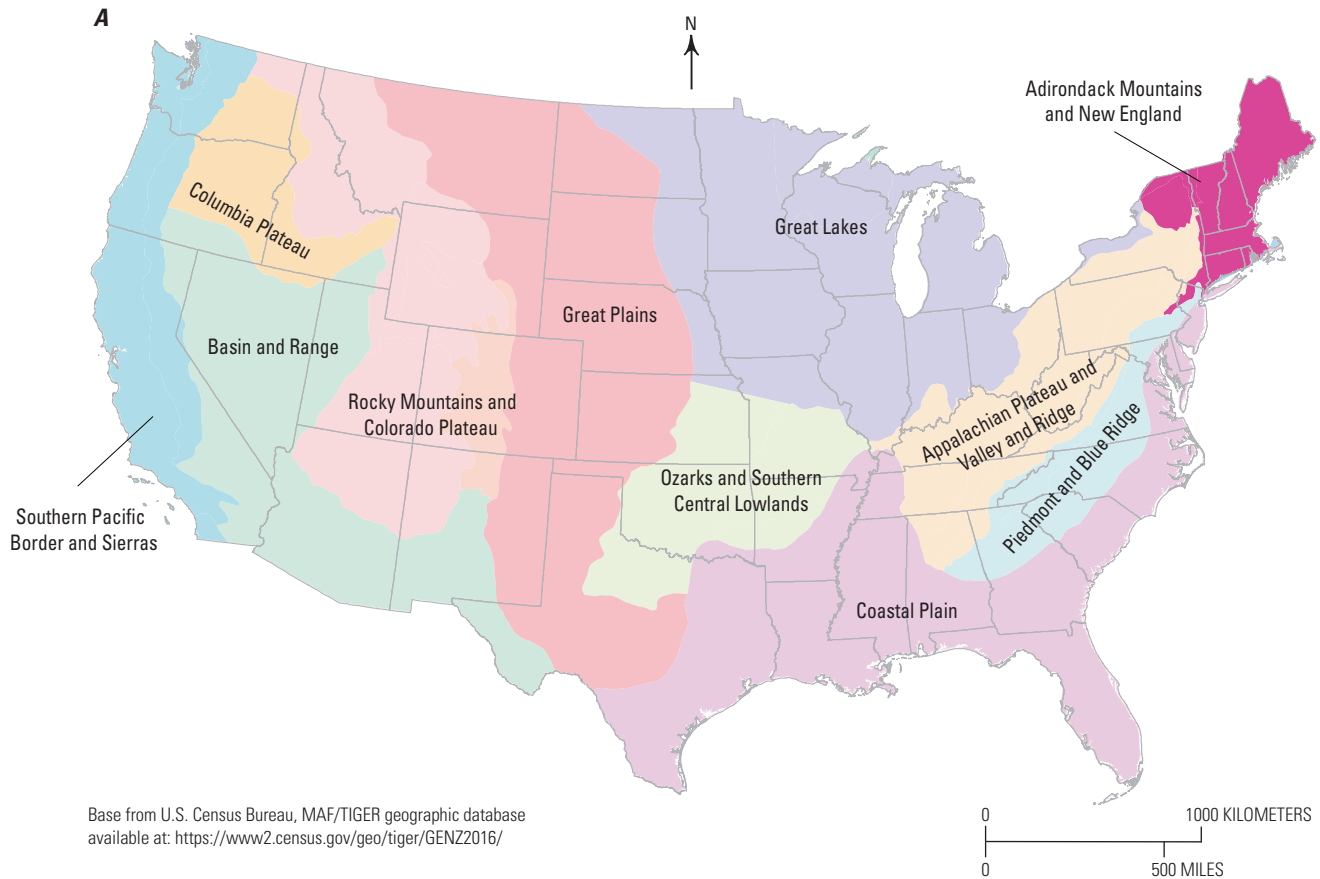


Figure 2. Maps showing physiographic provinces in (A) the conterminous United States (modified from Fenneman, 1970), and (B) (following page) the Adirondack Mountains (Adirondacks), St. Lawrence and Champlain Valleys, and New England provinces.

Synopsis of Recently Sponsored National Cooperative Geologic Mapping Program Science and Mapping

For the last two decades, NCGMP-supported research in the Northeast region included 1:24,000- to 1:125,000-scale bedrock and surficial map products and framework geochronologic and hydrogeologic studies. Recent FEDMAP-supported projects in the Northeast region are listed below. Maps, reports, and data developed during these projects were often in direct cooperation with State geological surveys through STATEMAP⁹ (figs. 3 and 4) and provide a catalyst for future work in the region.

The bedrock mapping projects include—

- 1998–2005, “Bedrock Regional Aquifer Systematics Studies,” project leaders, T.R. Armstrong, W.C. Burton, and G.J. Walsh.

- 2005–2010, “Geologic Mapping and Hydrogeology of Crystalline Rocks,” project leader, G.J. Walsh.
- 2010–2015, “Northern Appalachian Bedrock Mapping,” project leader, G.J. Walsh.
- 2015–2022, “Northeast Bedrock Mapping,” project leader, G.J. Walsh.

Surficial and bedrock mapping projects include—

- 2022–present, “Glaciated Regions,” project leader, C.S. Swezey
- 2018–2022, “Great Lakes Geologic Mapping,” project leader C.S. Swezey
- 2013–2018, “Quaternary Glacial Stratigraphic Framework,” project leader, B.D. Stone.
- 2003–2012, “Glacial Aquifer Systems Stratigraphy,” project leaders, J.R. Stone and B.D. Stone.
- 2007–2022, “Quaternary Stratigraphic Framework of Massachusetts and part of southern Michigan,” project leader, B.D. Stone.

⁹STATEMAP establishes the geologic framework of areas vital to the economic, social, or scientific welfare of individual States (USGS, 2018b).

