Northeastern U.S. Atlas of Mineralogy and Geochemistry

Introduction

The Northeastern U.S. Atlas of Mineralogy and Geochemistry (NUSAMG) is a compilation of data obtained from over 650 published journals, bulletins and professional papers, publications from individual state geological surveys, academic theses, and from personal communication with geological researchers. Given the varied nature of scientific research interests, it was uncommon for a single resource to contain *all* of the data we sought for a single rock unit. Thus, there are information gaps within NUSAMG that are due to research that did not fully address our needs, a general lack of research, or our inability to locate suitable research publications.

Geological Terminology

NUSAMG is a compilation of mineralogical and geochemical data for most bedrock types in the northeastern U.S., including the states of Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island and New York. Over 1,300 geological units are represented within the northeast.

Number of Bedrock Units per Northeastern State*

Maine	340
Massachusetts	312
New York	177
New Hampshire	152
Connecticut	137
Vermont	130
Rhode Island	60

* As identified on the Bedrock Geological Maps for each state.

To begin compiling data for NUSAMG we identified the names and rock type of each individual bedrock unit. We did this on a state-by-state basis using each state's Bedrock Geological Map. Bedrock Geological Maps categorize each rock unit as being part of a Group, Formation, Member, a combination of various Formations or Members, or as a Series. Definitions of these terms are as follows:

Group (Gp) - Two or more successive Formations, related by lithology or by position with reference to unconformities, may be assembled as a Group (Krumbein & Sloss, 1963).

Formation (Fm) - A body of rock strata that consists dominantly of a certain lithologic type or combination of types (Bates & Jackson, 1984). Formations must be of a definite lithologic composition (or interbedded/ intergraded successions of lithologic types), show observable lithologic separation from adjacent units above and below, and they must be traceable from exposure to exposure (Krumbein & Sloss, 1963).

Member (Mbr) - A lithostratigraphic unit of subordinate rank, comprising some specially developed part of a Formation (Bates & Jackson, 1984). Members may be recognized and utilized in only part of the area of distribution of a Formation (Krumbein & Sloss, 1963).

Series – [This is a]…term often misused for an assemblage of formations, esp. in the Precambrian." (Bates & Jackson, 1984). Use of the word "Group" would likely be more appropriate in the case of various igneous rock Series in the northeast.

Many of the Bedrock Geological Maps contain areas of uncertainty as to the underlying bedrock type. In some instances a rock unit may be labeled as "unknown" and it is assumed that insufficient mapping or research has been performed to suitably identify the rock type. Some areas are mapped as being covered with glacial or alluvial deposits and therefore the underlying bedrock is unknown. Other areas are mapped with bedrock described as consisting of "undivided" Formations or Members.

Geological Unit Name Changes

Over the years the names of bedrock units are often changed, or combined with others in an attempt to better represent the apparent geologic setting. We encountered many readily apparent bedrock unit name changes during the research for NUSAMG. However, other changes tended to be more subtle, such as re-mapping projects that resulted in a different areal extent of the bedrock unit; splitting a unit into two or more separate units with new names; or lumping several units into new designations, each with a different areal extent. In each of these situations we made an effort to identify both the former and current unit names within the database, and make notes regarding the nature of the changes.

Bedrock Geologic Maps

For each state we obtained the most recent Bedrock Geologic Map. Most state Geological and/or Natural History Surveys also provided lists of state geological publications. In addition, ERG obtained electronic copies of each map, along with parameters for individual digitized bedrock unit polygons. Rock unit names presented on the Bedrock Geologic Maps were transferred directly into a blank database.

