NCGMP09—draft standard format for digital publication of geologic maps

version 1.0, October 2009

USGS National Geologic Map Database Project and Pacific Northwest Geologic Mapping Project
Contributors: Ralph Haugerud, Stephen Richard, David Soller, and Evan Thoms
(in alphabetical order)

NOTE: For the most current version of this document, and for further information, see
http://ngmdb.usgs.gov/Info/standards/NCGMP09/

Table of Contents

Introduction

This document proposes a standard format for geologic map publications funded by the National Cooperative Geologic Mapping Program of the U.S. Geological Survey. It specifies a database schema to encode content analogous to that contained in a traditional geologic map published by the USGS and by state geological surveys. It stipulates an ESRI database format in order to adhere to USGS policy[1] and because this is the GIS most commonly used in the USGS, in the state geological surveys, and in the larger community. Migration to a non-proprietary format, such as the GML-based GeoSciML, is a worthy goal, and the database schema described here is designed with this in mind.

Further, this design is intended to provide a stepping-stone toward development of multi-map databases, in particular the National Geologic Map Database (NGMDB). The NGMDB Project assists with coordination of database design work between the USGS and state geological surveys, and is mandated to build a national archive of standardized geologic map information. The database design proposed herein will significantly promote that goal.

Objective

Geologic mappers, geologic mapping agencies, and geologic map users would benefit from a standard database schema for digital representation of geologic maps. This document proposes such a schema for the representation of a single geologic map. The schema is focused on the transfer and archiving of map data, with less concern for the creation of map data, the visual representation of map data, or the compilation of data from many maps. With increased use of extended versions of this schema we anticipate reductions in the cost of map production and publication (data compilation and synthesis, review, editing, cartography, pre-press, training, and tool development).

We focus on the representation of a single map for two reasons: this is the issue the geologic community (and our workgroup) understands best, and this is the problem that we perceive is most in need of a solution. The construction and maintenance of multi-map databases brings several issues that we do not here address, including versioning, multiple-scale representations, vocabulary management, maintenance of the stratigraphic lexicon, and access control.

For the purposes of this design, ‘single geologic map’ means a package of data (bearing in mind that many geologic ‘data’ are inherently interpretations) that pertains to a single portrayal of the geology of some area (the map extent), directly analogous to the traditional paper geologic map. While this package may include different views of the data—e.g., the principal map view, one or more cross sections, perhaps one or more detail maps—each view is represented by a unique mapping between the data and symbols (graphical elements). As a publishable product similar to a conventional geologic map, the database package is attributed to an author or authors who have either collected original data and developed the data package and portrayal, or have compiled data from existing sources and developed the portrayal.

1 General policy stated in Section 6.1.3 (USGS-only link at http://geology.usgs.gov/usgs/policy/policy6.shtml), supplemented May 24, 1999 by details shown at http://ngmdb.usgs.gov/Info/standards/dataexch/USGSpolicy.html (see section 3, but disregard reference to SDTS, which no longer is applicable).

This document is intended to bridge between geologic mapping and GIS communities at an operational level. We are codifying lessons from our experience and we expect that this document will be successful largely to the extent that it tells its readers what they already know.

Lessons learned in the last two decades

Geologic map data producers have been developing and using GIS representations of geologic maps for more than two decades. In the course of this effort we have learned some lessons.

The distinction between map data and its symbolization is important. Maps can be represented digitally by scanning them and storing the image file, but this is a very small step towards making the map more useful and its constituent data more easily used for various purposes. Similarly, maps should be more than vector graphic files (e.g., in Adobe Illustrator format). Map data are most usefully stored and analyzed in a geographic information system (GIS), with feature locations given in a real-world spatial reference framework (e.g., UTM10, NAD83) and feature attributes stored explicitly in database tables (e.g., line number 27 is an accurately located thrust fault, line 28 is an approximately located contact, line 29 is the shoreline of Lake Erie on Aug. 27, 1978). A map image, composed of lines, colored areas, patterns, and markers, is a symbolization of the data contained in the database, analogous to a tabular report based on financial data in an accounting database.

Maps need metadata for the overall dataset and for individual elements. Early GIS practices, largely stemming from limitations of storage space and database architecture, as well as paper-map precedent, led to the creation of a significant number of databases in which key fields were populated with symbols (e.g., map unit = Ks) and these symbols were not defined within the database. This is inadequate. Most geologic maps have mixed origins and data qualities; map users benefit from feature-level metadata that describes data source and quality. Map data should be closely linked to authorship because maps are interpretations made by individuals or workgroups, and linked to sponsoring entities because most maps could not be made without significant support from a governmental agency, academic institution, professional society, and (or) private industry.

Real-world database schemas reflect compromises between the intrinsic complexity of geologic map data, the needs of geologists and GISers who work with a schema, the capabilities of GIS and database software, and the limitations of the underlying computer operating system and hardware. Schemas that do not make such compromises are unlikely to be widely used. Even the names of data entities (e.g., of spatial feature sets, tables, fields) must be carefully crafted to be readily understood by users with different backgrounds, to facilitate adaptation and re-use of software tools, and to promote distribution, translation, and compilation of data.

It is difficult to obtain community acceptance for data architecture (tables and spatial feature sets), data attributes, attribute names, and attribute vocabularies that extend beyond the precedents set by our paper mapping tradition. This conservatism is a good thing because our paper map tradition embodies a great deal of hard-won wisdom. But it is also unfortunate because our tradition reflects compromises necessitated by the limitations of the paper map format.

There is also a widely-shared perception that paper geologic maps, with their subtleties of layout, sometimes carefully ambiguous descriptions, and textual and visual vocabularies that are often opaque to the uninitiated, are not readily used by the public that needs (and pays for) the information contained within these maps. We hope this proposed schema contributes to a better understanding and wider use of geologic map data.

Acknowledgments

This database design is an outcome of years of research and collaboration by many scientists and GIS specialists, under auspices of numerous projects and initiatives. We gratefully acknowledge what we have learned from them, and hope this draft design sufficiently meets with their approval to warrant comment and improvement. In particular, we thank Peter Lyttle (Program Coordinator, National Cooperative Geologic Mapping Program) for his recommendation in 2008 that we undertake this work. We also thank: Ray Wells (Chief, Pacific Northwest Geologic Mapping Project) for his support and advice; David Percy (Portland State University and NGMDB project) for his critical review and his input during early stages of developing the design; Dan Nelson (Illinois State Geological Survey) for his general comments on a prototype NCGMP09 design; and our colleagues who attended the DMT'09 Workshop, where the prototype design was discussed and critiqued.

Review, comment, and revision

This document introduces the proposed NCGMP09 standard database schema. The design is an outcome of more than a decade's work among numerous individuals and projects, in NCGMP and in other programs and in many agencies. In particular, during this period the National Geologic Map Database (NGMDB) project has been charged under the Geologic Mapping Act to support the development of geologic map standards and guidelines. Throughout this time, it has been clear that there is no single "right" approach – geologic map content, and database requirements, vary from project to project and address to different degrees the long-term requirements for the national database. The design presented herein is intended to address the needs of geologic mapping projects, particularly for data delivery; requirements for the NGMDB are under development concurrently, and will be compatible with the NCGMP schema.

We seek a schema that has broad support from the geologic mapping community. Therefore, we ask that you review the document and the schema and provide comment in order to, collectively, improve the database design, the documentation that explains it, and the tools and templates that facilitate its use. Please contact us via email, at ncgmp09@flagmail.wr.usgs.gov.

Regarding availability and maintenance of this database design, under the authority of the Geologic Mapping Act of 1992 (and subsequent reauthorizations), the National Geologic Map Database project will function on behalf of the NCGMP as coordinator of database design changes and maintenance. This activity will be conducted in cooperation with NCGMP projects and other identified stakeholders (e.g., the Association of American State Geologists).

Design considerations

We have attempted to meet the following considerations:

- Encode all the content of a traditional paper geologic map.
- Focus on the digital storage and transfer of a single geologic map. Facilitate interactive display and query. Provide a foundation for publication-quality visualization. Do not here try to solve the many-map database problem.
- Define the names and types of all constituent elements in order to meet user needs for consistency and to facilitate re-use of code and tools by map-producers. Use names that have

obvious meaning to geologist and GISer alike.

- Address the persistent perception that traditional geologic maps do not meet the public's (and the scientist's) need for consistently named and defined earth materials data, by providing standard terms and definitions.
- Preserve, and facilitate the analysis of, map topology.
- Normalize map data for robustness and compactness of the database, but not to the extent that user comprehension is reduced.
- Allow queryable description of map features with as much (or as little) granularity as desired.
- For flexibility, interoperability, and data longevity, strive toward use of open file formats.

Content of a traditional geologic map

Traditional geologic maps have rich semantic content that should be preserved in the digital publication. This content is outlined below. Yellow background denotes content for which we do not specify a digital form.

1. Map-graphic
    1. Base map
    2. Map-unit polygons (polygons that cover the mapped area with no voids and no overlaps. May include open water, permanent snowfields and glaciers, and unmapped areas).
    3. Contacts and faults that, with a few exceptions, bound and separate map-unit polygons.
    4. Several elements that are present as needed to portray the content of a particular map:
        1. Overlay polygons, e.g., alteration zones, perhaps extensive artificial fill, surface projection of mined-out areas. Note that while these polygons commonly represent features that are within, or beneath, the rocks and deposits represented by map-unit polygons, they are commonly represented on the map as patterned overlays.
        2. Other lines, including traces of fold hinges, facies boundaries, isograds, cross-section lines, dikes and sills, marker beds, structure contours, etc. In general, overlay polygons and other lines do not conform to the strict topological rules that constrain map-unit polygons and contacts & faults (no polygon voids or overlaps, contacts lie on polygon boundaries, faults may dangle but contacts may not).
        3. Point data, which may include (but are not limited to) structural data (orientation measurements: axes and vectors), samples, geochronologic results, fossils, chemical analyses, prospect locations, displacement (fault-slip) measurements, and points for map-unit polygons too small to show at scale.
2. Zero to many cross sections (each with elements analogous to map elements, except that the base map is replaced by a topographic profile).
3. Correlation of Map Units diagram that includes unit designators, brackets, dividing lines, and text.
4. Symbolization for above, including:
    1. Map-unit area fills (color and optional pattern)
    2. Patterns for overlay polygons
    3. Line symbols and/or point markers for map-unit areas too small to show as polygons at map scale

    4. Text tags for some (but not necessarily all) polygons
    5. Leaders for text tags for some polygons
    6. Line symbols (with variable color, weight, dot-dash pattern, repeated marker ornament, etc) for some lines
    7. Text labels for some lines and groups of lines
    8. Point (marker and/or text) ornaments for some linear features
    9. Markers and/or text for some point data
    10. Leaders for markers and/or text for some point data.
5. Description of Map Units, or List of Map Units with descriptions in an accompanying pamphlet. Traditionally does not describe water, permanent snow and glaciers, unmapped area, and some overlays and underlays. Includes headings and some units not shown on map (e.g., Group that is entirely mapped as constituent Formations). Is strongly hierarchical. Each unit shown on the map has area fill color and pattern, tag, unit name, age, description, position in hierarchy, and a paragraph style that (in part) denotes position in hierarchy. Headings and units not shown on the map lack area fill color and pattern and tag.
6. Explanation of line symbols
7. Explanation of point symbols
8. Miscellaneous collar material. Includes report title, author(s), date of publication, publisher, series and series number, mapped-by statement, edited-by statement, cartography-by statement, specification of spatial reference framework, and scale.
9. Zero to many figures
10. Zero to many tables
11. Zero to many additional maps (e.g., sources of map data; distribution of facies in the Cambrian)
12. Extended text, as needed
13. References Cited, as needed

Extensions to traditional geologic map content

We include several extensions to traditional geologic map content. Two are required: feature-level metadata and the supplementing of map unit descriptions with standard lithology descriptions. Optional extensions are extended attributes and structured, more detailed descriptions of the ages of geologic events, which may be used to store content that otherwise might be stored in extended text, or in tables or figures.

Feature-level metadata

All elements of a geologic map database should be accompanied by an explicit record of the data source. Many elements should have explicit statements of scientific confidence: How confident is the author that a feature exists? That it is correctly identified? How confidently are feature attributes known? All spatial elements in the database should be accompanied by quantitative statements of how confidently their location is known. Specification of these confidence values may at first seem to constitute an undue burden on the geologic mapper. However in many cases, default values for the entire map area are appropriate; in others, tools to efficiently assign confidence values can be developed. If facilitated by software tools for data input, the inclusion of confidence values should create little extra work for the mapper, and users will benefit significantly from the additional information.

Data source (provenance). Typically, a single map database will have very few data source records, as many features will have identical sources. For a database composed entirely of new mapping, there could be a single data source: “this report”. Some data elements have compound sources: geochemical analysis of a rock sample will typically have one source for the map location and stratigraphic provenance of the sample (the field geologist) and another source for the chemical analysis (the geochemist). In such cases, multiple source fields in the relevant data table are appropriate, e.g., LocationSource and AnalysisSource.

Location confidence (spatial accuracy). Reported locations of geologic features are commonly uncertain because of probable error in locating observation points (because, for example, of GPS error or an imprecise base map). This is because some geologic features are subtle and difficult to locate, or because the locations of features are known indirectly by inference from the locations of other observations. Because most users locate geologic features in relation to an associated base map, and because most spatial analyses of geologic map data are in relation to the base map or to other data in the same database, the location confidence relative to features on the base map and to other data in the geodatabase is important. In general compliance with the FGDC Digital Cartographic Standard for Geologic Map Symbolization (FGDC-STD-013-2006, http://ngmdb.usgs.gov/fgdc_gds/, section 4.2.2.1), this location confidence is reported as the radius (in meters) of the circle of uncertainty about a point location, or the half-width (in meters) of the zone within which a line is asserted to be located. But as further defined here, the location confidence is a combination of the error in positioning of the observed feature relative to the base map (the positional accuracy of the FGDC Standard, section 4.2.2) and one aspect of the locatability of the FGDC Standard (i.e., how precisely, relative to where I am standing, can this contact be placed?). Because estimates by the map producer of location confidence are likely to be much better informed than estimates made by others, this information is of significant value to map users.