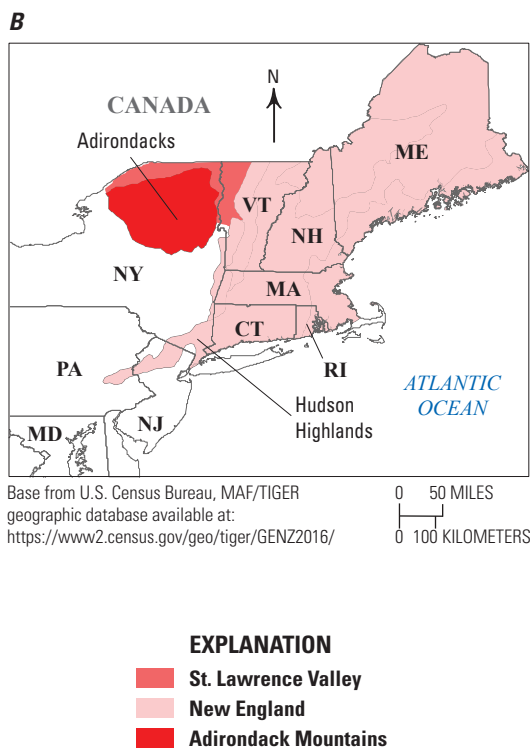


Figure 2.—Continued

Status of Geologic Mapping

In the Northeast region, statewide geologic maps of bedrock and surficial geology range from 1:100,000- to 1:500,000-scale and were published from 1951 to 2011 (fig. 3, and the “References Cited” section). Cooperative work between FEDMAP and the State of Massachusetts is nearing completion for a 1:100,000- to 1:125,000-scale statewide Quaternary map, and work has been completed on a map and database of surficial materials at 1:24,000-scale data (for example, Stone and others, 2018). The USGS is cooperating with the newly formed New England States Geologic Mapping Coalition (NESGMC) to meet future geologic mapping goals. This coalition of the six State geological surveys in New England signed a formal charter in April 2021 that seeks to “advance the understanding of the common characteristics of the crystalline bedrock and three-dimensional distribution of the glacial, periglacial, and post-glacial deposits underlying New England” (NESGMC, 2021).

In the last two decades, NCGMP-sponsored science and mapping has occurred in all States in the Northeast region with only limited mapping in Rhode Island. Limited FEDMAP bedrock mapping was completed over the Massachusetts-Rhode Island border along the Worcester-Providence Turnpike in northern Rhode Island (Walsh, 2014). FEDMAP is currently compiling a surficial materials map of Rhode Island (DiGiacomo-Cohen, 2023).

Status of Topographic Mapping

The USGS 7.5-minute series topographic quadrangles at 1:24,000-scale exist for the entire Northeast region. Most topographic maps have been revised within the last 30 years. Digital topographic data now exist for the entire area, at different levels of quality (fig. 4). The availability of light detection and ranging (lidar) data is rapidly expanding to cover the eastern United States. As of February 2023, the entire Northeast region is covered by lidar mapping. Data gaps from as recently as 2020 no longer exist, and even the most remote areas of the region in the western Adirondack Mountains and northern Maine now have lidar coverage (fig. 4).

Status of Geophysical Surveys

In the northeastern United States, historical mineralization is well-known where bedrock is exposed. Thorium, rare earth elements (REEs), titanium, and graphite occur in the Adirondack Mountains of New York and are considered a priority area for the research and assessment of critical minerals potential (Schulz and others, 2017; Van Gosen and others, 2019; Hammarstrom and Dicken, 2019). Bedrock geologic mapping in the Adirondack Mountains by FEDMAP, STATEMAP, and EDMAP¹⁰ has advanced over the last eight years and represents the first modern 1:24,000-scale mapping in the area in decades (Walsh and others, 2022). FEDMAP activities in the Adirondack Mountains have been coordinated with STATEMAP and the Mineral Resources Program (MRP). The NCGMP and the MRP have cooperatively funded research in the Adirondack Mountains.

In New England, beryllium occurs in New Hampshire and gallium, lithium, cobalt, and manganese occur in Maine (Schulz and others, 2017). Maine is currently the most active northeast state in the new USGS Earth Mapping Resources Initiative (Earth MRI) program (see Hammarstrom and others, 2020, and USGS, 2021), and coordination of the complementary mapping programs of the MRP and the NCGMP can provide opportunities for mapping in the Northeast region. The lack of modern, detailed geologic, topographic, and geophysical datasets impedes mineral exploration, and, conversely, the addition of these data can lead to significant investments from the private sector (Fortier and others, 2019).

Little modern airborne geophysics data exist for the northeastern United States (fig. 5). The high-priority Adirondack Mountains region has the potential for critical mineral resource discovery but has only about 3 percent modern geophysical-data coverage at needed resolutions (Shah, 2016; Drenth and Grauch, 2019; Shah and others, 2021) (fig. 5) and even less 1:24,000-scale geologic map coverage (Walsh and others, 2018; Walsh and others, 2022).

¹⁰EDMAP is a 1-year, mentor-guided program that teaches students geologic mapping techniques through field mapping (USGS, 2018a).