Bedrock Geologic Maps used for NUSAMG

Connecticut – Bedrock Geological Map of Connecticut, 1985
Maine – Bedrock Geologic Map of Maine, 1985
Massachusetts – Geologic Map of Massachusetts, 1983
New Hampshire – Bedrock Geologic Map of New Hampshire, 1997
New York – Geologic Map of New York, 1970 (reprinted 1995)
Rhode Island – Bedrock Geologic Map of Rhode Island, 1994
Vermont – Centennial Geologic Map of Vermont, 1961

Geological Reference Materials

We initially reviewed lists of publications offered by each state Geological Survey. Most of these publications were very helpful in providing a thorough overview of the regional and local geology. These documents typically contained verbal descriptions of rock units, often accompanied by data including modal abundances of mineral phases.

The scope of our search for additional materials widened to peer-reviewed journal publications, academic theses, and other publications (e.g., U.S. Geological Survey [USGS, Geological Society of America [GSA], and others). We identified these reference materials primarily using the internet search engines GeoRef.cos.com and GeoBase. Several searches for reference materials using both GeoRef and GeoBase suggested that GeoRef tended to locate more reference articles than GeoBase.

Internet searches were performed as follows. For each rock unit (Group, Formation, or Member) identified on the state Bedrock Geological Map, we first searched using two descriptors - the unit name followed by the state (e.g., Hazens Notch Formation, Vermont). If necessary, a third descriptor (typically “petrology”, “mineralogy”, or “geochemistry”) was used to refine the focus of the search. However, if GeoRef located fewer than two or three references, we altered the search parameters by leaving out descriptors such as “Formation”, “Member”, or the state name. In many instances, typically for areally limited Members, when GeoRef was unable to locate any reference materials we then performed an additional search using GeoBase.

Searches were conducted for each rock unit listed on a Bedrock Geologic Map. In some cases this included searching both a Group and a corresponding Formation included within that same Group. For example, in the Hudson, New York region, separate searches were performed for both “Hamilton Group” and “Portland Point shale”, even though the Portland Point shale is a unit enveloped within the Hamilton Group.

Each list of potential resource materials obtained by the GeoRef or GeoBase search engines was archived electronically and later reviewed for relevancy to this project.

Data Sources

Mineralogical, geochemical, and stratigraphic data were obtained from several types of sources including articles from refereed journals, bulletins and professional papers, publications from individual state geological surveys, academic theses, personal communication, and our own field sampling.

Journals used in NUSAMG

Alcheringa
American Mineralogist
Canadian Mineralogist
Contributions to Mineralogy and Petrology
Economic Geology
Geology
Journal of Metamorphic Geology
Journal of Paleontology
Journal of Sedimentary Petrology
Keck Symposium in Geology
Mineralogical Magazine
Northeastern Geology and Environmental Sciences
Organic Geochemistry
Palaeogeography, Palaeoclimatology, Palaeoecology
PreCambrian Research
Science
Sedimentology

American Journal of Science
Canadian Journal of Earth Sciences
Chemical Geology
Earth and Planetary Science Letters
Geochimica et Cosmochimica Acta
Geological Society of London
Journal of the Nature
Journal of Petrology
Journal of Structural Geology
Marine Geology
Northeastern Geology
Oil & Gas Journal
Palaios
Rocks & Minerals
Sedimentary Geology

Bulletins and Reports used in NUSAMG

AAPG Bulletin
EOS – Transactions of the American Geophysical Union
Geological Society of America-Abstracts with Programs
Geological Society of America- Bulletin
Geological Society of America-Special Paper
Maine Geological Survey- Bulletin
Maine Geological Survey-Geologic Map Series
New Hampshire Dept. of Resources and Economic Development – Bulletin
New York State Museum- Bulletin
New York State Museum- Map and Chart Series
State Geological and Natural History Survey of Connecticut
University of Massachusetts, Amherst- Contribution
U.S. Geological Survey-Bulletin
U.S. Geological Survey- Circular
U.S. Geological Survey- Open-File Report
U.S. Geological Survey- Professional Paper
Vermont Geological Survey-Bulletin

We also obtained detailed mineralogical and geochemical information from the following sources:

1. Ph.D. dissertations, M.S./M.A theses., and B.S./B.A. theses. Typically, photocopies of theses were obtained through InterLibrary Loan;
2. Personal communication. Data for the Iberville shale in Vermont were obtained through personal communication with Dr. Helen Mango, a professor of geology at Castleton State College in Castleton, Vermont;
3. Some limited data were obtained from published abstracts, such as the Geological Society of America - Abstracts with Programs; and
4. In Maine, New Hampshire, and Vermont there were several rock units for which we were unable to locate published modal or geochemical data. For these units we collected hand samples and performed rock thin section point counts. Using state Bedrock Geological Maps to verify sampling locations, we collected fresh hand samples. Mineral Optics of Wilder, Vermont prepared thin sections from the samples. Richard Ziegler provided a verbal description of the samples, and performed manual thin section point count analyses using a Leitz petrographic microscope with mechanical stage. The data collected for these units are included in the database.

Most articles, bulletins, and abstracts were located and photocopied in the University of Minnesota, Walter Library (Science & Engineering Library) located at 117 Pleasant Street SE in Minneapolis, MN. Paper copies of photocopied reference materials are on file.

Geological Reference Management

As we gathered reference materials each article was logged into a Master Reference List (see Appendix A) under a heading of "Article", "Bulletin or Professional Paper", "Thesis or Dissertation", or "Abstract". Each heading is subdivided by state.

Each entry in the "Article" heading was assigned an identification tag typically consisting of the state abbreviation followed by a number (e.g., NH–16). The exception is articles collected for the state of Vermont; each Vermont article identification tag consists of only a number. Identification tags for entries in the "Bulletin / Professional Paper" heading consist of the state abbreviation, followed by "B", and then a number (e.g., VT-B-20). Likewise, theses/dissertations are identified by state abbreviation, a "T", and a number (e.g., NY-T-32), and abstracts are identified by the state abbreviation, "A", and a number (e.g., CT-A-3).

NUSAMG began as a pilot study within the state of Vermont, and continued through the New England states and New York. At times we have inadvertently gathered, logged, and numbered reference sources that were duplicates of references used earlier in another state. Duplicate sources are labeled with each identification tag that was assigned to them (i.e., MA-B-14 / RI-B-12).

Information contained within the Master Reference List includes the title, author(s) name, year of publication, journal of publication, volume, issue, and page numbers. In addition, we list the names of all rock units included within each reference source.

Geological Data

We reviewed each reference source for mineralogical, modal abundance, or bulk rock geochemical data, and additional information regarding sampling locations and descriptions of rock units. Some source articles listed in the Master Reference List were not used for NUSAMG; these sources either provided redundant or insufficient information as follows:

- Redundant information typically included data from samples collected at an outcrop or locale for which we already had similar or more complete data. However, in order to adequately represent the variability of a rock type we do often present data from multiple samples at the same outcrop; and
- Sources deemed to contain insufficient information usually did not contain modal or geochemical data, or did not present detailed descriptions suitable for differentiating between rock types.

There were some rock units for which we were either unable to locate reference sources or we did not pursue detailed information. In most cases there is undoubtedly information available somewhere –we were just unable to locate it in a timely manner. We did not seek detailed geological information for rock units that were clearly limestone and dolomite. However, we did search for data on rock units that consisted of intercalated carbonate and non-carbonate layers, and we did include any data available for primarily carbonate rock units.

Rock units for which we did not find either mineralogical or geochemical data are identified in the database, and were assigned either a general "description" (and approximate mineralogy) of the specific rock type, or actual mineralogical data for a very similar rock type found elsewhere in the northeast. Details including the source of the general rock type description and the location and rock type of the representative sample are presented in the database.