Location method. We propose to record the process of observation or inference used to locate each feature. Values for this field could include “observed in field, location by map inspection”, “observed in field, location by recreational GPS”, “inferred beneath mapped covering unit”, “color or texture change on aerial photograph”. This field provides information useful for estimating location confidence and records another aspect of the locatability of the FGDC Standard (section 4.2.1), information that has been denoted on some maps by categorization of contacts and faults as *observed, inferred, or concealed*.

We note that the observed, inferred, or concealed categorization is problematic because a contact mapped as concealed is always inferred, but not necessarily vice versa, and most observation methods involve some degree of inference—e.g., that a color or vegetation change seen on an air photo or a break in slope on a hillside corresponds to a geologic contact.

Existence confidence, identity confidence, and scientific confidence. The FGDC Standard notes that scientific confidence may have multiple dimensions. For a map unit area, scientific confidence has one dimension: confidence that the map unit is correctly identified. In the case of faults, contacts, and other feature traces, the situation is more complex. There may be uncertainty as to whether a boundary between two units is a contact or fault. There may be uncertainty as to what kind of fault is mapped. In both cases, this uncertainty is specified by an identity confidence value. In some cases, the presence of a fault may be suspected but is not certain. Fold hinge surface traces, dikes, marker beds may also be mapped where their existence is suspected but not certain. This uncertainty is specified by existence confidence. Contacts are rarely mapped where their existence is uncertain; if different map units are identified, there must be a boundary of some sort between them, in which case the identity of that boundary may be questionable, but not its existence. Useful values for existence confidence and identity confidence are “standard” (or “std”) and “low”, or “certain” and “uncertain”. NCGMP09 includes ExistenceConfidence and IdentityConfidence for line feature classes, and IdentityConfidence for polygon and point observation features. We discussed at length whether to combine these confidence concepts into a single ScientificConfidence field in the database, perhaps with 4 or 6 values to allow for various combinations of existence and identity confidence, but decided that it makes more sense to leave both as separate fields, as specified in the FGDC Standard. We expect that symbolization will in some cases be assigned on the basis of feature type and the appropriate confidence terms. As noted above, in many situations default values for the entire map area are appropriate; in others, tools to efficiently assign confidence values can be developed.

Orientation confidence. For measurements of rock structures (bedding, foliation, lineation, joints, etc.) it is useful to describe how accurately the orientation has been measured. This is specified as the circular error of a direction (for planar features, of the pole to the plane), which is most usefully expressed as an angular measure similar to the $alpha_{95}$ value often reported for paleomagnetic directions. The OrientationPoints feature class includes an OrientationConfidenceDegrees field to record this uncertainty.

Standard Lithology

A traditional “Description of Map Units” can provide a rich description of earth materials, but may use obscure nomenclature, may use it in a fashion that is inconsistent from map to map, and may fail to be quantitative. Jargon, lack of consistency, and lack of precision reflect the infinite variety of earth materials, imperfect geologic knowledge, and our evolving understanding of earth processes. Nonetheless, geologists and non-geologists alike have decried the lack of consistent, queryable, earth-materials descriptions in traditional geologic maps.

We supplement the richness and flexibility of traditional descriptions with strongly-structured descriptions using a small number of defined lithologic terms. These descriptions are encoded in the table StandardLithology, using term lists provided by the National Geologic Map Database Project (Appendix A). Description of a single map unit may span several rows in this table. This allows description of multi-part (spatially variable, interbedded, block-in-matrix) units, with quantitative or qualitative description of the relative abundance of each component. See the specification of StandardLithology (below) for details.

Geologic Events (ages)

Standard ages in traditional map-unit descriptions (which are the terms in parentheses that follow map-unit names in the Description of Map Units) offer limited resolution and do not easily represent multiple ages (e.g., ages for deposition and metamorphism). Traditional paper geologic maps provide no mechanism, short of mention in extended text, for assigning ages to faults and other features that are not map units. An optional GeologicEvent table, in conjunction with ExtendedAttribute associations, allows representation of complex history with multiple ages of some units, more age resolution, and association of ages and history with faults or other structures. The GeologicEvent table includes attributes for assigning upper and lower bounding ages, either using stratigraphic era names or numeric age values. It allows ages to be associated with geologic events such as deposition, crystallization, eruption, cooling, peak metamorphism, and fault displacement.

Extended attributes

An optional ExtendedAttributes table allows structured, queryable description of any element in the database. This table correlates an owning item (e.g., a DescriptionOfMapUnits record) with a property and property value pair (e.g., ‘bulk density g/cc’, 2.7). Information associated with any table in the database can be added by defining a new property in the Glossary, and assigning values using the ExtendedAttributes table.

Particular strengths of this data structure are its extensibility and efficiency. Extensible in that it doesn't require that designers of the database foresee all attributes that might be stored in the database. Efficient in that memory is not allocated to store values for attributes of features for which they are not defined.

Naming database elements

Fixed, easy-to-comprehend names for all elements are key to a functional geodatabase schema. Names have been chosen according to the following criteria:

- Names convey content to the geoscientist, to the GISer, and to the public
- Names use uniform concatenation protocol (CamelCase)
- Names do not exploit case sensitivity. Note that case should be conserved, as some languages and operating systems distinguish between *ThisName* and *thisName*
- Names do not contain spaces or special characters
- Long names are acceptable and informative
- Names are easy to code and calculate
- Names reflect data type
- Names point to related tables
- Field names which contain "_ID" are reserved for primary keys. These are of the form *TableName_ID* or *FeatureClassName_ID*

We have chosen not to encode the publication identity (map name or map series number) in the names of feature datasets and feature classes. Feature dataset and feature class names that include a map identifier (name or series number) simplify the joint display of multiple publications in an ArcMap project because each layer name will automatically include the map identifier for the layer. Our choice to use a single name for feature datasets and feature classes in all delivery databases keeps the naming scheme simple, and facilitates the coding and sharing of tools to manipulate geodatabases. Utilizing this approach, users must manually update the field alias or the names of layers in ArcMap projects as necessary to reflect the map source for the data in a layer.

Transparent identifiers

We recommend that identifiers in the database for map units, line types, and point feature types have fairly obvious plain English meaning. The map unit identifier is used as a foreign key from the DMU table to various other tables, and our recommendation is that this simply be the unique label used to identify that unit in map displays. Entries in the DMU that are not symbolized on the map may have null map unit identifier values. The type identifiers for lines and points are references to terms in the glossary, and we recommend that these simply be the geologic term for the line or point type represented. This is in contrast to common database design that dictates that identifiers used as foreign keys in database are best implemented as numbers or text string that have no inherent meaning to human users, which are referred to as opaque identifiers. Though opaque identifiers may be more robust, we think that for a delivery database this advantage is outweighed by the greater intelligibility for people gained by using human-interpretable identifiers. Note that this specification does not prohibit the use of opaque identifiers, particularly for primary key (table_ID) values.

Open file formats

In principle, we encourage the use of open file formats, because: 1) open formats facilitate writing and redistribution of 3rd-party code; 2) open formats reduce the risk of locking data up in formats that become obsolete and unreadable; when open formats are superseded, documentation for them is likely to remain available; and 3) open formats are likely to change in a more measured fashion than proprietary formats. Many in the geologic mapping community are still coping with the costs of the relatively rapid transitions from coverages to shapefiles and from shapefiles to geodatabases.

Text should be stored as .txt, .html, .odt (Open Document Format, ISO/IEC 26300:2006 or its successor), or .pdf files. For images, .png files are preferable to .gif or .tif files. Tables may be stored as .dbf files, for which there appears to be no published standard but for which documentation is readily available, or as xml files that most modern database software can import.

Our desire to endorse open file formats is superseded by our need to prescribe a database file format that preserves topology, allows long attribute names, and works well within ArcGIS, thus we specify the use of ESRI's personal geodatabase (.mdb) or file geodatabase (.gdb) file formats for spatial data. To make geologic map data more widely available, we require that data also be released in shapefile formats (see below). We look forward to wider implementation and use of text-based, application-independent delivery formats such as GeoSciML.

Required, as-needed, and optional contents of a digital geologic map publication

For a map publication named mapXYZ, the publication package should include the files described below. Note that "as needed" elements must be present if they are appropriate to the content of the map publication, e.g., if there is a Figure 1 in the map publication, then a file Figure1.png (or equivalent) must be present in the digital product. "Optional" elements may or may not be present at the discretion of the author or publisher. Required elements are highlighted in pale red; as-needed elements are highlighted in pale gray.

mapXYZ.pdf *Reference map visualization. Publication quality*

mapXYZ-browse.png (.jpg, .tif) *Browse graphic. A **small** file*

mapXYZ-pamphlet.pdf *Map pamphlet, as needed*

mapXYZ-metadata.xml *FGDC metadata. More-or-less human-readable metadata files (.txt, .html) are optional*

mapXYZ-gdb.zip *When unzipped, this file contains:*

- mapXYZ.gdb (file geodatabase folder) or mapXYZ.mdb (personal geodatabase file)
- mapXYZ.mxd *ArcMap document stored with relative pathnames and including relevant VBA macros*
- resources (folder)
  - figures (.png, .pdf, .tif) *As needed*

tables (.dbf, .ods, .xls)	*As needed*
CMU (.pdf, .png, …)	*Optional. Graphic representation of correlation of map units*
DMU (.pdf)	*Optional. Additional document for description of map units*
mapXYZ.style	*ArcGIS style file for area, line and marker symbols used in preferred symbolization of map . Will be largely a subset of the FGDC geology symbol set. Must include all symbols specified elsewhere in database*
vocabularies (.dbf, .xls .odt, …)	*Copies of referenced standard vocabularies, e.g., Standard Lithology. As needed*
mapXYZ-pamphlet.pdf	*Map pamphlet, as needed*
base.gdb or base.mdb (folder or file)	*As needed; required if base-map geospatial data are not published elsewhere. Otherwise optional*
mapXYZ-metadata.xml	*More-or-less human-readable metadata files are optional*
mapXYZ-simple.zip	*Simple version of database. See below for contents*
mapXYZ-open.zip	*Open version of database. See below for contents*

The geodatabase schema

There are required, as-needed, and optional elements in a single-map geologic map geodatabase (Figure 1). These elements are specified below. For each element (feature dataset, feature class, non-spatial table) we provide a name, identify the element type, state whether it is required, to be used as needed, or optional, and enumerate the fields (attributes) in the relevant table. Required elements are highlighted in pale red; as-needed elements are highlighted in light gray.

Unless otherwise noted, all fields are of data type text (=string). Any length is appropriate, so long as it is sufficient to store the associated values; we recommend 50 characters for ID fields and 255 characters for most other fields. For each field we briefly discuss content and domains where appropriate. For some elements this is followed by a short example table and further discussion.

The values in certain fields must be defined in the Glossary table or a referenced external data dictionary. Such fields are shown with cyan backgrounds below.

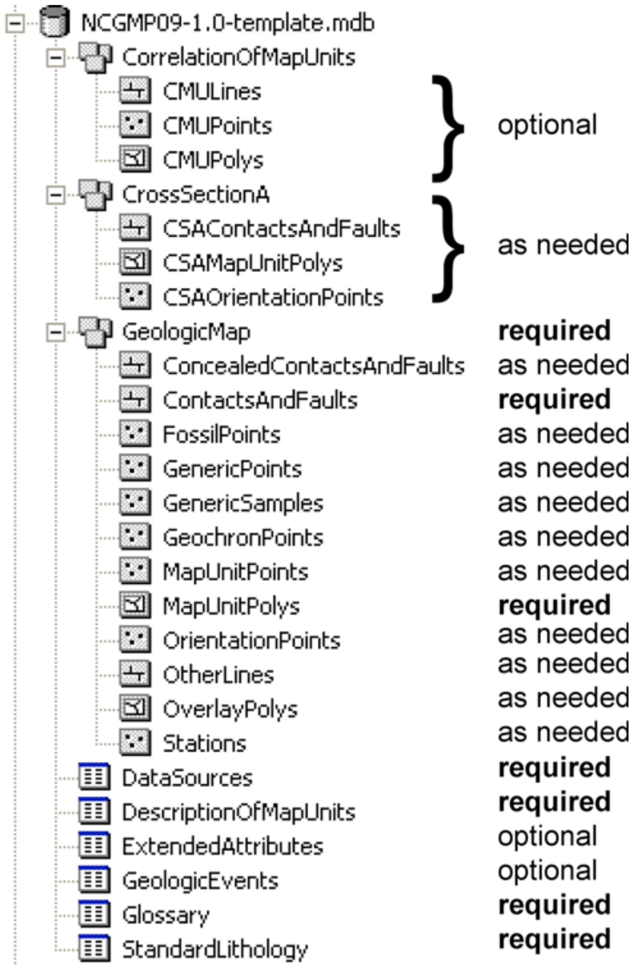

Figure 1. ArcCatalog view of NCGMP09-style geodatabase, showing required, as-needed, and optional database components. As-needed elements must be present if they are appropriate to the content of the map publication. Optional elements may or may not be present at the discretion of the author or publisher. There may be more than one cross-section feature dataset, named CrossSectionA, CrossSectionB, …

Every feature class and table has a primary key field with a name of the form <TableName_ID>. Where values of this primary key populate a field in another feature class or table, that field has a different name. For example, values of DataSources_ID populate fields named DefinitionSourceID (DescriptionOfMapUnits) and LocationSourceID (point data tables) and DataSourceID (many tables).

Example primary keys here are generated with a three letter prefix based on the name of the containing table and an integer numeric suffix that could be the string representation of the ObjectID included in all geodatabase-registered tables. As long as all table prefixes are unique in the dB, this will provide unique identification across the dataset, as well as some human intelligibility of the keys in foreign key relationships. If data loaded into this delivery database do not already have a user-managed primary key, this paradigm is suggested for generating primary keys.

Polygons, lines, and topology: what goes where?

By convention, a geologic map depicts the distribution of earth materials on a particular map horizon, commonly the earth's surface. Map unit polygons (including water, snowfields, and glaciers) are bounded by contacts, faults, shorelines, snowfield boundaries, scratch boundaries, or the map boundary. With some exceptions, which are unusual enough to require mention, contacts do not separate polygons of the same map unit. Map-unit polygons may be interrupted by faults.