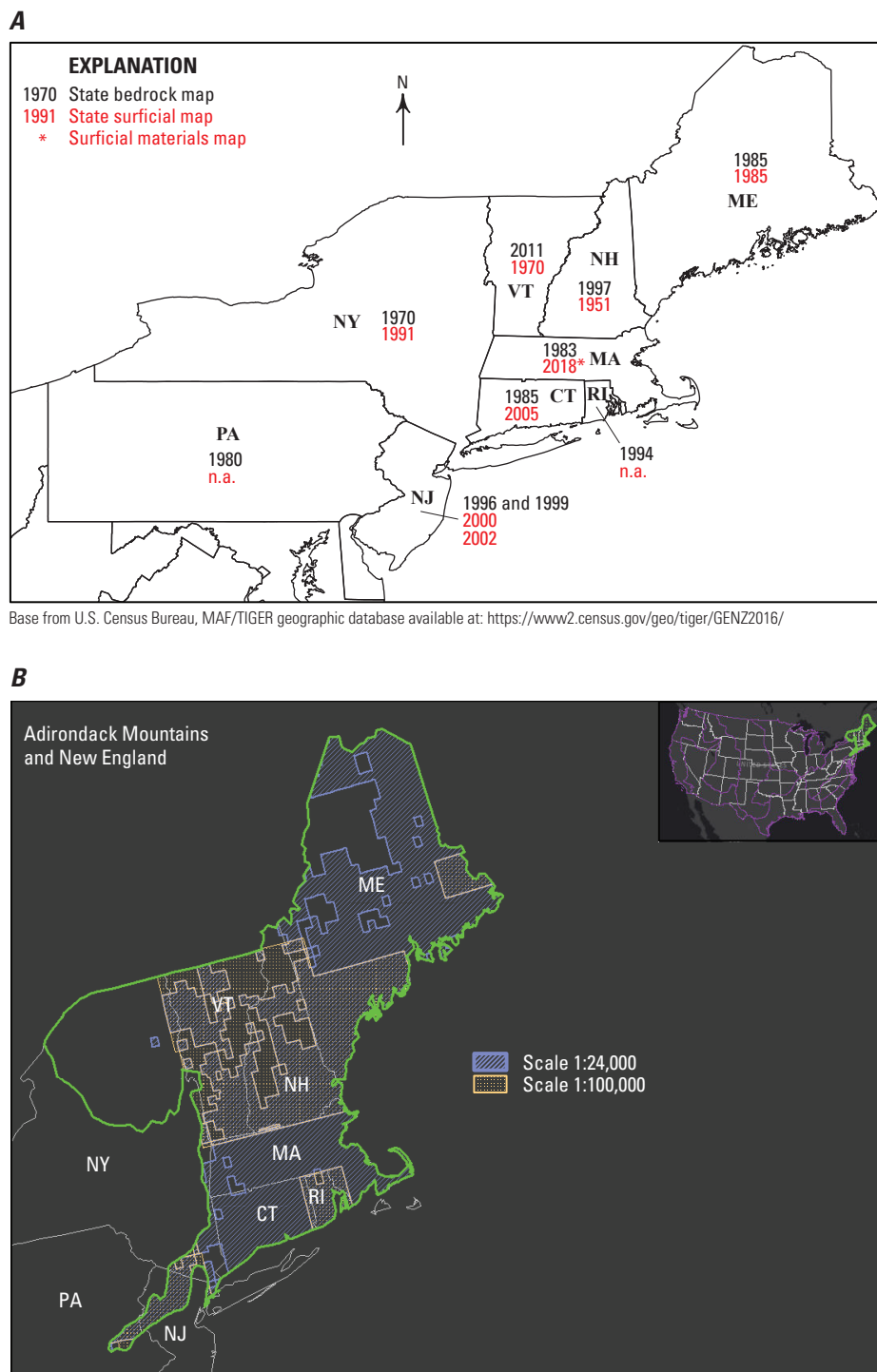


Figure 3. Index maps of the Northeast region of the United States. *A*, Map showing the year of publication of the State bedrock and surficial geologic maps, 1951–2011 (Goldthwait and others, 1951; Fisher and others, 1970; Stewart and MacClintock, 1970; Berg and others, 1980; Zen and others, 1983; Osberg and others, 1985; Rodgers, 1985; Thompson and Borns, 1985; Cadwell and others, 1991; Hermes and others, 1994; Drake and others, 1996; Lyons and others, 1997; Owens and others, 1999; Newell and others, 2000; Stone and others, 2002, 2005; Ratcliffe and others, 2011; Stone and others, 2018). In Massachusetts, a surficial materials map database is published (Stone and others, 2018), and a Quaternary map is being developed. *B*, Map showing the status of coverage of undifferentiated bedrock or surficial geologic maps published at 1:24,000- and 1:100,000-scale, provided by the National Cooperative Geologic Mapping Program in March 2018. Note the lack of 1:24,000-scale maps in the Hudson Highlands, the Adirondack Mountains, and northern Maine. *C*, (following page) Index map of bedrock geologic mapping in the United States showing detailed (1:24,000-scale) and intermediate scale (1:48,000- to 1:63,360-scale) maps deemed most useful (Fortier and others, 2019). n.a., not available.

C

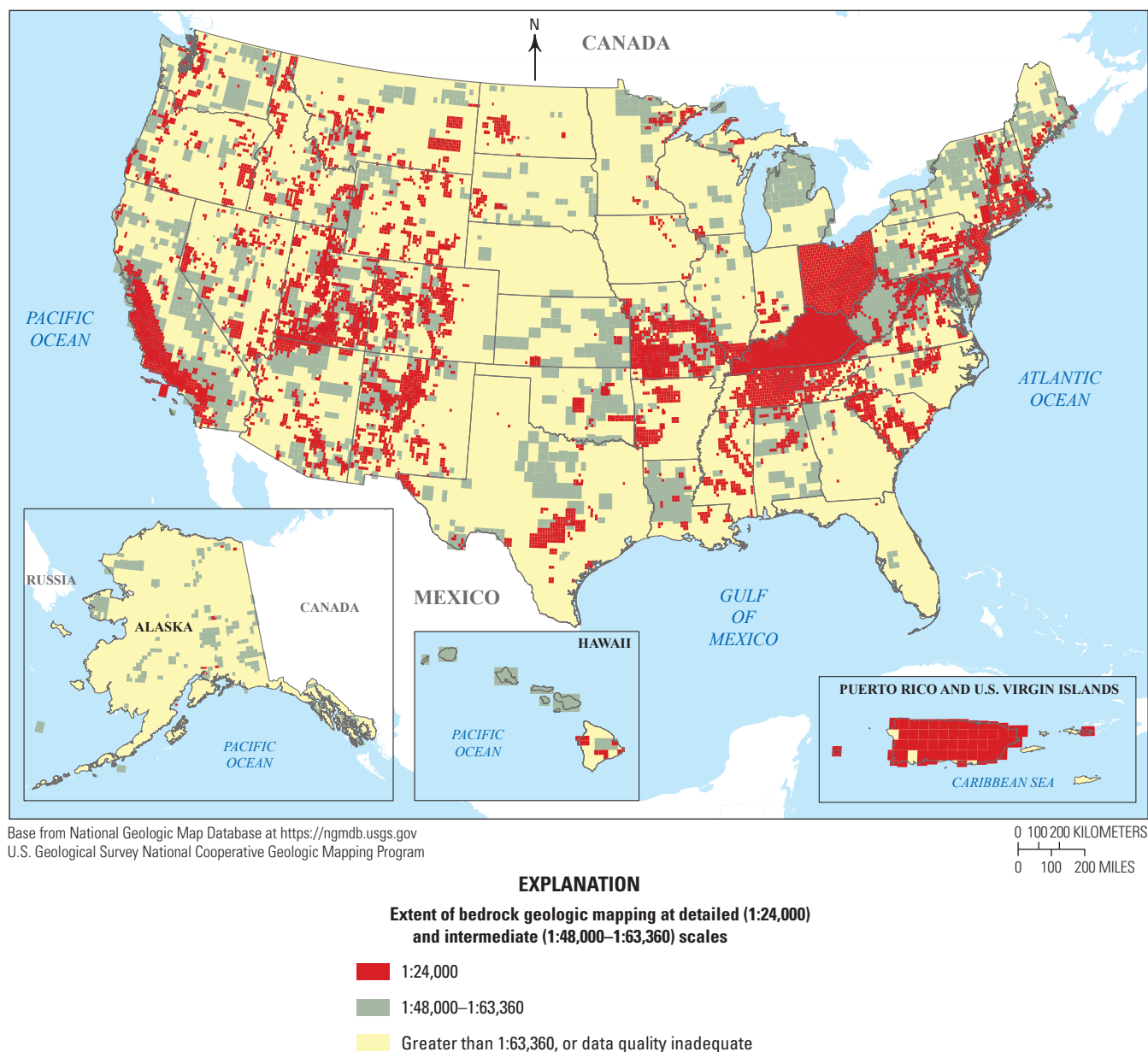


Figure 3.—Continued

Recent airborne magnetic and radiometric geophysical data published on the eastern Adirondack Mountains (Shah, 2016; Shah and others, 2021) and northern Maine (Shah, 2022) represent the only modern geophysical data in the Northeast region, and new, high-quality airborne surveys can help the search for additional mineral deposits (Wang and others, 2023) and enhance geologic mapping. Historical airborne geophysical surveys in the Northeast region were conducted from the 1940s through the 1980s and subsequently digitized (Daniels and Snyder, 2004).