Mapping and Sampling Locations

Most sources that contained mineralogical, modal, or bulk rock data provided clear notations of sampling locations either by a map, by listing latitude and longitude coordinates, or by providing a verbal description. Sample locations provided in reference sources were either compared to digital and/or paper copies of the Bedrock Geologic Map visually, or by using the topographic mapping software TopoUSA. As could be expected, there were often discrepancies such as:

1. **Slight latitudinal / longitudinal offsets in comparison to the digital Bedrock Geologic Map, likely an artifact of the digitizing process.**

   We accounted for this by keeping the actual sample location in the same relative location within the polygon on the digitized map;

2. **Mapping / plotting errors likely introduced primarily due to authors focusing on the geology of an area at the quadrangle-scale, versus Geologic Bedrock Map editors focusing on the geology at a statewide scale.**

   We made notations in the database that indicate this kind of problem and explain that error is likely due to the mapping scale;

3. **Rare lack of agreement between reference source authors and Geologic Bedrock Map editors for bedrock unit names.**

   We noted this type of error in the database, and noted both bedrock unit names;

4. **Poor or vague verbal descriptions of sampling locations, or reference to landmarks that no longer exist.**

   We used TopoUSA and any other clues provided in the source text to estimate sample locations. We typically noted uncertainties in sample locations in the database; and

5. **Individual bedrock polygons on the digital Bedrock Geologic Map that had been mislabeled.**

   We confirmed the correct labeling of each mislabeled polygon on the digital Bedrock Geologic Map and made appropriate corrections to the digital file.

Many sources did not provide discrete sampling information, but instead provided a general rock type description(s) for an entire quadrangle or region. In general these documents can be grouped into three categories as follows:

1. **The document presented a verbal description of each rock unit, perhaps accompanied by a notation of one or two locations of a representative outcrop.**

   With these sources we did our best to identify the general area of the mentioned outcrops using TopoUSA, confirmed that the outcrop areas were within the desired rock unit as mapped on the Bedrock Geologic Map, and then used these locations as "sample" locations;

2. **The source provided only verbal descriptions of bedrock units.**

   With no indication of either sample or outcrop locations, we arbitrarily chose latitude and longitude coordinates within the appropriate rock unit area. Arbitrary coordinates are noted as such within the database; and

3. **In rare instances a reference source contained data collected from rock samples but with no indication of sample numbers or sampling locations.**

   As noted above, with no mention of sampling locations we arbitrarily chose a coordinate within the appropriate rock unit area, and made notes accordingly within the database.

Latitude / Longitude

All sample locations in the database include coordinates for latitude and longitude. Very few reference sources provided actual latitude and longitude coordinates. Most coordinates were listed in a degrees-minutes format, which we converted to decimal degrees. Otherwise, most sampling locations were either identified on a map, or with written verbal descriptions. We used the provided sample maps/verbal descriptions, the Bedrock Geologic Map, and TopoUSA software to estimate the sampling location, and then estimated the latitude and longitude coordinates.

Additional Sample Information

Information provided regarding the metamorphic zone, or grade, for rock samples is noted in the database, along with indications of a subunit name (e.g., Rawsonville facies of the Mt. Holly complex biotitic gneiss), and estimates of the percent of the map unit represented by the rock sample. Information pertaining to these questions was typically not readily available in most reference sources.

Modal Mineralogy

Source references often contained both mineralogical and geochemical data for a rock unit. However, it was common for a source to contain either mineralogical data, or geochemical data, and not both. As a rule, we present as much of the data for a rock unit provided in a reference source as is possible.

Mineralogical data were evaluated and handled as follows:

1. Typically, modal mineralogical data were presented as "percent by volume"; we checked to confirm that totals were close to 100%. One exception: in the Vermont database most of the modes for samples from the Waits River Formation (dw) are presented in units of mols per liter of rock. This is noted within a comment for each sample;
2. Most modal data were gathered from manual point counts; however, some are based on visual estimates. We made notes in the database if the mode was a visual estimate;