The distribution of map units on the particular map horizon is recorded in the polygon feature class “MapUnitPolys”. Contacts between map units, faults that bound map units, and associated dangling faults (fault arcs that terminate within a polygon) are recorded in the line feature class “ContactsAndFaults”. Elements of these feature classes participate in topological relations that are described below. Elements are assigned to these feature classes to simplify enforcement of the topological relations (when constructing a geodatabase) and to facilitate topological queries (when using a geodatabase).

Some maps, in some places, show contacts and faults that are concealed beneath covering units (e.g., beneath thin unconsolidated deposits, or beneath open water). These concealed contacts and faults do not, in general, participate in map-unit topology. For this reason they are recorded in a separate feature class, “ConcealedContactsAndFaults”.

Often we show underlying material, or overlying material, or some additional aspect of earth materials (dike swarm, alteration zone, etc.) with an overlay. On a map graphic, such an overlay is commonly shown by a pattern—diagonal lines, scattered red dots, or other—overprinted on the map-unit color and (optional) map-unit pattern. The topological relations of these overlays are likely to be complicated (e.g., alteration area boundary does not coincide with bedrock map-unit boundaries, but does coincide with unconsolidated-deposit boundaries) and not easily prescribed by a simple set of rules. On many published maps the edges of most overlay polygons are shown without a bounding line (i.e., a scratch boundary). The elements are recorded in feature class “OverlayPolys”.

Dikes, veins, cross-section lines, hinge-surface traces, isograds, ice-sheet margins, structure contours, etc., typically are recorded in feature class “OtherLines”. All of these lines share the property that they do not participate in map-unit topology.

We understand that some producers of geodatabases will choose to create polygons and edit linework in the absence of a topology relationship class, as they exist within the ESRI geodatabase framework. For instance, rather than using topology editing tools to synchronously edit shared boundaries between lines and polygons, many users prefer to edit through a procedure involving lines, polygon attribute label points, and the creation of polygons only when the linework is finished, without the use of geodatabase topology rules. For the purposes of this schema (data delivery), the method used to produce the feature classes does not matter, only that the feature classes in the published database follow the topology rules outlined above.

GeologicMap (feature dataset, required)

This feature dataset is equivalent to the map graphic: it contains all the geologic content (but not the base map) within the neatline. All elements share a single spatial reference framework. Required elements are highlighted in pale red; as-needed elements are highlighted in pale gray. Blue highlighting indicates fields whose content must be defined in the glossary.

MapUnitPolys (polygon feature class, required)

Fields:

MapUnitPolys_ID	*Primary key. Example Values = MUP1, MUP2, MUP3, etc. Values must be unique in database as a whole*
MapUnit	*Short plain-text key (identifier) for the map unit. Generally no more than 4 characters. Example values: Qal, Tg, Kit, Trc3, etc. Foreign key to DescriptionOfMapUnits table. Null values not permitted—a mapped polygon must have an assigned map unit*
IdentityConfidence	*How confidently is this polygon identified as MapUnit? Value is usually 'std' (= standard) or 'low'. Null values not permitted. Suggest setting default value to 'std'*
Label	*Calculated from MapUnit//Label and IdentityConfidence: if IdentityConfidence = low, append "?" to MapUnit//Label. Allows for subscripts and special characters. Null values OK*
Symbol	*References an area fill symbol (background color + optional pattern). Area fill symbols must be defined in an accompanying style file. Null values permitted*
Notes	*Null values OK. Free text for additional information specific to this polygon*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

Topology rules: polygons must not overlap. Polygons must not have gaps. Boundaries must be overlain by lines in ContactsAndFaults.

Note that open water (lakes, double-line rivers), glaciers, and unmapped areas are polygons, and so have non-null MapUnit values (perhaps water, glacier, unmapped). Water and glacier areas commonly are not labeled (Label=null).

ContactsAndFaults (line feature class, required)

Fields:

ContactsAndFaults_ID	*Primary key for database record. Example values = COF1, COF2, … Values must be unique in database as a whole*
Type	*Specifies the kind of feature represented by the line. Values = 'contact', 'fault', 'scratch boundary', 'waterline', 'glacier boundary', 'map boundary', etc… Values must be defined in Glossary or by reference to external glossary. Null values not permitted*
LocationConfidenceMeters	*Half-width in meters of positional uncertainty envelope; position is relative to other features in database. Data type=float. Null values not permitted*
ExistenceConfidence	*Values = 'std', 'low'. Null values not permitted. Suggest setting default value = 'std'*
IdentityConfidence	*Values: 'std' , 'low'. Null values not permitted. Suggest setting default value = 'std'*
LocationMethod	*Short text string that specifies how a line feature was located. Domain is NGMDB*

		LocationMethodTerms list. Value is 'not specified' if no other information is available.
	Symbol	*References a symbol in the accompanying style file. Calculated from Type, LocationConfidenceMeters, ExistenceConfidence, IdentityConfidence, and expected map display scale. Null values OK.*
	Label	*Typically blank, can be used to store fault name, or human-readable name for each line feature. To group line segments into a specific structure trace, e.g."San Andreas Fault", use Extended Attributes. Null values OK*
	Notes	*Null values OK. Free text for additional information specific to this feature*
	DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

Topology rules: Must not overlap. Must not self-overlap. Must not self-intersect. Must not have dangles, unless marked as exceptions. All dangling-line exceptions should be Type=fault (or one of its subtypes, e.g., thrust fault, or low-angle normal fault, or …).

Map boundaries, open water boundaries, and snowfield and glacier boundaries all bound map unit polygons and in this sense are contacts. They are thus included in this feature class.

Lines shown as "contact", "contact inferred" and "contact approximately located" are Type = 'contact', but have differing LocationConfidenceMeters, ExistenceConfidence, and (or) IdentityConfidence. While these lines are all Type = 'contact', they are typically symbolized differently and the symbolization may change with map scale. Manual assignment of symbols is likely to be tedious and error-prone. Symbol values may be calculated with code of the form

> **if** Type = 'contact' **and** LocationConfidenceMeters < ConfidenceZone(mapscale) **and** ExistenceConfidence = 'std' **and** IdentityConfidence = 'std' , **then** Symbol = '1.1.1'

'1.1.1' is the string that identifies "Contact—Identity and existence certain, location accurate" in the FGDC-STD-013-2006, 'FGDC Digital Cartographic Standard for Geologic Map Symbolization. Alternately,

> **if** Type = 'contact' **and** LocationsConfidenceMeters > ConfidenceZone(mapscale) **and** ExistenceConfidence = 'std' **and** IdentityConfidence = 'std' , **then** Symbol = '1.1.3'

'1.1.3' is the string that identifies "Contact—Identity and existence certain, location approximate" in the FGDC Standard.

ConfidenceZone(mapscale) is the permissible uncertainty for an accurately-located line at a given scale. The confidence zone might be calculated as:

> ConfidenceZone(mapscale) = 0.001 meters * ScaleDenominator

In this case, for 1:24,000 scale, ConfidenceZone is 24 meters, and for 1:100,000 scale, it is 100 meters. Note that the ConfidenceZone is specific to the scale of the visualization. If visualization scale changes the calculation must be repeated and the symbolization might change. The multiplier (0.001 meters, above) may vary from map to map and should be specified in the metadata for the dataset as a whole. Alternatively, for regions of markedly different location confidence within a map (e.g., lowland areas underlain by sediments, versus mountainous areas underlain by igneous rock) the ConfidenceZone may be separately specified.

OverlayPolys (polygon feature class, as needed)

Fields:

OverlayPolys_ID	*Primary key. Values = OVP1, OVP2, OVP3, … Values must be unique in database as a whole*
MapUnit	*Short plain-text key (identifier) to the overlay map unit. USGS tradition is no more than 4 characters. Qal, Tg, Kit, Trc3, etc. Foreign key to DescriptionOfMapUnits table. Null values not permitted*
IdentityConfidence	*How confidently is this polygon identified as MapUnit? Value is usually 'std' or 'low'. Null values not permitted. Suggest setting default value to 'std'*
Label	*Calculated from MapUnit//Label and IdentityConfidence: if IdentityConfidence = Low, append "?" to MapUnit//Label. Allows for subscripts and special characters. Null values OK*
Symbol	*References an area fill symbol (background color + optional pattern) in the accompanying style file. Calculated from MapUnit. Null values OK*
Notes	*Null values OK. Free text for additional information specific to this feature*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

Topology rules: None.

Overlay polygon boundaries will typically have complex relationship with lines in ContactsAndFaults and ConcealedContactsAndFaults: in part coincident, in part not coincident. In general, overlay polygon boundaries will not be stroked.

ConcealedContactsAndFaults (line feature class, as needed)

Fields:

ConcealedContactsAndFaults_ID	*Primary key. Values = CCF1, CCF2, CCF3, … Must be unique in database as a whole*
Type	*Values = 'concealed contact', 'concealed fault', ''concealed thrust fault' … Values must be defined in Glossary or by reference to external glossary. Null values not permitted*
LocationConfidenceMeters	*Data type = float. Half width in meters of positional uncertainty envelope. Null values not permitted*
ExistenceConfidence	*Values = 'std', 'low'. Null values not permitted. Suggest setting default value = 'std'*
IdentityConfidence	*Values: 'std', 'low'. Null values not permitted. Suggest setting default value = 'std'*
LocationMethod	*Short text string that specifies how a line feature was located. Domain is NGMDB LocationMethodTerms list. Default value is 'concealed beneath mapped cover'*
Symbol	*References a symbol in the accompanying style file. Calculated from Type, LocationConfidenceMeters, ExistenceConfidence, and IdentityConfidence. Null values OK*
Label	*Typically blank, can be used to store fault name, or human-readable name for each*

	line feature. To group line segments into a specific structure trace, e.g.“San Andreas Fault”, use Extended Attributes. Null values OK
Notes	*Null values OK. Free text for additional information specific to this feature*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

Topology rules: Must not overlap. Must not self-overlap. Must not self-intersect. All dangling nodes, unless marked as exceptions, should be coincident with nodes in ContactsAndFaults.

OtherLines (line feature class, as needed)

Fields:

OtherLines_ID	*Primary key. Values = OTL1, OTL2, OTL3, … Values must be unique in database as a whole*
Type	*Values='cross-section line', 'syncline hinge surface trace', 'biotite isograd', … Values must be defined in glossary or by reference to external glossary. Null values not permitted*
LocationConfidenceMeters	*Data type = float. Half width in meters of positional uncertainty envelope. Null values not permitted.*
ExistenceConfidence	*Values = 'std', 'low'. Null values not permitted. Suggest setting default value = 'std'*
IdentityConfidence	*Values: 'std', 'low'. Null values not permitted. Suggest setting default value = 'std'*
LocationMethod	*Short text string that specifies how a line feature was located. Suggested domain is NGMDB LocationMethodTerms list. Value is ‘not specified’ if no other information is available. Concealed features in this feature class must specify ‘inferred beneath covering mapped unit’ for use in symbolization rules*
Symbol	*References a symbol in the accompanying style file. Calculated from Type, LocationConfidenceMeters, ExistenceConfidence, IdentityConfidence, LocationMethod, and expected visualization scale*
Label	*Typically blank, can be used to store fault name, or human-readable name for each line feature. To group line segments into a specific structure trace, e.g.“San Andreas Fault”, use Extended Attributes. Null values OK*
Notes	*Null values OK. Free text for additional information specific to this feature*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

Topology rules: Must not self-overlap. Must not self-intersect.

'Hinge surface trace', 'approximately located hinge surface trace', and 'inferred hinge surface trace' are all Type = 'hinge surface trace' but have differing LocationConfidenceMeters, ExistenceConfidence, and (or) IdentityConfidence. Note that concealed dikes, marker beds, veins, hinge surface traces, etc., are included in this feature class. Assignment of a dotted line symbol in these cases should be based on the value of LocationMethod.

About point data

Observations of structure orientations, mineral occurrences, or geochemical, paleontologic, geochronologic and other kinds of sample analyses, etc., are made at field stations or on samples collected at field stations. There are two modes for representing such observations and their accompanying locations:

1. a normalized mode, in which a “Stations” feature class stores location information, a non-spatial Sample table stores information on samples related to stations, and other non-spatial tables store observations and analyses, one for each observation or analysis type, related to either a sample or station; and
2. a denormalized mode, in which there is a separate feature class for each type of observation or analysis that also—and in some cases repeatedly—stores station location and sample information.

Each mode has advantages. The first allows error-resistant editing of location and sample information and is well suited for a voluminous (e.g., corporate) data management and archiving system. The second allows slightly easier symbolization and certainly is more convenient for separating analytical information from the geodatabase by simply copying the relevant feature class.

For NCGMP09, we endorse the second mode. We note that to create a compliant database it is likely to be useful to start in the first mode, creating a Stations point feature class with related sample and non-spatial data tables, including a Samples table, and from these create the appropriate data-type-specific point feature classes that will be included in the delivery database. Note that the example datasets do not include a Station feature class or Sample table because of our endorsement of the denormalized approach.

Below, we describe attributes that should be included for any point data feature class, and three example point feature classes, one for measurements made directly at a station (OrientationPoints), one for measurements related to a sample collected at a station (GeochronPoints), and one for stations (Stations). None of the example feature classes is required, though all are likely to be needed for many maps. Other point feature classes (e.g., GeochemPoints, PhotoPoints, FieldNotePoints, SamplePoints, and FossilPoints) should be created as needed, following the patterns outlined here.