Few areas have geophysical data line-spacing resolutions higher than 0.5 kilometers (km), and most of the data are rank 4 or 5, which are the lowest quality rankings (fig. 5).

Only recently were data collected at the resolution required for accurate, modern geologic mapping (as in the 0.25-km line spacing of Shah, 2016, 2022, and rank 1 data of Drenth and Grauch, 2019). New airborne surveys combined with geologic mapping, planned through the Earth MRI program and currently targeting the mineral potential in northern Maine, can address this regional need (Hammarstrom and others, 2020; USGS, 2021; Wang and others, 2023).

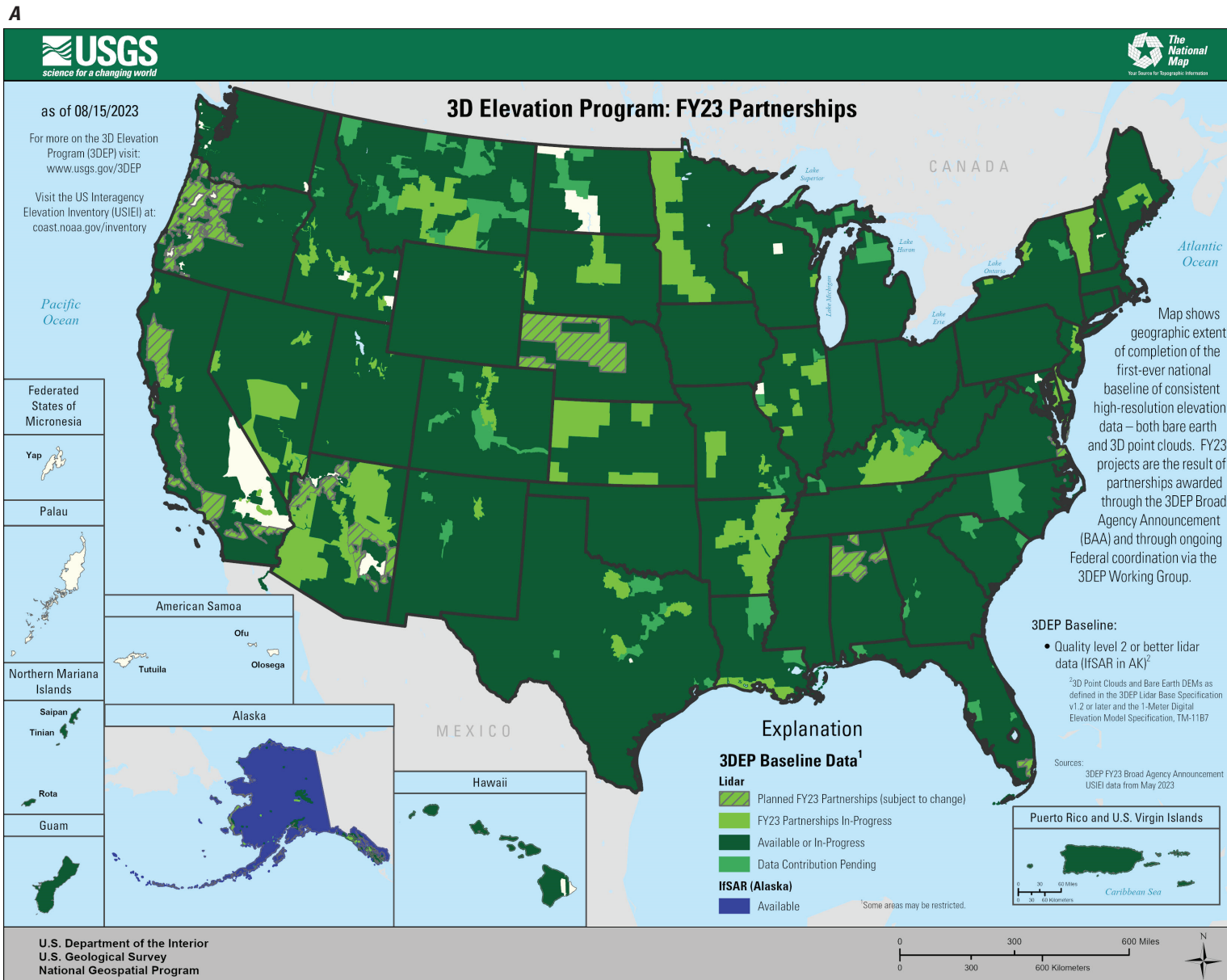


Figure 4. Map screenshot and map showing the status of light detection and ranging (lidar) mapping in the United States. *A*, Screenshot showing lidar coverage as of February 28, 2023 (U.S. Geological Survey, 2023). *B*, (following page) Map of the Northeast region of the United States showing the distribution and quality level of available lidar data—lidar quality levels QL1–QL4 (and below)—as of February 2, 2023 (U.S. Interagency Elevation Inventory, 2023).

B

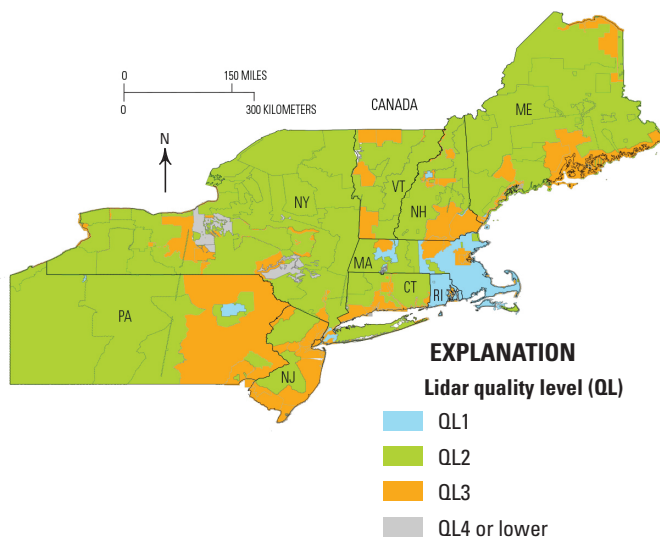


Figure 4.—Continued

Scientific and Societal Relevance

A Congressional report by the Committee on Natural Resources addressing a bill submitted for reauthorization of The National Geologic Mapping Act of 1992 (Public Law 102–285 as amended, 106 Stat. 166) explained that the NCGMP is “designed to foster cooperation and coordination between the USGS and the State geologic surveys in generating modern, detailed, digitized, geologic maps in a cost effective and efficient manner” (U.S. Congress, House of Representatives Committee on Natural Resources, 2018).