3. Some modes only contained major mineral phases, and not minor constituents. If the presence of minor mineral phases were noted in the text, we included them in the mode, with notes addressing the uncertainty of the corresponding values;
4. **Opaque minerals:** Identification of various opaque minerals was not common, as most were lumped together and labeled “opaques”. If there was no indication within the text as to what opaque minerals were present, we noted this with a comment, and entered the “opaques” mode as either the mineral magnetite or ilmenite;
5. **Carbonates:** Identification of individual carbonate minerals was not common. In these cases we looked for clues, but if there were none, we put the value for “carbonate” under calcite and flagged it with a comment.
6. **Plagioclase feldspar:** Many references provided anorthite (An) content of plagioclase feldspar in samples. However, most sample data did not include An content in plagioclase for individual samples; however, notes within the text would often indicate the general An range of plagioclase (oligoclase, andesine, labradorite, etc.). We handled this as follows: if the An content of a sample was listed as oligoclase, we made a note of this in the database and entered the average for oligoclase, An_{20}, for that sample;
7. **Multiple occurrences of the same mineral type:** If two types of amphibole were present, or if a amphibole was present both in the groundmass and as porphyroblasts, we entered the total of the two, and made note of each individual mode in a comment;

Verbal Descriptions of Mineralogy

In many instances we were unable to locate reference sources that contained modal mineralogy or geochemical data. These sources often contain verbal descriptions of a specific mineral assemblage, such as:

> "The Hanover Shale Member consists of intensely bioturbated green-gray silty pyritic shale interbedded with argillaceous carbonate beds, calcareous nodules, and organic-rich laminated shales." (Over, D. Jeffrey, 1997, p.165)

Translating this type of description into an estimate of modal abundances was challenging. Decisions regarding both the actual mineral phases present in the rock unit, and the modes, were typically based on actual modal data gathered in other areas for similar types of rock units, and an understanding of the common components of that particular rock type.

We note in the database whether the mineralogical information for each sample is from an actual point count (P), an estimate of abundance based given in a descriptive narrative (N), or estimated from a rock type classification (E). In some instances we have included data for a single rock unit that was taken from two or more sources in which one source may have provided data from actual point counts, and the other from “N”-type estimates. The level of certainty obviously diminishes with N and E estimates, however, as a whole the data are still useful.

Geochemistry of Variable Composition Minerals

Geochemical data was occasionally available for compositionally variable minerals such as hornblende, pyroxene, epidote, garnet, muscovite, biotite, and chlorite within a rock sample. When available, geochemical data for other compositionally variable phases including plagioclase, staurolite, calcite, ankerite, siderite, ilmenite, and hematite were included in the database.

Within the database we present variable phase chemical formulas as molar proportions of ions based on the appropriate number of oxygens. However, some reference sources provided chemical formulas on a weight percent of oxides basis, so we recalculated those compositions to a molar ion basis (see sidebar). Within the database we made notes of samples for which we had performed recalculations. We also include additional notes in the database if, for instance, geochemical data provided indicated separate values for Fe^{2+} and Fe^{3+}, or Al^{IV} and Al^{VI}.

CHEMICAL FORMULA RECALCULATIONS

	molar ions on basis of
Hornblende -	23 oxygens
Pyroxene -	6 oxygens
Epidote -	12 oxygens
Garnet -	12 oxygens
Biotote -	11 oxygens
Muscovite -	11 oxygens
Chlorite -	17 oxygens

When geochemical data for compositionally variable phases were not available, we chose from a wide variety of simplified, "ideal" chemical formulas, as was appropriate. Mineral phase names for the "ideal" formulas are indicated in comments. A list of the ideal formulas used in the database is presented in Appendix B.

Bulk Rock Geochemistry

For many rock units reference sources provided bulk rock geochemistry data for individual samples. When available this information, presented in a weight percent of oxides basis, was transferred directly to the database. Notes were included in the database as necessary.

Conclusions

The NUSAMG collection of mineralogical and geochemical data will serve many purposes. Geological researchers, government agencies and regulators, environmental and geological engineers and consultants, teachers, and students will benefit from the accessibility of regional, state, and local bedrock mineralogical and geochemical data for various types of projects. In addition, areas of the northeast that warrant additional geological research are readily apparent.