Point feature classes: general

Each point feature class shall contain the following fields:

TableName_ID	*Primary Key. Substitute actual table name for ‘TableName’. Null value not permitted.*
Type	*Values must be defined in Glossary or by reference to external glossary. Null values not permitted*
StationID	*Foreign key to Stations point feature class. Null values OK*
MapUnit	*One commonly would like to know what map unit an analysis or observation pertains to. Foreign key to DescriptionOfMapUnits. Null values not permitted*
Symbol	*References a symbol in the accompanying style file. Null values OK*
Label	*What text should accompany the symbolization? Null values OK*
LocationConfidenceMeters	*Radius in meters of positional uncertainty envelope. How well located*

	is the observation or sample locale? Null values not permitted
PlotAtScale	*Data type = float. At what scale (or larger) should this observation or analysis be plotted? At smaller scales, it should not be plotted. Useful to prevent crowding of display at small scales and to display progressively more data at larger and larger scales. Value is scale denominator. Null values not permitted*
Notes	*Null values OK. Free text for additional information specific to this feature*
LocationSourceID	*Foreign key to DataSources. Identifies source of point location. Null values not permitted*
DataSourceID	*Foreign key to DataSources. Identifies source of data at this point. Null values not permitted*

All sample-oriented point feature classes also have fields:

FieldSampleID *Sample ID given at time of collection. Null values OK*
AlternateSampleID *Museum #, lab #, etc. Null values OK*
MaterialAnalyzed *Null values OK*

OrientationPoints (point feature class, as needed)

Point structure data (bedding attitudes, foliation attitudes, slip vectors measured at a point, etc.) are recorded in OrientationPoints, one point per measurement. This table has point-data fields as defined above, plus:

OrientationPoints_ID	*Primary Key. Example values = ORP1, ORP2, ORP3, … Null values not permitted*
Azimuth	*Data type=float. Values limited to range 0..360. Strike or trend, measured in degrees clockwise from geographic North. Use right-hand rule (dip is to right of azimuth direction). Horizontal planar features may have any azimuth. Null values not permitted*
Inclination	*Data type=float. Values limited to range -90..90. Dip or plunge, measured in degrees down from horizontal. Negative values allowed when specifying vectors (not axes) that point above the horizon, e.g., paleocurrents. Types defined as horizontal (e.g., horizontal bedding) shall have Inclination=0. Null values not allowed*
IdentityConfidence	*Values = 'std', 'low'. Specifies confidence that observed structure is of the type specified. Null values not permitted*
OrientationConfidenceDegrees	*Data type=float. Estimated circular error, in degrees. For planar features, error in orientation of pole to plane. Null values not permitted*

The Type field identifies the kind of feature for which the orientation was measured, e.g., bedding, overturned bedding, stretching lineation, open joint. Type definitions (in the Glossary table) shall specify the orientation-measurement convention for that Type (strike & dip, trend & plunge, dip direction & dip, et cetera). Data creators should ensure that multiple measurements at a single station (e.g., bedding and cleavage) have the same StationID. ExtendedAttributes relationships may be necessary to represent relationships between measurements (e.g., lineation in foliation, intersection lineation to intersecting foliations).

GeochronPoints (point feature class, as needed)

Point-data fields as defined above, plus:

GeochronPoints_ID	*Primary key. Values = GCR1, GCR2, GCR3, … Null values not permitted*
Age	*Data type=float. Appropriate value is the interpreted (preferred) age calculated from geochronological analysis, not necessarily the date calculated from a single set of measurements. Null values not permitted*
AgePlusError	*Data type=float. Record type of error (RMSE, 1 sigma, 2 sigma, 95% confidence limit) in Notes field. Null values OK*
AgeMinusError	*Data type=float. Record type of error (RMSE, 1 sigma, 2 sigma, 95% confidence limit) in Notes field. Null values OK*
AgeUnits	*Values = years, Ma, ka, radiocarbon ka, calibrated ka, … Units defined in glossary or by reference to published vocabulary. Null values not permitted*
FieldSampleID	*Null values OK*
AlternateSampleID	*Null values OK*
MaterialAnalyzed	*Null values OK*

Use the Type field to identify the geochronological method (K-Ar, radiocarbon, whole-rock RB-Sr isochron, etc.). Analytical data can be represented using ExtendedAttributes, or in an analysis-specific table such as K-ArPoints if there is much data of a single analysis type.

Stations (point feature class, as needed)

If a map author chooses to include station information in digital publication, we suggest the following fields. A Stations feature class may be extremely useful during initial creation of a map database.

Fields:

Stations_ID	*Primary Key. Example values = STA1, STA2, STA3 ... Unique in database*
FieldID	*Primary key within field stations list/table. E.g., RH09-234. Identifier for station assigned by original station locator*
LocationConfidenceMeters	*Radius in meters of positional uncertainty envelope. How well located is the observation or sample locale? Null values not permitted*
MapUnit	*Foreign key to DescriptionOfMapUnits. The map unit identified as outcropping at the station*
Notes	*FreeText; any observation narrative associated with station*
Symbol	*Identifier for symbol to use in map portrayals of station location. Null values indicates station should not be shown in map display*
Label	*Text string to display on map portrayal next to station symbol*
PlotAtScale	*Data type = float. At what scale (or larger) should this observation or analysis be plotted? At smaller scales, it should not be plotted. Useful to prevent crowding of display at small scales and to display progressively more data at larger and larger scales. Value is scale denominator. Null values not permitted*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

A stations point feature class might also include these fields:

TimeDate	*Time and date of observation at station*
Observer	*Name of the person who located station*
SignificantDimensionMeters	*Significant dimension of exposure (e.g., thickness of stratigraphic section, depth of auger hole, or least diameter of outcrop), in meters. Null values OK.*
LocationMethod	*Values = RecreationalGPS, SurveyGradeGPS, ByInspection, ByOffset, …*
GPSCoordinates	*May differ from map coordinates because of GPS error or (more likely) base map error*
PDOP	*Data type=float. Predicted Dilution Of Precision; an estimator of GPS accuracy*
MapCoordinates	*Station coordinates as compiled on the base map; base map should be identified for the station in the DataSources record.*

Cross Sections (feature datasets, as needed)

Cross sections should be identified as cross-section A, cross-section B, cross-section C, and so on, abbreviated as CSA, CSB, CSC in the dataset and feature class names. Each cross-section exists in a separate map-space, and thus requires a separate feature dataset for each cross-section. For each cross section there are, at a minimum, two feature classes:

CSAContactsAndFaults	*(primary key is CSAContactsAndFaults_ID, values = CSACOF1, CSACOF2, …)*
CSAMapUnitPolys	*(primary key is CSAMapUnitPolys_ID, values = CSAMUP1, CSAMUP2, …)*

Field names, data types, usage, and topology rules for these feature classes are identical with those for ContactsAndFaults and MapUnitPolys. If lines that don't participate in MapUnit topology or point-based data are depicted on the cross-section, the appropriate feature classes (e.g., CSAOtherLines, CSAOrientationPoints) should be created.

Correlation of Map Units (feature dataset, optional)

The Correlation of Map Units (CMU) diagram found on many geologic maps can be encoded as a feature dataset in a geodatabase. Doing so makes it easier to have symbolization of the CMU match symbolization of the map and stores the information in the CMU in a fashion that is (slightly) more queryable than storing the CMU as a simple image. Two feature classes are necessary and a third (CMUText) will almost always be needed. If map units are depicted as point features an additional feature class is needed.

CMUMapUnitPolys (polygon feature class)

Fields:

CMUMUP_ID	*Primary key. Example values - CMUMUP1, CMUMUP2, CMUMUP3, … Null values not permitted*
MapUnit	*Foreign key to DescriptionOfMapUnits. Null values not permitted*

Label	*Value = MapUnit//Label. Null values OK*
Symbol	*Value = MapUnit//Symbol. Null values OK*

Values for Symbol and Label are calculated with reference to DescriptionOfMapUnits. Ghost boxes (e.g., protolith of a metamorphic unit) may be shown as MapUnitPolys with Symbol = null. Or the box outline alone can be stored in CMULines.

CMULines (line feature class)

Fields:

CMULIN_ID	*Values are CMULIN1, CMULIN2, CMULIN3, … Null values not permitted*
Type	*Term to classify meaning of lines. Values include Contact, GhostContact, CmuLeader, CmuRule, CmuBracket, or <MapUnit>_line. Values must be defined in Glossary. Null values not permitted*
Symbol	*References a symbol in accompanying style file. Null values OK*

CMUText (annotation feature class, as needed)

Fields:

CMUTEX_ID	*Primary key. Example values - CMUTEX1, CMUTEX2, CMUTEX3, … Null values not permitted*
ParagraphStyle	*Null values not permitted*

Annotation text and annotation attributes, including font, font size, font effects, and text angle, are stored in default fields of the annotation feature class. Values for font, font size, and font effects can be calculated from ParagraphStyle.

CMUPoints (point feature class, as needed)

Fields:

CMUPNT_ID	*Primary key, example values - CMUPNT1, CMUPNT2, CMUPNT3, … Null values not permitted*
Type	*Values are <MapUnit>_point. Values must be defined in Glossary. Null values not permitted*
Symbol	*Null values OK*

Non-spatial tables

DescriptionOfMapUnits (non-spatial table, required)

This table captures the content of the Description of Map Units (or equivalent List of Map Units and associated pamphlet text) included in a geologic map published by the USGS and state geological surveys.

Fields:

DescriptionOfMapUnits_ID	*Primary key: DMU1, DMU2, DMU3; ExtendedAttributes table OwnerID is a foreign key using this value. Null values not permitted*
MapUnit	*Short ASCII string that identifies map unit: Qal, Tec, Qvt; Triassic Newark Formation can be Trn or TRn, your choice! Unit abbreviations must be unique in the database. Null values OK, and are commonly associated with headings or headnotes. Use of special characters is not recommended in this field*
Label	*Text string used to place label in map display; includes graphic elements such as special fonts and formatting for subscripts. For example, Triassic Newark Formation might be "<font=SpecialAgeFont>#n". Null values OK for units that do not appear on map or are not labeled, e.g., headings, headnotes, water, glacier, some overlay units*
Name	*Boldface name in traditional DMU, identifies the unit within its hierarchical context. Examples: 'Chinle Formation', 'Shnabkaib Member'. These names should be verified in the U.S. Geologic Names Lexicon (GEOLEX); if your usage does not agree with GEOLEX's, notification should be submitted to the Lexicon website. Null values OK*
FullName	*Full name of unit, including identification of containing higher rank units, e.g., 'Shnabkaib Member of Moenkopi Formation'. This is the text you would like to see as fly-out when cursor lingers over polygon in an electronic map display. See Lexicon-related note in "Name", above. Null values OK (e.g., for headings, headnotes, geologic units not shown on map)*
Age	*As shown in bold within parentheses in traditional DMU. Null values may be used for map units that inherit Age from a parent unit, or for headings, headnotes, or overlay units. To designate age with more resolution than permitted by DMU standards, or to record multiple ages (e.g., deposition and metamorphism) for a unit, create entries in ExtendedAttributes and GeologicEvent tables*
Description	*Free-format text description of map unit. Commonly ordered (lithology, thickness, color, weathering and outcrop characteristics, distinguishing features, genesis, age constraints) and terse. Allows markup (e.g., HTML) specification of new paragraphs, super- and subscripts, and geologic-age font (sans-serif and with special characters). Null values OK*
HierarchyKey	*Has form nn-nn-nn, nnn-nnn, or similar. Numeric, left-padded with zeros, dash-delimited. Each HierarchyKey fragment of each row MUST be the same length to allow text-based sorting of the DMU entries. These strings are useful for resolving queries involving hierarchical relationships, e.g., 'find all members of formation x', 'what is the parent unit of map unit y'. Null values not permitted. Table 1, below, illustrates the use of HierarchyKey to describe the structure of a complex*

	Description of Map Units
ParagraphStyle	*Values are Heading1st, Heading2nd, Heading3rd, …, Headnote, DMU1, DMU2, DMU3, or similar. Formatting associated with a paragraph style should be explained with a definition of the style in the glossary. Null values not permitted*
AreaFillRGB	*{Red, Green, Blue} tuples that specify the color (e.g., '255,255,255' for white) of area fill for symbolizing the unit. Especially important to non-ESRI users unable to use the .style file. Null values OK (headings, headnotes)*
AreaFillPatternDescription	*Text description (e.g.,' random small red dashes') provided as a convenience for users who must recreate symbolization. Especially important to non-ESRI users unable to use the .style file. Null values OK (headings, headnotes, unpatterned map units)*
DefinitionSourceID	*Foreign key to DataSources. Identifies source of DescriptionOfMapUnits entry. Null values not permitted*

The traditional Description of Map Units (DMU), or equivalent List of Map Units with descriptions in an accompanying pamphlet, is strongly formatted and typically hierarchical. The hierarchy can carry a significant amount of information. This table encodes the traditional DMU as specified in Suggestions to Authors (Bishop et al., 1978, p. 137-140; Hansen, 1991, p. 49-52) without loss of information and without imposing additional structure or content. It is not designed to produce uniform, easily-queried earth-materials descriptions; for this, see StandardLithology below.

There are entries in this table for all map units and overlay units assigned to polygons on the map (or in any of the cross sections), and for all headings and headnotes beneath "DESCRIPTION OF MAP UNITS" (or under LIST OF MAP UNITS). The entries should include map units that are traditionally not listed in the DMU/LMU such as 'water', 'glacier', and 'unmapped area', and all geologic units that are listed in the DMU/LMU as parent units but are not represented as polygons on the map.

The text of headings and headnotes should be stored in the Description field. Heading and headnote text should have initial capitalization only and no font specifications—these are given by ParagraphStyle.

The ParagraphStyle field eases automatic construction of a traditional text DMU or LMU from DescriptionOfMapUnits. ParagraphStyle values can, with difficulty, be calculated from HierarchyKey, Description text, and feature class MapUnitPolys. The partial redundancy between HierarchyKey and ParagraphStyle allows some automated checking of DescriptionOfMapUnits for logical consistency.

DescriptionSourceID commonly points to Source = 'This report' or Source = 'Modified from <earlier report>'.

Table 1. Truncated, abbreviated Description of Map Units (3rd column, headings and unit names only) from a recent geologic map of northwest Washington, with paragraph styles and HierarchyKey.