New bedrock mapping is set to focus on areas that lack detail or modern maps. The new maps can contribute to framework studies, help characterize the distribution of mineral resources, and address questions about the tectonic evolution of mountain belts and the behavior of groundwater and groundwater contaminants in fractured rock. Research by the FEDMAP staff, States, and universities can integrate mapping, geochronology, petrology, geochemistry, geophysics, paleontology, and surficial geology in scientifically appropriate areas. The FEDMAP staff, together with State and university researchers, possess expertise in these areas; however, some States in the Northeast region may not have a full complement of experts. Modern, large-scale (1:24,000) bedrock geologic maps now include detailed fracture information for use in characterizing the recharge potential of bedrock lithologies and identifying potential pathways for groundwater and contaminant flow—such information is often lacking in older geologic maps.

“Top of rock,” which in this report refers to the surface between the regolith and the bedrock, is an important three-dimensional (3D) surface in geology, hydrology, hydrogeology, geomorphology, soil science, and engineering; however, specific data on this surface is nearly absent. Before the advent of lidar, even the top of rock at or near the land surface was difficult to accurately map in forested regions like the

Northeast. A modern, high-resolution database of the bedrock surface-altitude is lacking. The FEDMAP and STATEMAP programs can develop an inventory of available data and develop a plan with the NESGMC for creating a model of the bedrock surface-altitude in New England.

The objectives include creating a seamless geographic information system (GIS) database and surface of the altitude of the top of rock beneath the unconsolidated glacial deposits, mapping the two-dimensional boundary between exposed bedrock and surficial deposits regionwide, and designing a robust spatial database for 3D modeling (Mabee and others, 2023). Long-term objectives include developing 3D models and depictions of the thickness of surficial deposits. The model of the top of rock can incorporate surficial geologic mapping, water-well and borehole data, subsurface geophysical data, and data on land-surface elevations.

Mapping projects target scientific research in tectonics, structural geology, igneous and metamorphic processes, mineral resource assessment, ore petrogenesis, geochronology, hydrogeology, hydrology, stratigraphy, glacial erosion and depositional processes, coastal processes, erosion, and geomorphology. Specific examples from ongoing work include tectonics and the origin of ancient volcanic arcs, precise geochronology in high-grade rocks, the origins of REEs in iron oxide apatite deposits in high-grade settings, the metasomatism of high-grade granite gneiss, the petrogenesis of lithium in pegmatites, the tectonics of Ordovician arc systems, and the geochronology of Acadian tectonics.

Mapping projects target societal goals addressing mineral and energy resources, karst, fractured-rock hydrogeology, water quality and availability, naturally occurring and anthropogenic contaminants, landslides, coastal and seismic hazards, construction aggregate, sulfidic rock and pyrrhotite hazards in aggregate, infrastructure, coastal and fluvial erosion, education, land-use planning, 3D mapping of the top of rock, and the synthesis of regional water-well and borehole data. Specific examples from ongoing FEDMAP program work include the assessment of rare earth elements (REEs) in iron oxide apatite deposits in abandoned iron mines, the mapping of mineral deposits with airborne geophysics, and determining the precise location of abandoned-mine lands with lidar.

A few examples from recent and ongoing FEDMAP program research include—

- tectonics and the geochronology of ancient volcanic arcs (Valley and others, 2019; Walsh and others, 2021);
- reactions and timing in ductile shear zones (McAleer and others, 2017; Regan and others, 2019);
- the use of integrated mapping, lidar, and geophysics in searching for REE potential in abandoned magnetite mines in the eastern Adirondack Mountains (Walsh and others, 2018; 2020a; Taylor and others, 2019; Shah and others, 2021; Walsh and others, 2022);

- the evaluation of fractured-rock contamination due to explosives used in road construction (Degnan and others, 2016);
- mapping the top of rock in New England (DiGiacomo-Cohen and others, 2020; Mabee and others, 2023);
- a geologic map of Mount Ascutney, Vermont’s most famous volcano (Walsh and others, 2020b);
- applying high-precision U-Pb geochronology in granulite facies rocks (Aleinikoff and others, 2021);
- mapping glacial and postglacial deposits using lidar (Stone and others, 2018); and
- mapping infrastructure in abandoned mine lands (Walsh and Walsh, 2023).

A few examples from recent and ongoing STATEMAP research include—

- nitrate contamination in fractured rock aquifers, Vermont (Kim and others, 2010, 2016);
- framework geologic mapping of volcanic massive sulfide deposits, Maine (Wang, 2021);
- framework bedrock mapping in the Connecticut River Valley, New Hampshire (Thompson, 2016);
- mapping the geology of historic parks, Connecticut (Moritz and others, 2019);
- mapping the Neoproterozoic Boston Basin, Massachusetts (Thompson, 2017); and
- mapping the surficial geology of Cayuga County, New York (N.Y.) (Kozlowski and others, 2018).

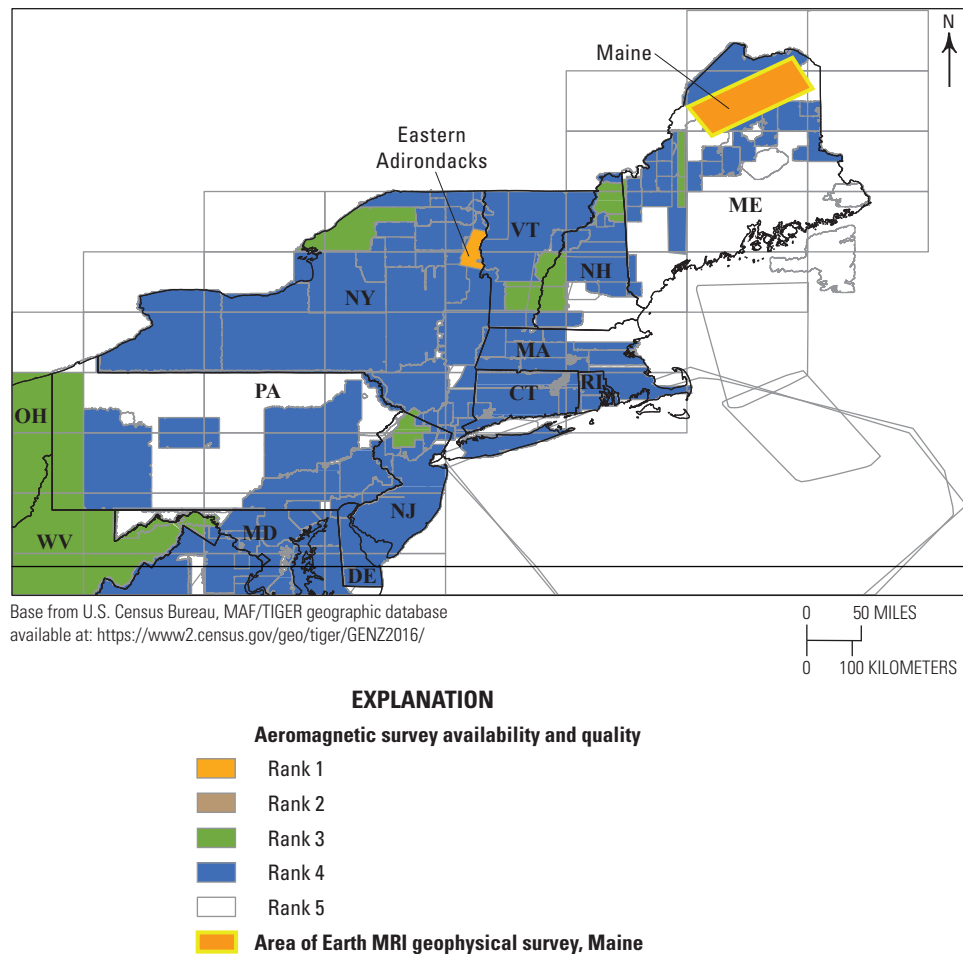


Figure 5. Map showing the status of airborne geophysical-survey coverage in the Northeast region from Drenth and Grauch (2019, fig. 3). Only the area of the Adirondack Mountains labelled “Eastern Adirondacks” and northern Maine have a flight line spacing of 0.25 kilometers and are deemed rank 1 quality and adequate by modern standards (Shah, 2016, 2022; Drenth and Grauch, 2019; Shah and others, 2021). Most of the Northeast region contains rank 4 or 5 data.

Scientific Objectives

Scientific research directly associated with geologic mapping that is funded by the NCGMP and its many cooperators is an essential part of the process that delivers geologic maps that meet the primary national goal of research and data characterization of the Earth (Bristol and others, 2013). Research and mapping help achieve the USGS strategic science goals (Gundersen and others, 2011) summarized below:

- Goal 1—Characterize and interpret the geologic framework of the Earth.
- Goal 2—Understand surface processes and their effects on the ecosystem.
- Goal 3—Understand and quantify the availability of Earth's natural resources.
- Goal 4—Increase resilience to hazards.
- Goal 5—Apply advanced technology and best practices.
- Goal 6—Develop a flexible and diverse workforce for the future.

The overall scientific objectives of geologic mapping in the Northeast region aim to improve our understanding of the geologic framework and tectonic evolution of Mesoproterozoic to Paleozoic terranes and Mesozoic basins and the glacial stratigraphic framework related to Pleistocene glaciation.

The societal relevance of the scientific objectives includes the study of tectonics and seismic hazards in the Hudson Highlands (as in Ratcliffe, 1992); critical minerals in the Adirondack and Appalachian Mountains; landslides and per- and polyfluoroalkyl substances (PFAS) contamination in fractured bedrock in Vermont; landslides and river evulsion in New Hampshire; coastal hazards, sea-level rise, and ground-water and aggregate availability in Massachusetts; naturally occurring radionuclides in well water and pyrrhotite-bearing concrete aggregate in Connecticut and Massachusetts, and mineral resources and coastal hazards in Maine.

Since 2015, FEDMAP program activities in the Adirondack Mountains have been operating a prototype of the Earth MRI program due to the combined efforts of the USGS Florence Bascom Geoscience Center (Reston, Va.) and the USGS Geology, Geophysics, and Geochemistry Science Center (Lakewood, Colo.), in cooperation with the New York State Geological Survey. Scientific objectives include the tectonics and geochronology of granulite facies rocks, ore petrogenesis of iron oxide apatite deposits, and related REE petrogenesis and metasomatism in high-grade rocks. Future opportunities exist in the petrogenesis of volcanic massive sulfide deposits in northern Maine where Earth MRI-funded research is currently coordinated with new airborne geophysics and STATEMAP program geologic mapping (Wang and others, 2023). Additional Earth MRI and NCGMP coordinated research opportunities exist in critical minerals associated with pegmatites.

Geologic Mapping Objectives

Phase 1 Geologic Mapping Objectives

The Phase 1 objectives are threefold: (1) to produce detailed, high-quality 1:24,000-scale bedrock geologic maps that improve our understanding of crystalline bedrock in the Northeast region and define the geospatial infrastructure needed for future compilations and regional syntheses, (2) to complete the Quaternary geologic map of Massachusetts, and (3) to begin assembling data to assemble a surface model of the top of rock for New England. FEDMAP program activities can be coordinated with STATEMAP program investigations at State geological surveys and with USGS activities such as the Florence Bascom Geoscience Center (FBGC), the Geology, Geophysics, and Geochemistry Science Center (GGGSC), the MRP, and the Earth MRI program. Mapping can also be coordinated with hydrogeologic investigations by the Water Resources Mission Area (WMA) and cooperating State agencies to maximize the scientific and societal impact of the new research. Synergistic activities by the States (to assist with meeting the objectives) include the acquisition of grants from the WMA Water-Use Data and Research Program, Federal Emergency Management Agency Hazard Mitigation Grant Program, Earth MRI program, and State highway departments.

The 1:24,000-scale bedrock mapping and synthesis in the Adirondack Mountains includes the Champlain Valley in southern Essex County, N.Y., and adjacent Vermont. Framework geologic mapping is tied to critical minerals in Mesoproterozoic rocks and stratigraphic problems in Paleozoic rocks across state borders. Collaborative research between the USGS, the New York State Geological Survey, the University of Massachusetts Amherst, the National Science Foundation, and student researchers has focused on the tectonic, geochronologic, and metamorphic evolution of the Adirondack Mountains with emphasis on iron ore petrogenesis, REE-bearing minerals, and metasomatism in high grade rocks.

The 1:24,000-scale bedrock mapping and 1:50,000-scale synthesis in the Hudson Highlands of New York, with an emphasis on Putnam County, N.Y. and adjacent Connecticut, are emeritus-related research tied to the completion of about ten quadrangles. The 1:50,000-scale mapping is helpful for the compilation of work completed at the 1:24,000-scale because virtually all of the details can be shown on the smaller scale maps. New compilations at the 1:100,000-scale, or smaller, require a simplification of the more detailed mapping, in some locations, to produce a legible product that meets cartographic standards.