HierarchyKey	Paragraph Style		Headings and Map Units
1	Heading2		***Unconsolidated deposits***
1-1	Heading3		**Nonglacial deposits**
1-1-1	DMU1	Qa	**Alluvium of valley bottoms (Holocene and Pleistocene)**
1-1-2	DMU1	Qu	**Alluvium (Holocene and Pleistocene)**
1-1-3	DMU1	Qt	**Talus deposits (Holocene and Pleistocene)**
1-1-4	DMU1	QTl	**Landslide deposits (Holocene, Pleistocene, and Pliocene?)**
1-1-5	DMU1	Qlh	**Lahars (Holocene and Pleistocene)**
1-2	Heading3		**Glacial deposits**
1-2-1	DMU1	Qag	**Alpine glacial deposits (Holocene and Pleistocene)**
1-2-2	DMU1	Qga	**Deposits of alpine glaciers and Cordilleran Ice Sheet (Holocene and Pleistocene)**
1-2-3	DMU1		**Deposits of Vashon stade of Fraser glaciation of Armstrong and others (1965) (Pleistocene)**
1-2-3-1	DMU2	Qvr	**Recessional outwash deposits**
1-2-3-2	DMU2	Qvt	**Till**
1-2-3-3	DMU2	Qva	**Advance outwash deposits**
1-2-4	DMU1	Qud	**Upland deposits (Holocene and Pleistocene)**
	-----many headings and map units omitted-----		
5	Heading2		***Orogenic and pre-orogenic rocks mostly west of Straight Creek Fault***
5-1	Heading3		**Rocks northeast of Darrington-Devils Mountain Fault Zone**
5-1-1	Heading4		Northwest Cascade System
5-1-1-1	Heading5		***Rocks of Autochthon***
5-1-1-1-1	DMU1	KJn	**Nooksack Formation (Early Cretaceous to Middle Jurassic)**
5-1-1-1-1-1	DMU2	Jnw	**Wells Creek Volcanic Member**
5-1-1-2	Heading5		***Welker Peak and Excelsior nappes***
5-1-1-2-1	DMU1	KJb	**Bell Pass mélange (Cretaceous to Late Jurassic)**
5-1-1-2-1-1	DMU2	KJya	**Yellow Aster Complex of Misch (1966) (Paleozoic or older protolith age)**
5-1-1-2-1-2	DMU2	KJts	**Twin Sisters Dunite of Ragan (1961, 1963)**
5-1-1-2-1-3	DMU2	KJv	**Vedder Complex of Armstrong and others (1983) (pre-Permian protolith age)**
5-1-1-2-2	Heading6		**Chilliwack River terrane**
5-1-1-2-2-1	DMU1	JTrc	**Cultus Formation of Brown and others (1987) (Early Jurassic and Late Triassic)**
5-1-1-2-2-2	DMU1	PDc	**Chilliwack Group of Cairnes (1944) (Permian, Carboniferous, and Devonian)**
5-1-1-3	Heading5		***Shuksan nappe***
5-1-1-3-1	Heading6		**Easton terrane**
5-1-1-3-1-1	DMU1	Ket	**Tonalite gneiss of Hicks Butte (Early Cretaceous)**
5-1-1-3-1-2	DMU1		**Easton Metamorphic Suite**
5-1-1-3-1-2-1	DMU2	Ked	**Darrington Phyllite (Early Cretaceous)**
5-1-1-3-1-2-2	DMU2	Kes	**Shuksan Greenschist (Early Cretaceous)**

StandardLithology (non-spatial table, required)

This table represents the lithologic composition of map units by associating with the unit one or more lithology categories from a NGMDB controlled vocabulary. Each associated lithology category has a part type that indicates how the rock type occurs within the unit (veins, layers, stratigraphic part, interbedded, inclusions, blocks…) and a proportion (either a qualitative term or numeric value).

Fields:

StandardLithology_ID	*Primary key. Example values = STL1, STL2, STL3, … Null values not permitted*
MapUnit	*Unit abbreviation, foreign key to DescriptionOfMapUnits. Null values not permitted*
PartType	*Domain is NGMDB StandardLithology PartType list. Null values not permitted*
Lithology	*Domain is NGMDB StandardLithology list. Null values not permitted*
ProportionTerm	*Domain is NGMDB StandardLithology ProportionTerm list*
ProportionValue	*Data type = float. Range 0..1.0. Must not sum to more than 1.0 for a given MapUnit*
ScientificConfidence	*Values = 'std', 'low'. Default value = 'std'. Value of 'low' indicates either that the assignment of the constituent to a lithology category from the controlled vocabulary is problematic, or that the proportion is poorly constrained. Null values not permitted*
DataSourceID	*Foreign key to DataSources. Identifies source of StandardLithology description. Null values not permitted*

Below are some examples of StandardLithology data. Field names are at the top of each column, and each row represents a separate data instance. Numeric proportions are fractional values between 0.0 and 1.0.

StandardLithology_ID	MapUnit	PartType	Lithology	ProportionTerm	ProportionValue
STL26	Tx	beds	Sandstone	Dominant	
STL327	Tx	stratigraphic part	Siltstone	Minor	
STL579	Tx	stratigraphic part	Tuff	Minor	
STL264	Txt	beds	Tuff	Dominant	
STL265	Kit	whole	Tonalite	Dominant	
STL266	KJz	beds	Limestone		.55
STL770	KJz	beds	Mudstone		.45

StandardLithology provides a simple structure for describing all map units in terms of a limited number of lithology categories. Use it in parallel with DescriptionOfMapUnits, which allows for unstructured free text descriptions, and ExtendedAttributes, which permits open-ended structured descriptions.

Use ProportionTerm or ProportionValue as appropriate. Both may not be null in a single record.

If you generate StandardLithology records by interpreting map unit descriptions in an existing map or database, set DataSourceID to point to an entry in the DataSources table, such as DAS2, Source = 'Smith and others, USGS Map I-37, interpreted by <your-name>' or similar.

DataSources (non-spatial table, required)

Fields:

DataSources_ID	*Primary key. Example values = DAS1, DAS2, DAS3, … Null values not permitted*
Source	*Plain-text short description to identify the data source. By convention, for*

		DataSources_ID = DAS1, Source = 'This report'. Null values not permitted
	Notes	*Notes on source, providing more complete description of processing or data acquisition procedure. Can include a full citation and (or) URL. Null values OK*

Some example DataSources records:

DataSources_ID	Source	Notes
DAS1	This report	Field compilation automated by A. Digitdroid, using georeferenced scan of green-line mylar, ESRI ArcScan tools, and manual editing
DAS2	This report, interpreted from 6ft lidar DEM	Data acquired winter 2003-2004 by Puget Sound Lidar Consortium
DAS3	This report, Ralph Haugerud field data, 2005	
DAS4	USGS Open-file Report 2004-197	
DAS5	C. A. Hopson, written communication 2005	Sketch map of lower Chelan creek, used for tonalite phase - gabbro phase contact. University of California-Santa Barbara, written communication 17 July 2005, scale 1:24,000
DAS6	Beta Laboratories, Report 1999-451.	K-Ar dates determined using constants from Dalrymple, 1985.
DAS7	Jackson, J.A., 1997	Cited in Glossary table for sources of term definitions. Jackson, J.A., 1997, Glossary of Geology: Alexandria, VA, American Geologic Institute, 657 p.
DAS8	Modified from DAS4	Digitized 3 new large landslides.

All features and table entries need to be associated with a data source. For maps that contain all new information and use a single vocabulary source, this table will be very short. For compilations with data from many sources which have been edited and (or) reinterpreted so that the data source has effectively been changed, this table becomes longer and more useful. See ChangeLog (below) for advice on maintaining accurate DataSourceID values.

Glossary (non-spatial table, required)

Fields:

	Glossary_ID	*Primary Key. Example values = GLO1, GLO2, GLO3, … Null values not permitted*
	Term	*Natural language word for a concept. Values must be unique within database as a whole. Example values: granite, foliation, syncline axis, contact, thrust fault, std, low, fission track, K-Ar. Null values not permitted*
	Definition	*Plain-English definition of Term. Null values not permitted*
	DefinitionSourceID	*Foreign key to DataSources. Identifies source of Definition. Null values not permitted*

Glossary_ID	Term	Definition	DefinitionSourceID
GL001	contact	Line denoting genetic boundary (depositional, intrusive, metamorphic...) between two geologic map units	DAS7
GL002	Biotite isograd	Line marking 1st appearance, going up-grade, of newly-formed biotite in metamorphosed siltstones and shales	RichardDGM18

Terminology used in the database must be defined in this Glossary or in a referenced external glossary that is either formally published or is persistently available online from an authoritative source. Terms that require definition include all values of Type; all non-numeric ScientificConfidence values; Property names, non-numeric PropertyValue terms, and Qualifiers for ExtendedAttributes; Lithology and ProportionTerm in StandardLithology, and some other terms. Lithology terms used in StandardLithology *must not be redefined* from the NGMDB standard. If there are no intellectual property restrictions, it is permissible and recommended to replicate all or part of an external glossary here. Provide appropriate credit via the DefinitionSourceID. Values of Term must be unique within the database because they are used in fields in other tables where they function as foreign keys to the Glossary table.

There shall be a clear statement in report-level metadata that all terms not defined in Glossary are defined in external glossaries, e.g., the AGI Glossary of Geology (Neuendorf et al., 2005), or Webster's Dictionary. This typically will be accompanied (preceded) by statements like "Igneous rock nomenclature follows Streckeisen (1976)" or "Numerical ages of geologic time periods after Ogg et al., (2008)."

We expect that building Glossary tables for the first few reports produced by a workgroup will be a significant effort. Subsequent Glossaries should be much easier, as a prior Glossary can be recycled with minor amendments and updated DefinitionSourceIDs.

ExtendedAttributes (non-spatial table, optional)

Fields:

ExtendedAttributes_ID	*Primary key. Example values = EXA1, EXA2, EXA3, … Null values not permitted*
OwnerTable	*Full name of table that contains owning element, e.g., DescriptionOfMapUnits, or OverlayPolys. May be any table in the database. Null values not permitted*
OwnerID	*Foreign key to table specified by the OwnerTable value. If Owner_ID record is deleted, associated extended attribute should be deleted (cascade delete). Null values not permitted. Convention is that this Foreign key will link to the TableName_ID field in the OwnerTable.*
Property	*Name of property specified by this attribute or relationship between Owner and ValueLinkID items. Values defined in Glossary or external glossary; we strongly recommend Glossary definitions of all properties used in the ExtendedAttributes table. Definition of property should include explanation of formatting and units used to specify property values. Null values not permitted*
PropertyValue	*String, could be number (+ measurement unit) or defined term. Not closed. Data-entry tool might enforce consistency between PropertyValue and Property (such that Property=thickness does not have PropertyValue=fine-grained). NGMDB or*

		individual projects might choose to supply Property | PropertyValues lists. Numeric values (for instance, 500 meters) are not defined in Glossary
	ValueLinkID	*Foreign key to data instance that specifies property value. E.g., GrainSizeAnalyses_3. Or a link to another ExtendedAttributes record (e.g., this thing overlies / succeeds / is-a-part-of another thing). Null values OK. If null, PropertyValue must be non-null, and vice-versa. Definition of Property must specify table to which the ValueLinkID is a foreign key*
	Qualifier	*Expresses variability or extent of PropertyValue. Must be defined in Glossary or an external glossary. Null values OK*
	Notes	*Null values OK*
	DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

Extended-Attribute_ID	OwnerTable	Owner-ID	Property	Property-Value	ValueLinkID	Qualifier	Notes	Data-SourceID
EA01650	DescriptionOf MapUnits	DMU3	Permeability	Low		Typical	Rock is full of alteration clays	DS2140
EA01654	DescriptionOf MapUnits	DMU3	Permeability	High		Rare		DS0001
EA01680	DescriptionOf MapUnits	DMU27	Metamorphic Grade	Low		Uncommon		DS0364
EA0162476	DescriptionOf MapUnits	DMU27	Metamorphic Grade	Medium		Typical		DS2069
EA01636	DescriptionOf MapUnits	DMU27	Metamorphic Age	Early Proterozoic		Probable		DS2106
EA01639	DescriptionOf MapUnits	DMU27	Metamorphic Age	Middle Cretaceous		Possible		DS045
EA016289	Geologic-Events	Slip-Event1	Displacement	4 km				DS1045
EA016233	Geologic-Events	Slip-Event1	Displacement Type	Right-lateral strike slip				DS1130
EA016123	Geologic-Events	Slip-Event1	Successor		GE2466			DS1205
EA0160978	Geologic-Events	GE2466	Displacement	200 km				DS1135
EA0167032	Geologic-Events	GE2466	Displacement Type	Right-lateral strike slip				DS0980
EA016086	DescriptionOf MapUnits	Txt	Permeability	Low			Rock is full of alteration clays	DS8625
EA016146	MapUnit-Polys	Txt37a	Note				Big outcrop, good place for a quarry	DS2586
EA016826	Contacts-AndFaults	COF22	Has Photograph	Photo2008-11-12b				DS2640
EA016926	Contacts-AndFaults	COF22	Contact Character	Gradational				DS3656

This table provides a general structure for linking attributes of any sort with any feature in the database. The pattern associates a data item identified by ‘OwnerTable/OwnerID’ with a property identified by the value in the ‘Property’ that has a value specified by the ‘PropertyValue or ‘ValueLinkID’. Each attribute assignment may have a qualifier to express quality or frequency or intensity, may have notes related to the attribute value, and has an identified data source. Data engineers will recognize this as the fundamental subject-predicate-object pattern, analogous to an RDF triple with the addition of metadata for each statement. This data structure could be used to express everything in the database, but its use requires creation of database views. It is included here to provide a mechanism to add content that may be sparse (available for only a few of many possible items), or attributes that may have multiple values (many to many relationships). For data that can not be represented using the other NCGMP09 database tables, a decision will need to be made whether these data are important enough to include, and if so, whether these data should be put in ExtendedAttributes or in a new datatype-specific table. We anticipate that best-practice recommendations will emerge for particular kinds of data.

Inclusion of the GeologicEvent table represents such a design trade-off between the flexibility of the ExtendedAttribute pattern for attribute assignment, and the clarity of including information in a separate, explicitly defined table. We judged that geologic history is especially significant and common to most maps, and thus merits an explicit table entity (GeologicEvent). On the other hand, geochemical analytical data are quite variable in terms of the attributes that may be measured, and may only be available for a few map units. Such data could be stored in ExtendedAttributes, a special feature class, or a non-spatial table. We choose not to recommend a particular approach for this kind of data. If normalized data are to be recoverable from the ExtendedAttributes data structure, each of the extended attributes instances must represent a single fact.