The 1:24,000-scale bedrock mapping in Connecticut, Vermont, New Hampshire, and Maine requires collaborative tectonics and geochronology research with the State geological surveys and universities. Planned cooperative research includes investigating natural and anthropogenic contaminants in drinking water and mineral resources of pegmatites.

Phase 1 plans involve assembling a database for development of a 3D model of the top of rock in New England. A cooperative research project among the NESGMC, the New England Water Science Center, and the NGMDB intends to produce a national database of boreholes (see Medalie and others, 2021). Key datasets in New England include (1) surficial geology, (2) borehole databases showing depth to bedrock, and (3) altitude of land surface (lidar and 10-meter digital elevation models [DEMs]). Subsurface geophysical datasets are limited but can be useful in some areas. The horizontal-to-vertical spectral ratio seismic method can fill data gaps and be applied to test models in crucial areas. Researchers can contribute to the NCGMP 3D Working Group and evaluate potential 3D modeling software and receive training. Algorithms can be developed for feature extraction of the bedrock-overburden interface from new lidar and older DEMs. Massachusetts is developing a statewide model to guide future top-of-rock mapping in the region (Mabee and others, 2023).

An ongoing FEDMAP-STATEMAP program partnership includes completion of the 1:100,000-scale compilation map of the Quaternary geology of Massachusetts. This work stems from completion of a statewide 1:24,000-scale database of surficial materials (Stone and others, 2018) in cooperation with activities in the Great Lakes region.

Additional Phase 1 objectives include—

- continued contributions to the Earth MRI Working Group;
- cooperative research with the NGMDB for assembling a national database of geochronology, a national borehole database, and improving regional stratigraphic correlations and the North American Stratigraphic Code;
- cooperative research with the NGMDB and the NESGMC to ensure accurate regional-scale compilations and resolve cross-border stratigraphic problems; and
- continued testing and development of digital mapping platforms, rugged field equipment, and integrated methods for facilitating field data collection and expediting the completion of geologic maps and databases. Results have been obtained in recent years using Apple iPad tablet computers and Bluetooth Global Positioning System receivers running the “Fieldmove” application, and new products and services are continually developed and tested. Additionally, portable gamma radiation detectors, gamma ray spectrometers, and portable x-ray spectrometers are being tested and deployed to assist with the petrophysical characterization of rocks for mapping and critical mineral studies (Shah and others, 2019; Suarez and others, 2020).

Examples of anticipated Phase 1 objectives by the States include—

- 1:24,000-scale bedrock mapping in Connecticut, Maine, and New Hampshire;
- 1:24,000-scale surficial mapping in Maine, New Hampshire, and Vermont;
- 1:24,000-scale bedrock and surficial mapping completion in populated areas of Maine;
- 1:24,000-scale bedrock mapping to support revised tectonic and critical mineral assessments in northern and western Maine; and
- 1:24,000-scale surficial mapping in landslide risk areas posed by glacial-marine clay units in Maine.

Phase 2 Geologic Mapping Objectives

Phase 2 objectives involve greater compilation efforts and continued 1:24,000-scale mapping that targets “cornerstone” quadrangles to constrain the compilations. FEDMAP-STATEMAP program partnerships have the following objectives:

- 1:50,000-scale compilation and bedrock-synthesis mapping in Putnam County, N.Y.;
- 1:24,000- to 1:100,000-scale compilation of the surficial materials map of Rhode Island—this is the only State in the region without a published, statewide, peer-reviewed surficial geologic map ([fig. 3A](#));
- 1:24,000-, 1:50,000-, and 1:100,000-scale compilation and bedrock-synthesis mapping in Connecticut;
- 1:100,000-scale compilation of the 3D model of the top-of-rock surface in New England, in cooperation with the NESGMC;
- Coordination between the FEDMAP program, the NESGMC, and the Great Lakes Mapping Coalition on a seamless 3D model of the top-of-rock surface for the glaciated regions of the north-central and northeastern United States.

Examples of anticipated Phase 2 STATEMAP program activities include the following:

- 1:100,000-scale compilation and synthesis mapping of the surficial geology of the Montpelier 30- × 60-minute quadrangle, Vermont;
- 1:100,000-scale compilation and synthesis mapping of surficial geology in the Concord and Lowell 30- × 60-minute quadrangles, New Hampshire;
- 1:50,000- and 1:100,000-scale compilation and synthesis mapping of bedrock and fracture characterization of the I-495 corridor of Massachusetts;

- 1:24,000-scale publication of legacy mapping around the Quabbin Reservoir and in the Shutesbury area, Massachusetts; and
- the potential acquisition of rank 1 airborne geophysics to resolve cross-border stratigraphic problems and identify sulfide-rich rocks that might contain pyrrhotite, especially in Massachusetts and Connecticut.

Phase 3 Geologic Mapping Objectives

Phase 3 objectives, although flexible due to unanticipated demands and future needs, are expected to involve greater compilation efforts and continued 1:24,000-scale mapping that targets “cornerstone” quadrangles to constrain the compilations. FEDMAP-STATEMAP program partnerships have the following objectives:

- 1:100,000-scale map compilation of a new bedrock geologic map of Connecticut;
- a 3D model of top of rock in New England, merged with data from New York and the Great Lakes region; and
- seamless 1:100,000-, 1:250,000-, and 1:500,000-scale map compilations of the bedrock and surficial geology for the New England region and Appalachian Mountains.

Needed Capabilities

A significant workforce challenge is the declining number of qualified bedrock and surficial geologic mappers. Training students has helped limit the decrease, and continued hiring actions can help to maintain and grow high levels of expertise in the field of geologic mapping. Workforce planning is “Goal 6” of Gundersen and others (2011) and continues to be important today in order to support geologic mapping at the State and Federal levels. This challenge applies to both the USGS and State surveys in the Northeast region, where staffing is limited.

Scientists and technical staff must be skilled in GIS and digital mapping techniques. Complex and evolving database models and digital standards require increased time commitments from qualified technical staff to complete GIS deliverables along with attendant metadata. Hiring junior-level staff could help to increase productivity. Engaging students through various hiring mechanisms or through collaborations with partners can support training and mentoring for future science and technical staff.

Successful efforts to map and model the Earth in 3D may require costly software, advanced computers, and highly specialized staff with skills in programming and computer science (see MacCormack, 2018). 3D mapping is a science priority for the USGS (Brock and others, 2021), even as

resources and personnel are limited; this presents an ongoing challenge, and innovative solutions are required. Hiring staff with 3D mapping and modeling expertise is a potential goal, and the USGS Pathways program may help expand junior-level staff and student hires.