For example, to represent a slip displacement event in a sequence of displacements on a complex fault or fault segment: “San Andreas Slip Event 1, Displacement 4 km right lateral strike slip” is composed of several facts: 1. SanAndreasFault has GeologicEvent xxxx; 2. GeologicEvent xxxx has SuccessorEvent = GeologicEvent yyyy (if there is a slipEvent2); 3. GeologicEvent xxxx has displacementMagnitude_m = 4000. 4. GeologicEvent xxxx has displacementType = ‘Right Lateral Strike Slip’. The GeologicEvent xxxx age value is the time bracket for the slip event. ‘San Andreas fault’ might be a concept in the Glossary that is associated with many individual fault segments in ContactsAndFaults feature class through other ExtendedAttributes links. Each of these facts would be a separate row in the ExtendedAttributes table.

The OwnerID in ExtendedAttributes is a foreign key that links to a data instance in any table, e.g., DescriptionOfMapUnits, Glossary (for named faults that are ‘supersets’ of elements in the ContactsAndFaults and ConcealedContactsAndFaults feature classes), MapUnitPolys for description of individual polygons, or GeologicEvent to describe a displacement event (if logic above is followed) or to add additional process and environmental information associated with an event. Map units are referenced by DescriptionOfMapUunits_ID, not MapUnit. This contrasts with use of MapUnit as foreign key to the DescriptionOfMapUnits table in other parts of the geodatabase; the alternate convention is adopted here for consistency with references from ExtendedAttributes to other database tables. The ‘OwnerTable’ attribute is the name of the table that OwnerID references. We expect that explicit identification of OwnerTable will speed searches that otherwise would have to reference the entire world of _ID values within the geodatabase. The same performance issue is raised by the ValueLinkID property, but in this case the Glossary definition of the ExtendedAttribute property may specify the table that contains the linked values.

ValueLinkID allows links to data elements in other tables as values for attributes. Having a pointer value to specify a property opens the door for use of ExtendedAttributes to represent many kinds of semantic relationships between features in the geodatabase. Such relationships could include, for example, the association of a lineation and foliation in a compound fabric, or multiple bedding measurements associated with a derived fold hinge orientation. The ExtendedAttributes Property in this case specifies a relationship type.

GeologicEvents (non-spatial table, optional)

Geologic ages are assigned by association with an event that is recorded in the rock record. Each event has an assigned age, specified either numerically or using a named era from a stratigraphic time scale.

Fields:

GeologicEvents_ID	*Primary key for event in this database. Example values = GEE1, GEE2, GEE3 ... Required*
Event	*This is the geologic process responsible for the observed, dateable feature in the rock record that is the basis for the age assignment. Example values: deposition, metamorphism, slipEvent1, etc. Required. Foreign key to Glossary or vocabulary authority cited in dataset metadata. At the NGMDBvocab website (see Appendix A) a table of suggested terms is provided.*
AgeDisplay	*Formatted text that conveys the age assignment to a human reader, analogous to the Age attribute in the DMU table. Required*
AgeYoungerTerm	*Younger bound of interval for age of geologic event. Specified by a named time ordinal era from a stratigraphic time scale that is specified in the dataset metadata. Required if no numeric age provided*
AgeOlderTerm	*Older bound of interval for age of geologic event. Specified by a named time ordinal era from a stratigraphic time scale that is specified in the dataset metadata. Required if no numeric age provided*
TimeScale	*Name of a geologic time scale in which the age terms are defined. Various time scales may be used in a single data set, e.g., ICS 2008, North American Land Mammal Stages 2005. Required if age terms are used*
AgeYoungerValue	*Data type = float. Number that specifies the younger bound of the interval for the age assignment. Use of numeric age range boundaries makes for simpler geologic age query resolution. Units used for numeric age assignment should be consistent within the database and the units should be specified in the Notes field. Required if no age term provided*
AgeOlderValue	*Data type = float. Number that specifies the older bound of the interval for the age assignment. Use of numeric age range boundaries makes for simpler geologic age query resolution. Units used for numeric age assignment should be consistent within the database and the units should be specified in the Notes field. Required if no age term provided*
Notes	*Free text, any additional information on this event or age assignment. Null values OK*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*

Geologic-Events_-ID	Event	Age-Display	Age-Younger-Term	Age-Older-Term	Age-Younger-Value	Age-Older-Value	Notes	Data-SourcesID
GE00001	FaultSlip	Early Miocene	Early Miocene	Early Miocene	20	22		DS26904
GE00022	FaultSlip	Pliocene to Quaternary	Quaternary	Pliocene	0	4		DS62016
GE2465	Deposition of Tvt	Miocene Deposition	Miocene	Miocene	8	22		DS105

GE23609	Laramide orogeny	Laramide age	Early Eocene	Cenomanian	40	80		DS20656

The GeologicEvents table allows explicit representation of complex histories and non-simple ages. Geologic events may be associated with multiple processes and environments (e.g., depositional environments) through extended attributes. This content is required for compatibility with GeoSciML. AgeYoungerValue and AgeOlderValue are numeric and represent ranges or bounds on the 2-sigma uncertainty envelop on a measured numeric age, unless otherwise specified in the Notes field for the age.

There are four ways to represent an event in the history of a map unit: (1) the Age field of table DescriptionOfMapUnits, by convention this field has limited age resolution and can only represent the dominant event in the history of the unit; (2) in the Description field of table DescriptionOfMapUnits; (3) in the table ExtendedAttributes (property=MinimumAge, propertyValue=Maastrichtian); (4) this GeologicEvents table, with link via ExtendedAttributes table (property = preferredAge, ValueLinkID = GEE13). For ages of other features (e.g., faults, single map-unit polygons) methods 3 and 4 are applicable, as is recording the age in the Notes field of the appropriate record(s) of the relevant spatial feature class.

We provide multiple options to record geologic ages because (a) we're not sure which option is best (and hope that in a short time best practice recommendations will emerge), and (b) we think it is likely that the best option depends on the quality and quantity of age information to be recorded.

Symbolization

Symbolization is a critical aspect of a geologic map, as it provides the geologist's interpretation and most significant representation of the data and interpretations. Creating an adequate symbolization of a geologic map database can be a significant amount of work, thus provision of an acceptable set of symbolization instructions is often a significant convenience to database users. For these reasons, we require that geologic-map databases include symbolization instructions for a preferred visualization. These instructions should include a single ESRI .style file for all symbols (area, line, marker) used in the preferred visualization and an ESRI map composition (.mxd) file.

Line and point symbolization should be from the FGDC Digital Cartographic Standard for Geologic Map Symbolization (FGDC-STD-013-2006). Where the FGDC Standard does not define a suitable symbol, the Standard may be supplemented with custom symbols or with FGDC symbols that are "repurposed" for the map. Where a symbol is copied from the FGDC Standard, it should be named with the FGDC Standard identifier.

Shapefile versions of the geodatabase

We require that two shapefile versions of the geodatabase be provided: a simple version, designed to permit ready symbolization and query without need to establish relates or joins to non-spatial tables, and without all the content of the full database; and an open version that uses well-documented file formats to supply as much of the database content as possible.

Script ncgmp09_TranslateToShape.py (available at http://ngmdb.usgs.gov/Info/standards/NCGMP09/) translates an NCGMP09-style geodatabase to both simple and open shapefile versions.

Simple version

At a minimum, the simple shapefile version of the database must include shapefile equivalents of MapUnitPolys and ContactsAndFaults. OverlayPolys, ConcealedContactsAndFaults, OtherLines, and various point-feature shapefiles from the GeologicMap feature data set are optional additions. Attribute data are included with every shape record, thus no related tables or joins are required to browse the data.

To create the MapUnitPolys shapefile, join DescriptionOfMapUnits (via the MapUnit field) and DataSources (via DataSourceID field) tables to the MapUnitPolys feature class. Create a new field, StdLith, and populate it with values created by concatenating the appropriate StandardLithology records using the protocol Proportion_1:Lithology_1; $\text{Proportion}_2\text{Lithology}_2$; … where subscripts refer to StandardLithology records for a map unit and records are ordered from largest to smallest proportion using the guidance of the Proportion vocabulary in Appendix A. Delete OBJECTID, _ID, Source, and Notes fields from the DescriptionOfMapUnits and DataSources tables. Map long field names from the geodatabase to short (10 characters or less), DBF-compatible names and export to a polygon shapefile. Field-name translation should be documented in an accompanying text file. Certain fields (e.g., Text field in DescriptionOfMapUnits) are likely to be truncated to fit the 255-character limit for DBF fields; this is acceptable.

To create the ContactsAndFaults shapefile, join Glossary (via the Type field) and DataSources (via the DataSourceID field) tables to the ContactsAndFaults feature class. Delete OBJECTID, _ID, Source, and Notes fields from Glossary and DataSources. Map long field names from the geodatabase to short, DBF-compatible names and export to a line shapefile.

Other feature classes may be exported to shapefiles following similar procedures.

Open version

The open shapefile version of the geodatabase consists of shapefile and DBF translations of all feature classes and non-spatial tables. Each feature class and non-spatial table is exported to a shapefile or dbf table as appropriate, with long field names translated to short (10 characters or less) DBF-compatible field names and the translation documented in an accompanying file. Fields more than 255 characters long are truncated, as necessitated by the DBF file format, but are also translated to delimited text files.

In the long run, we recommend that an application-independent, open interchange file format be adopted as an alternate data delivery mechanism. The IUGS Commission for Management and Application of Geoscience Information (CGI) is supporting development of an xml-based markup for geoscience information interchange (GeoSciML, http://www.geosciml.org/), which has the potential to be this format. The USGS and AASG participate in development of GeoSciML, and are testing it as an output format for NCGMP09.

Building a compliant database

Note to readers: The following section is, of necessity, incomplete pending finalization of the database schema. When the schema is finalized, we expect to flesh this section out with further advice on how to construct compliant databases.

Empty compliant databases into which data can be imported or created can be built from scratch using the specification in this document, by running script ncgmp09_CreateDatabase.py (available at http://ngmdb.usgs.gov/Info/standards/NCGMP09/), by copying an empty geodatabase template, or by exporting the schema (without data) from a template database as an ESRI XML-workspace file and then importing the XML file and adjusting the spatial references if necessary.

We imagine that the most common objects (tables or feature classes) included in addition to those specifically described in this document will be point feature class tables. See ‘About point data’ above for the required fields. The design of other fields is at the discretion of the producer.

The production of a compliant database should be assisted by a number of custom tools and scripts. For example, we imagine tools to automate the population of the ChangeLog table, and to calculate symbol field values (line symbols, for instance, reflect values in the Type, LocationConfidenceMeters, and ExistenceConfidence, and IdentityConfidence fields as well as the output map scale). Script ncgmp09_ValidateDatabase.py checks the names of feature data sets, feature classes, tables, and fields, checks data types, and finds missing Glossary entries, undefined map units, etc.

Additional database elements

Construction of compliant databases will be facilitated by the creation of an additional point feature classes and a non-spatial table.

MapUnitPoints (point feature class, optional)

Some map producers generate the MapUnitPolys feature class from the ContactsAndFaults feature class and a feature class of ‘label’ points that holds the attributes associated with the polygons. This workflow utilizes the Feature to Polygon tool in the Data Management toolbox. A MapUnitPoints feature class facilitates this workflow.

Most map producers will find it easier to attach correct symbol values to polygon features if they first add field AreaSymbol to the DescriptionOfMapUnits table and populate this field with signifiers for the chosen area fills.

ChangeLog (non-spatial table, optional)

This table maintains information about updates to information contained in the database and is essential for documentation of the provenance of data from another source that are modified in the course of creating a new geologic map database. Each record records changes to a single database row, with old value, new value, and (if desired) the reason for a change in a NOTES field. One ChangeLog entry can record simultaneous changes to values in several fields of a single record. All fields except Notes could be populated automatically upon editing of a data record, and, for the sake of completeness, we highly recommend this. Changes to feature geometry (e.g., moving a vertex) are recorded by indicating that the changed field is ‘shape’. To simplify the logging process, record only that the geometry was changed, not the explicit geometric changes. Creation of a new record need not generate a ChangeLog entry, as the creation event is recorded in the DataSources record initially associated with the data item.

Fields:

ChangeLog_ID	*Primary key. Example values = CHL1, CHL2, CHL3, … Null values not permitted*
OwnerTable	*Full name of table that contains owning element, e.g., DescriptionOfMapUnits, or OverlayPolys. Null values not permitted*
OwnerID	*Foreign key to any table in the database. Null values not permitted*

ChangedWhen	*System clock date/time. Null values not permitted. Date and time of update to the indicated records*
ChangedBy	*System userID. Null values not permitted. Generally obtained by operating system request. Login name for account under which the application is running*
OldValue	*String tuple of former values of all attributes changed, placeholders for unchanged attributes, with a flag for shape. Null values OK if entry documents a new feature record*
NewValue	*String tuple of new values of all attributes changed, with placeholders for unchanged attributes, flag for shape. "Deleted" is special value. Null values not permitted*
Notes	*Place to (optionally) record why an attribute or shape has been changed. Null values OK*

Frequently asked questions

What about annotation?

> There are multiple ways to create and store annotation. We are not sure what data structure will best facilitate publication-quality cartography and allow economical creation and editing of annotation, so we have not prescribed a protocol for annotation. Map authors may wish to include one or more ESRI annotation feature classes along with instruction on how to use them.

My map is a grid. How does it fit into this schema?

> Grid-based datasets are outside the scope of this schema. Suggestions for good raster-based database design are encouraged.

How should I encode structure contours?

> You have at least two choices. Structure contours may be encoded in the OtherLines feature class, with Type=TopFormationX (or whatever is contoured), where the type has a corresponding Glossary entry to clearly define the contoured surface. The elevation values could be put in the label field for the line, or associated through ExtendedAttributes. Alternately, create a new, appropriately-named line feature class with an elevation attribute.
>
> Contours are difficult to analyze automatically. The information contained in structure contours might be better stored as a raster (ESRI grid) or triangulated irregular network (TIN).

Does this standard apply to a visualization of already-published data?