Geochronology is a critical tool for a geologic mapping program. An essential tool for geochronology is the Sensitive High Resolution Ion Microprobe (SHRIMP). The Sensitive High-Resolution Ion Microprobe with Reverse Geometry (SHRIMP-RG) is operated by the USGS and Stanford University and is over two decades old. Other nations have begun to lead the way in SHRIMP technology, thereby indicating acquisition and development of state-of-the-art geochronology facilities is an area of consideration for USGS long-range planning.

Contemporary airborne geophysical data at rank 1 resolution (Drenth and Grauch, 2019) can benefit current, accurate geologic mapping in conjunction with mineral and hazard assessments. Current high-resolution data are limited in the Northeast region ([fig. 5](#)).

Partners

The primary partners for geologic mapping projects in the Northeast region include the U.S. Geological Survey, the New England States Geologic Mapping Coalition, the State geological surveys, the Great Lakes Geologic Mapping Coalition (which includes New York), and various universities. Contacts at the State geological surveys are shown in alphabetical order, by State, in [table 1](#).

Contributing financial partners to FEDMAP program activities include the National Science Foundation, the National Park Service, the USGS Coastal and Marine Hazards and Resources Program, the MRP, and the Toxic Substances Hydrology Program. In-kind work has been conducted with the New England Water Science Center and the U.S. Forest Service, and future possibilities for mapping may exist in the Green Mountain and White Mountain National Forests, including the Appalachian Trail. The FEDMAP program work in the Northeast has been managed by the USGS through the Florence Bascom Geoscience Center, in collaboration with the Geology, Geophysics, and Geochemistry Science Center and Geosciences and Environmental Change Science Center.

Examples of recent cooperative FEDMAP-STATEMAP program partnerships include:

- “Bedrock geologic map of Vermont” (Ratliffe and others, 2011);
- “Surficial Materials of Massachusetts—A 1:24,000-Scale Geologic Map Database” (Stone and others, 2018); and
- “Quaternary Geologic Map of Connecticut and Long Island Sound Basin” (Stone and others, 2005).

Current University FEDMAP or EDMAP Partners

Mike Williams, University of Massachusetts Amherst;
Robert Wintsch, Wesleyan University;

Craig Dietsch, University of Cincinnati; and
Yvette Kuiper, Colorado School of Mines.

Table 1. State geological agency contacts and contact information, by State.

[n.a., not available; URL, uniform resource locator]

State	Organization	Contact	Contact information	Organization website URL
Connecticut	Connecticut Geological Survey	Meghan Seremet—State geologist and director;	Telephone: 860–424–3583 Email: meghan.seremet@ct.gov	https://portal.ct.gov/DEEP/Geology/Geological-Survey
		Margaret A. Thomas—State geologist and director (retired).	n.a.	
Maine	Maine Geological Survey	Stephen Dickson—State geologist and director;	Telephone: 207–287–2801 Email: stephen.m.dickson@maine.gov	https://www.maine.gov/dacf/mgs/index.shtml
		Robert G. Marvinney—State geologist and director (retired).	n.a.	
Massachusetts	Massachusetts Geological Survey	Stephen B. Mabree—State geologist and director.	Telephone: 413–545–4814 Email: sbmabee@geo.umass.edu	http://mgs.geo.umass.edu/
New Hampshire	New Hampshire Geological Survey	Shane Csiki—State geologist and director;	Telephone: 603–271–2876 E-mail: shane.j.csiki@des.nh.gov	https://www.des.nh.gov/land/geology
		Rick Chormann—State geologist and director (retired).	n.a.	
New York	New York State Museum and New York State Geological Survey	Andrew Kozlowski—director of the New York State Geological Survey and State Geological Mapping Program.	Telephone: 518–486–2012 E-mail: andrew.kozlowski@nysed.gov	http://www.nysm.nysed.gov/research-collections/geology
Rhode Island	University of Rhode Island	Brian Savage—State geologist (acting), department chair and associate professor.	Telephone: 401–874–5392 Email: savage@uri.edu	https://web.uri.edu/geo/rhode-island-geological-survey/
Vermont	Vermont Geological Survey	Ben DeJong—State geologist and director;	Telephone: 802–461–5235 Email: ben.dejong@vermont.gov	https://dec.vermont.gov/geological-survey
		Marjorie Gale—State geologist and director (retired);	n.a.	
		Jon Kim—geologist.	Telephone: 802–522–5401 E-mail: jon.kim@vermont.gov	

Anticipated Geologic Mapping Outcomes

The following paragraphs explain the potential benefits that can result from implementation of the NCGMP's strategic plan. Digital geologic maps and databases that incorporate comprehensive structure, fracture, geochemical, geochronological, stratigraphic, and top-of-rock data can help many organizations, including (1) the State geological surveys of New York and the six New England States; (2) USGS water science centers; (3) other Federal agencies, including the National Park Service, U.S. Forest Service, Federal Emergency Management Agency, Natural Resources Conservation Service, and the National Oceanic and Atmospheric Administration; (4) the Mineral Systems Project of the USGS Mineral Resources Program; (5) the Earth MRI program; (6) the geotechnical, environmental engineering, and mining industries; (7) State-level departments of transportation and environmental conservation; (8) regional planning agencies; and (9) universities and educators.

New research in upstate New York produced the first peer-reviewed 1:24,000-scale bedrock geologic map of the Adirondack Highlands (Walsh and others, 2022). One quadrangle map is published and more 7.5-minute quadrangle maps are nearing completion. These new maps provide unprecedented detail, demonstrate applications of lidar, accurately show the locations of abandoned mines, provide updates and revisions to the stratigraphic and tectonic framework of the Adirondack Mountains, and present data that constrain the timing of igneous, metamorphic, and ore-forming events. As cornerstone maps, they are expected to set the standard for future bedrock mapping in the Adirondack Mountains.

New high-precision geochronology research (Aleinikoff and others, 2021) refined nearly three decades of scientific research on the origin of Mesoproterozoic granite gneisses in the Adirondack Mountains and their role in tectonics and ore petrogenesis.

New research on ancient deformed and metamorphosed arc volcanic rocks established new framework constraints on the tectonic evolution of New England (Valley and others, 2019; Walsh and others, 2021).

New geochemical and geophysical research on abandoned iron mines has shown that REEs are more common, abundant, and widespread than previously known and that waste rock piles may present a potential resource (Taylor and others, 2019; Shah and others, 2021).

Mount Ascutney is Vermont's most famous volcano and the place where early ideas for granite emplacement were first developed by Reginald Daly (1903). The new bedrock geologic map of Mount Ascutney (Walsh and others, 2020b) serves as an educational tool and resource guide and provides the scientific framework for the bedrock geology of the Connecticut Valley. The Mount Ascutney State Park and the Saint-Gaudens National Historical Park use the map and a guidebook article (Walsh and others, 2019) to educate and inform visitors about this iconic mountain.

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