> No. However, it does apply to a digital transcription (automation) of a geologic map that has only been published in analog (paper or PDF) form.

What about my fault map? It doesn't show geologic units.

> A fault map is not a geologic map, so this standard does not apply. However, most fault maps are analogous to parts of geologic maps and this standard may provide useful guidance. Faults are lines that could be encoded in ContactsAndFaults and associated tables. There could be at least one polygon, outlining the mapped area, and its map-unit might be 'area covered by this map'.

May I give my clients databases in another format?

Certainly. But make this format available also.

My map has auxiliary maps showing data sources and the distribution of sedimentary facies in the Miocene. Where do these maps fit in this schema?

The answer varies. Not all information depicted via an analog auxiliary map needs a separate digital map (feature class). Data sources are best handled as attributes of various map features and recorded via DataSourcesID and the DataSources table. Distribution of Miocene sedimentary facies could be handled via ExtendedAttributes for polygons of Miocene sedimentary rocks, via overlay polygons, or via a new polygon feature class. Use your judgment.

I have an existing database with thickness, minimum age, maximum age, and lithology fields for each map unit. Where does this information go if I translate the database to this schema?

There are several options. In general, such attributes can be (1) mapped into the appropriate existing fields in the geodatabase schema, or (2) stored in ExtendedAttributes. **Where option 1 is available, use it!** Minimum and maximum ages of map units should be stored in the GeologicEvents table and associated with DescriptionOfMapUnits using ExtendedAttributes. If the information in your existing lithology field can without loss be transformed into StandardLithology, it need not be stored separately.

If you are sure that your information has no designated place in this schema (e.g., unit thickness, tabular lithologic descriptions more nuanced than can be supported by StandardLithology), consider option 2. As a last resort, additional attributes can be (3) stored in new fields added to existing non-spatial tables, or (4) stored in new non-spatial tables. Your choice between these options should be driven by (a) how many data are there? (if attributes are only known for a few features, ExtendedAttributes is a more likely choice), (b) where are database users most likely to find and understand the data? and (c) what option is the least work and the least likely to generate transcription errors?

How can I tell if a database is compliant?

Try testing the database with script ncgmp09_ValidateDatabase.py. Note that passing the tests in this script does not ensure compliance. However, if a database fails these tests it is not compliant.

How do I use one of these databases to make a publication-quality map image?

This is a non-trivial problem. By standardizing a database schema we hope to see the emergence of community tools to solve it. Here are some hints: (A) Proper symbolization of faults with line ornaments (thrust triangles, extensional fault ticks) that are segmented by abutting contacts and (or) are locally concealed requires that you create a continuous fault trace analogous to 'routes' in workstation Arc-Info. Draw individual fault arcs as thick lines, thick dashed lines, and thick dots. Smooth (generalize, spline) the meta-faults and draw them with thrust triangles or extensional ticks as appropriate, but no line stroke. (B) Create good annotation (see FAQ on annotation above). We are not aware of tools that successfully automate this task. Dip and plunge values for measured orientations, text associated with other point data, map unit labels, and place names all may need to be positioned, eliminated, duplicated, or moved and have leaders added (unit labels). (C) Do as much of the preparation of the map image in ArcMap as possible. If necessary, the map image(s) can be exported to Adobe Illustrator, translating fonts as needed, for detailed graphic fine tuning. Insofar as possible, avoid cartographic work in a Illustrator or similar software as this often leads to synchronization problems, with the geology portrayed on the map image different from that recorded in the database. (D) Lay out the map sheet with page-layout software (e.g., Adobe InDesign), not Illustrator, as text formatting and figure placement are much easier.

I still don't know what metadata for a geologic map should look like. What do I do?

See http://geology.usgs.gov/tools/metadata/

Who is going to enforce this?

If adopted by the National Cooperative Geologic Mapping program, conformance to some degree may be required on delivery of products to the Program. If adopted by the USGS as a whole, Enterprise Publication Network may check for conformance as part of the publication process. If the schema is widely adopted, users will demand conformance so that tools developed to manipulate these databases work.

I've got a better design for a standard geologic-map database. How do I go about getting this proposal changed?

See Review, comment, and revision section, above.

Appendix A. Vocabularies

Much of the benefit from a defined database schema depends upon use of clearly-defined vocabularies. Users of geologic map databases are best served if some vocabularies, particularly the lithology, proportion, and part-type terms used in StandardLithology, are consistent from one database to another. These commonly are referred to as controlled-term vocabularies. Other vocabularies (e.g., Type terms, ExtendedAttributes Properties) are uncontrolled vocabularies, and so terms should be defined in each database.

Development of controlled-term vocabularies presents a conundrum. To be accepted and used, they need to be carefully developed, most likely by way of evolution through prolonged use. Yet much of their potential effectiveness stems from their stability. Although several of these vocabularies have been developed by a lengthy process involving the North American Data Model Steering Committee (NADM), the NGMDB project, and the IUGS-sponsored GeoSciML working group, we do not consider them to be in final form. Please refer to the NGMDB vocabulary website (http://ngmdb.usgs.gov/Info/standards/NGMDBvocabs/) for latest versions. We anticipate that use of these vocabularies will promote their evolution into stable, authoritative form. We hope that much of this evolution happens during the review process for early versions of this schema.

We suggest that elements of uncontrolled vocabularies (e.g., LocationMethod terms, Property terms, GeologicEvent) be included, as needed, in the Glossary tables of individual databases. We recommend against inclusion of controlled-term vocabularies in Glossary tables; this is largely to guard against the possibility of difficult-to-recognize redefinition of terms. If a controlled-term vocabulary is incorporated into the Glossary table, perhaps in order to ease access to term definitions, we recommend that it be incorporated in its entirety. In all cases, metadata for a geologic map database should fully specify the sources and versions of all vocabularies used in that database.

Controlled-term vocabularies

ProportionTerm (for StandardLithology)

(NGMDB, v. 1.0)
These Proportion terms were compiled from common usage, found on geologic maps. Community consensus on definitions has, to our knowledge, not been reached; in fact, these terms are often used because a map author is unable to reliably estimate a percentage. Rather, the meaning of these terms as used on any particular map varies depending on numerous factors including the geology and the geologist, and generally is not explicitly stated. Therefore, we provide a “Guidance” column, which attempts to suggest some quantitative sense, a frame of reference, for what a given proportion term might mean.

Term	Guidance	Possible synonyms
all	Component constitutes effectively 100 percent of the volume of the unit.	
dominant	Component constitutes more than 50 percent of the volume of the unit.	predominant
major	Component constitutes more than 25 percent of	abundant, main, most

Term	Guidance	Possible synonyms
	the volume of the unit.	common, primary, significant
subordinate	Component constitutes less than 25 percent of the volume of the unit.	inferior, secondary, subsidiary
minor	Component constitutes less than 10 percent of the volume of the unit.	accessory, uncommon
rare	Component constitutes less than 3 percent of the volume of the unit.	sparse, trace
variable	Component varies in proportion throughout the unit; may be rare in some parts and dominant in others.	
present	Component is present, but proportion is unknown. The term is useful where compiling information from published maps in which the author did not specify proportions of lithologies within a map unit.	

PartType (for StandardLithology)

(NGMDB, v. 1.0)

A map unit can be composed of numerous rock types, and each constitutes some proportion of the whole, as described by the Proportion vocabulary. Further, the nature of each of these rock types typically occurs in some part of the unit that can be characterized according to its geometry, distribution, and genesis. This vocabulary includes terms to specify the kinds of parts that particular rock types are associated with in a geologic unit. These terms may be used to populate PartType in StandardLithology.

A complex geologic unit like a migmatite complex or a lithologically heterogeneous Pennsylvanian cyclothem stratigraphic unit will have many different lithologic components. The approach adopted here to representing this lithologic heterogeneity is to associate a StandardLithology instance for each lithologic component with the Description of Map unit instance. The PartType property provides information about what kind of part each of these StandardLithology instances represents, and perhaps something about its relationship to the unit as a whole.

HierarchyKey	Term	Synonyms	Definition
1	whole	dominant constituent, only part	Component forms the entire unit; any other parts are incidental.
2	part		Component is part of the unit, and there is at least one other significant part.
2-1	inclusions	blocks, knockers, enclaves	Bodies with generally sharp boundaries enclosed within a matrix of other material.
2-1-1	pendants		Blocks of wall rock material in an igneous intrusion. Pendants become xenoliths as the dimension becomes smaller than about 10 m in their longest dimension. Although term pendant has connotation of being suspended or supported from above, this is rarely demonstrable in geologic situations, and the concept here does not require connection to the wall of the containing intrusion (Neuendorf et al 2005).

2-1-2	concretions		Masses or aggregates of mineral matter, normally sub-spherical but commonly oblate, disc-shaped or irregular, formed after deposition of the enclosing rock Commonly formed by precipitation of (different) matrix minerals about a nucleus or center.
2-1-3	clasts		Fragments that were transported and deposited by sedimentary processes.
2-1-4	lenses	pods	Discrete lens-shaped bodies, not connected with other bodies.
2-2	layers		
2-2-1	beds		Sedimentary layers with thickness in the mm to (rarely) decameter range.
2-2-1-1	marker bed		Stratigraphic part that is a thin, laterally continuous, distinctive bed within a unit.
2-2-2	gneissic layers	bands	Recurring layers within a coarse-grained metamorphic rock.
2-2-3	veins, sills, or dikes		Intrusive, sheet-like bodies.
2-3	irregular bodies		
2-4	facies		Particular body of rock that is a lateral variant of a lithostratigraphic or lithodemic unit. Distinguished as a body of rock that has identity, as opposed to a kind of rock body that is repeated in many places in a unit.
2-5	stratigraphic part	member	A geologic unit part that occupies a particular stratigraphic position within a geologic unit. Part is a particular body of rock (has identity).
2-6	matrix	wall-rock	Forms the body of the unit within which other described parts are contained.

StandardLithology

(NGMDB, v. 1.0)

Numerous science vocabularies have been compiled for the National Geologic Map Database project (NGMDB) and are being prepared for release at http://ngmdb.usgs.gov/Info/standards/-NGMDBvocabs/. Those vocabularies are intended to provide users with consistent terminologies for various geologic properties. This particular vocabulary (Lithology) evolved from a rather comprehensive compilation of more than a thousand terms. It is the outgrowth of several years of compilation and testing, begun by the North America Geologic Map Data Model Science Language Technical Team (NADM SLTT, 2004a, 2004b), which produced a comprehensive vocabulary for sedimentary materials and a vocabulary for metamorphic rocks. Over a period of years, the NGMDB project then extended the SLTT vocabularies to a more comprehensive listing. That vocabulary was then evaluated by NGMDB project members and three state geological surveys (OR, WA, and ID) in a prototype database designed to serve via a web-mapping system a collection of national to 100k-scale geologic maps (http://maps.ngmdb.us/dataviewer/). It was determined that most users would be better served, and the database more readily built, if the vocabulary were simplified to a list of roughly 100-200 terms. That list was compiled and is provided below. As the list was being compiled, it was shared with a working group that is developing the GeoSciML standard for international information interchange (https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/ConceptDefinitionsTG); by this interaction it was somewhat modified and improved. The NGMDB StandardLithology list is now almost identical to the draft simple lithology vocabulary for GeoSciML (Richard and Soller, in preparation).

NOTES: In the StandardLithology table, the Hierarchy Key is an outline-numbered index used to arrange the terms hierarchically. The hierarchical arrangement here is one of several logically consistent arrangements that could be made. Some elements of the hierarchy have been deleted for this listing (e.g., “water” with Hkey ~00~01~). The Lithology Roadmap diagram (contained in the Vocabularies directory) depicts the logical relationship between various groups of lithology categories in a more extended fashion, and attempts to place these terms in context. The Excel version of this listing (see Vocabularies directory) provides source notes on the terms, and is arranged alphabetically to make locating a particular term as simple as possible.

Display Name	**Synonyms, narrower match terms**	**Description**	**Source**	**Hierarchy Key**
Compound material		An Earth Material composed of an aggregation of particles of Earth Material, possibly including other Compound Materials. This is 'top' of lithology category hierarchy, and should be used to indicate 'any rock or unconsolidated material'.	NADM C1, 2004	~00~
Breccia		Coarse-grained material composed of angular broken rock fragments; the fragments typically have sharp edges and unworn corners. The fragments may be held together by a mineral cement, or in a fine-grained matrix. Clasts may be of any composition or origin.	Neuendorf et al. 2005	~00~00~
Composite genesis material		Material of unspecified consolidation state formed by geological modification of pre-existing materials outside the realm of igneous and sedimentary processes. Includes rocks formed by impact metamorphism, standard dynamothermal metamorphism, brittle deformation, weathering, metasomatism and hydrothermal alteration (diagenesis is a sedimentary process in this context).	NGMDB	~00~02~
Fault-related material		A brittle fault-related material; category includes cataclasite series (cohesive cataclastic rocks) and breccia-gouge series (non-cohesive cataclastic rocks). Contains greater than 10 percent matrix; matrix is fine-grained material caused by tectonic grain-size reduction.	CGI concept definition task group, paraphrased from cataclasite definition of Marshak & Mitra, 1988	~00~02~00~
Breccia-gouge series	Gouge, Incohesive cataclastic rock	Fault material that displays evidence for loss of cohesion during deformation. Examples of evidence include void spaces (filled or unfilled), and non-consolidated matrix material between fragments. Includes fault-related breccia and gouge.	CGI Simple Lithology vocabulary	~00~02~00~00~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Cataclasite series	cataclasite, protocataclasite, ultracataclasite, Cohesive cataclastic rock	Fault-related rock that maintained primary cohesion during deformation, with matrix comprising greater than 10 percent of rock mass; matrix is fine-grained material formed through grain size reduction by fracture as opposed to crystal plastic process that operate in mylonitic rock. Includes cataclasite, protocataclasite and ultracataclasite.	Based on NADM SLTTm, 2004	~00~02~00~01~
Material formed in surficial environment		Rocks that are the product of surficial processes operating on pre-existing rocks, analogous to hydrothermal or metasomatic rocks formed at ambient Earth surface temperature and pressure. Includes duricrust of various sorts (silcrete, calcrete), soil, and weathered rock.	CGI Simple Lithology vocabulary	~00~02~01~
Duricrust	Caliche, calcrete, silcrete	Rock forming a hard crust or layer at or near the Earths surface at the time of formation, e.g. in the upper horizons of a soil, characterized by structures indicative of pedogenic origin. Typically consists of sand and gravel cemented by carbonate, silica, aluminous oxides, or iron oxide.	CGI Simple Lithology vocabulary	~00~02~01~00~
Residual material	Soil, residuum	Material of composite origin resulting from weathering processes at the Earth’s surface, with minor epiclastic, chemical, or organic input, and removal of chemical constituents by aqueous leaching. Consolidation state is not inherent in definition.	CGI Simple Lithology vocabulary	~00~02~01~01~
Bauxite		Highly aluminous material containing abundant aluminum hydroxides (gibbsite, less commonly boehmite, diaspore) and aluminum-substituted iron oxides or hydroxides and generally minor or negligible kaolin minerals; may contain up to 20 percent quartz. Commonly has a pisolitic or nodular texture, and may be cemented.	Taylor and Eggleton, 2001, p 324	~00~02~01~01~00~
Weathered rock		Rock that exhibits observable properties due to environmental conditions at or near the Earth surface affected by the atmosphere or hydrosphere. Corresponds to McMillan and Powell (1999) weathered rock grades II, III, and IV.	Neuendorf et al. 2005; NGMDB	~00~02~01~01~01~
Unconsolidated material		Material composed of an aggregation of particles that do not adhere to each other strongly enough that the aggregate can be considered a solid in its own right.	NADM C1, 2004	~00~03~
Anthropogenic unconsolidated material		Unconsolidated material known to have artificial (human-related) origin.	CGI Simple Lithology vocabulary	~00~03~00~
Natural unconsolidated material		Unconsolidated material known to have natural, i.e. not human-made, origin.	CGI Simple Lithology vocabulary	~00~03~01~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Sediment		Natural unconsolidated material consisting of an aggregation of particles transported or deposited by air, water or ice, or that accumulated by other natural agents, such as chemical precipitation, and that forms in layers on the Earths surface.	NADM SLTTs 2004	~00~03~01~00~
Clastic sediment		Sediment in which at least 50 percent of the constituent particles were derived from erosion, weathering, or mass-wasting of pre-existing earth materials, and transported to the place of deposition by mechanical agents such as water, wind, ice and gravity.	Based on NADM SLTTs 2004; Neuendorf et al. 2005	~00~03~01~00~00~
Diamicton	Till	Unsorted or poorly sorted, clastic sediment with a wide range of particle sizes, including a muddy matrix. Biogenic materials that have such texture are excluded. Distinguished from conglomerate, sandstone, mudstone based on polymodality and lack of structures related to transport and deposition of sediment by moving air or water. Assignment to another size class can be used in conjunction to indicate the dominant grain size.	Hallsworth & Knox 1999	~00~03~01~00~00~00~
Gravel (Gravelly sediment)		Clastic sediment consisting of 30 percent or more clasts that are 2 mm or more in diameter. Denotes that composition of clasts is not specified.	Based on NADM SLTTs 2004; Neuendorf et al. 2005; particle size from Wentworth grade scale, Folk 1954.	~00~03~01~00~00~01~
Sand (sandy sediment)		Clastic sediment consisting of less than 30 percent clasts that are greater than 2 mm in diameter, and in which the ratio of mud-size particles (less than 0.0625 mm diameter) to sand-size particles (0.0625 to 2 mm diameter) is less than 50 percent. Composition of clasts is not specified. Broad use of term sand recognized to conform with common usage.	Neuendorf et al. 2005; NGMDB	~00~03~01~00~00~02~
Mud (muddy sediment)		Clastic sediment consisting of less than 30 percent clasts that are greater than 2 mm in diameter, and in which the ratio of mud-size particles (less than 0.0625 mm diameter) to sand-size particles (0.0625 to 2 mm diameter) is greater than 50 percent. Composition of clasts is not specified. Broad use of term mud included to conform to common usage.	Based on NADM SLTTs 2004; Neuendorf et al. 2005	~00~03~01~00~00~03~
Chemical sediment		Sediment that consists of at least 50 percent material produced by chemical (organic or inorganic) processes within the basin of deposition. Includes organic-rich, non-clastic siliceous, carbonate, evaporite, iron-rich, and phosphatic sediment classes.	This vocabulary	~00~03~01~00~01~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Biogenic sediment		Sediment composed of greater than 50 percent material of biogenic origin.	CGI Simple Lithology vocabulary	~00~03~01~00~02~
Ooze		Mud (less than 1 percent gravel, and has a sand to mud ratio less than 1 to 9) that contains at least 30 percent skeletal remains of pelagic organisms, and less than 50 percent carbonate minerals.	Based on Neuendorf et al (2005) marine geology definition; Hallsworth & Knox 1999	~00~03~01~00~02~00~
Organic rich sediment		Sediment with color, composition, texture and apparent density indicating greater than 50 percent organic content by weight on a moisture-free basis.	NADM SLTTs 2004	~00~03~01~00~02~01
Peat		Unconsolidated organic-rich sediment composed of at least 50 percent semi-carbonized plant remains; individual remains commonly seen with unaided eye; yellowish brown to brownish black; generally fibrous texture; can be plastic or friable. In its natural state it can be readily cut and has a very high moisture content, generally greater than 90 percent.	Hallsworth & Knox 1999	~00~03~01~00~02~01~01
Iron rich sediment		Sediment that consists of at least 50 percent (by volume) iron-bearing minerals (hematite, magnetite, limonite-group, siderite, iron-sulfides), as determined by hand-lens or petrographic analysis; corresponds with a rock typically containing 15 percent iron by weight.	CGI Simple Lithology vocabulary	~00~03~01~00~03~00~
Phosphatic sediment		Sediment in which at least 50 percent of the primary and/or recrystallized constituents are phosphate minerals.	NGMDB	~00~03~01~00~03~01~
Non-clastic siliceous sediment		Sediment that consists of at least 50 percent silicate mineral material, deposited directly by chemical or biological processes at the depositional surface, or in particles formed by chemical or biological processes within the basin of deposition.	NGMDB; Hallsworth and Knox 1999	~00~03~01~00~03~02~
Carbonate sediment		Sediment in which at least 50 percent of the primary and/or recrystallized constituents are composed of one (or more) of the carbonate minerals calcite, aragonite and dolomite, in particles of intrabasinal origin.	NADM SLTTs 2004	~00~03~01~00~03~04~
Dolomitic sediment		Carbonate sediment with a ratio of magnesium carbonate to calcite (plus aragonite) greater than 1 to 1.	Based on NADM SLTTs 2004	~00~03~01~00~03~04~00~
Calcareous carbonate sediment		Carbonate sediment with a calcite (plus aragonite) to dolomite ratio greater than 1 to 1. Includes lime-sediments.	Based on NADM SLTTs 2004; Hallsworth & Knox 1999	~00~03~01~00~03~04~01~
Carbonate gravel		Carbonate sediment composed of more than 25 percent gravel-sized clasts (maximum diameter more than 2 mm).	Based on NADM SLTTs 2004; Hallsworth & Knox 1999	~00~03~01~00~03~04~02~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Carbonate sand [Sandy carbonate sediment]		Carbonate sediment consisting of less than 25 percent gravel-size (2 mm) particles and with a sand to mud ratio greater than 1.	NADM SLTTs 2004	~00~03~01~00~03~04~03~
Carbonate mud [Muddy carbonate sediment]		Carbonate sediment consisting of less than 25 percent gravel-size (2 mm) particles and with a mud to sand ratio greater than 1.	Based on NADM SLTTs 2004; Hallsworth & Knox 1999	~00~03~01~00~03~04~04~
Tephra		An unconsolidated pyroclastic deposit in which greater than 75 percent of the fragments are deposited as a direct result of volcanic processes and the deposit has not been reworked by epiclastic processes. Includes ash, lapilli-ash, lapilli tephra, ash breccia, bomb tephra, and block tephra of Hallsworth and Knox (1999).	Hallsworth & Knox 1999; LeMaitre et al. 2002	~00~03~01~01~
Ash and lapilli		Tephra in which less than 25 percent of fragments are greater than 64 mm in longest dimension.	Schmid 1981; LeMaitre et al. 2002	~00~03~01~01~00~
Ash breccia, bomb, or block tephra		Tephra in which more than 75 percent of particles are greater than 64 mm in largest dimension. Includes bomb tephra and block tephra of Gillespie and Styles (1999).	Schmid 1981; LeMaitre et al. 2002	~00~03~01~01~01~
Rock		Consolidated aggregate of one or more Earth materials, or a body of undifferentiated mineral matter, or of solid organic material. Includes mineral aggregates such as granite, shale, marble; glassy matter such as obsidian; and organic material such a coal. Excludes unconsolidated materials.	Neuendorf et al. 2005	~00~04~
Aphanite		Rock that is too fine grained to categorize in more detail.	CGI Simple Lithology vocabulary	~00~04~00~
Igneous rock		Rock formed by the cooling and solidification of magma. Rock for which only descriptive information is igneous origin. Typically characterized by textures indicating crystallization from melted material.	NGMDB	~00~04~01~
Glassy igneous rock	perlite, obsidian	Igneous rock that consists of greater than 90 percent glass.	NGMDB	~00~04~01~00~
Exotic composition [unusual] igneous rock		Rock with exotic mineralogical, textural or field setting characteristics; typically dark colored, with abundant phenocrysts. Criteria include: presence of greater than 10 percent melilite or leucite or presence of kalsilite, or greater than 50 percent carbonate minerals. These rocks are typically dark colored with abundant phenocrysts. Includes lamproite, lamprophyre, kimberlite, carbonatite, melilititc and kalsilitic rocks of LeMaitre et al. (2002).	Gillespie and Styles 1999; LeMaitre et al. 2002	~00~04~01~01~
Exotic alkaline rock [mafite]		Kimberlite, lamproite, or lamprophyre. Generally are potassic, mafic or ultramafic rocks. Olivine (commonly serpentinized in kimberlite), and phlogopite are significant constituents.	This vocabulary	~00~04~01~01~00~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Exotic alkalic igneous rock		Igneous rock containing greater than 10 percent melilite or kalsilite. Typically undersaturated, ultrapotassic (kalsilitic rocks) or calcium-rich (melilitic rocks) mafic or ultramafic rocks.	Grouped kalsilitic and melilitic rocks of LeMaitre et al 2002.	~00~04~01~01~01~
Carbonatite		Igneous rock composed of more than 50 percent modal carbonate minerals.	LeMaitre et al. 2002	~00~04~01~01~02~
Fragmental igneous rock		Igneous rock in which greater than 75 percent of the rock consists of fragments produced as a result of igneous rock-forming process. Includes pyroclastic rocks, autobreccia associated with lava flows and intrusive breccias. Excludes deposits reworked by epiclastic processes.	NGMDB	~00~04~01~02~
Pyroclastic rock	ignimbrite	Fragmental igneous rock that consists of greater than 75 percent fragments produced as a direct result of eruption or extrusion of magma from within the earth onto its surface. Includes pyroclastic rock of Gillespie & Styles (1999) and LeMaitre et al. (2002). LeMaitre et al (2002) explicitly exclude autobreccia related to lava flows. This is rejected here because of the difficulty it would present with fragmental deposits associated with silicic lava flows or exogenous domes (e.g. block and ash deposits). Autobreccia associated with lava flows is thus included here as a kind of pyroclastic rock. Deposits reworked by epiclastic processes are excluded from category (put in clastic sedimentary rock).	CGI Simple Lithology vocabulary	~00~04~01~02~00~
Tuff-breccia, agglomerate, or pyroclastic breccia		Pyroclastic rock in which greater than 75 percent of particles are greater than 64 mm in largest dimension. Includes agglomerate, pyroclastic breccia of Gillespie and Styles (1999).	Schmid 1981; LeMaitre et al. 2002	~00~04~01~02~00~00~
Ash tuff, lapillistone, and lapilli tuff		Pyroclastic rock in which less than 75 percent of rock by volume are more than 64 mm in longest diameter. Includes tuff breccia, tuff, lapilli tuff, and lapilli-stone.	Schmid 1981; LeMaitre et al. 2002	~00~04~01~02~00~01~
Phaneritic igneous rock [Coarse-grained igneous rock]		Igneous rock in which greater than 10 percent (by volume) of rock is individual crystals that can be discerned with the naked eye. Generally corresponds to not fine-grained in terms of Gillespie and Styles (1999) or LeMaitre et al (2002). Bounding grain size is on the order of 32 to 100 microns. Igneous rocks with exotic composition are excluded from this concept.	Neuendorf et al. 2005	~00~04~01~03~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Granitic rock		Phaneritic crystalline igneous rock that contains between 20 and 60 percent quartz in the QAPF fraction (see LeMaitre et al., 2002). A general term for all phaneritic igneous rocks dominated by quartz and feldspars. Includes rocks defined modally in QAPF fields 2, 3, 4 and 5 as alkali granite, granite, granodiorite or tonalite. Equivalent to granitoid of LeMaitre et al (2002) Fig 2.10 (p. 29), without denotation of field classification.	LeMaitre et al. 2002	~00~04~01~03~00~
Tonalite	trondhjemite, plagiogranite	Granitic rock consisting of quartz and intermediate plagioclase, usually with biotite and amphibole. The ratio of plagioclase to total feldspar is greater than 0.9.Includes rocks defined modally in QAPF field 5 (LeMaitre et al., 2002).	LeMaitre et al. 2002	~00~04~01~03~00~00~
Granite	syenogranite, monzogranite	Granitic rock with plagioclase to total feldspar ratio between 0.1 and 0.65. QAPF field 3 of LeMaitre et al. (2002).	LeMaitre et al. 2002	~00~04~01~03~00~01~
Granodiorite		Granitic rock that has a ratio of plagioclase to total feldspar between 0.65 and 0.90. QAPF mineralogy in field 4 of LeMaitre et al. (2002).	LeMaitre et al. 2002	~00~04~01~03~00~02~
Alkali feldspar granite	peralkaline granite, alaskite	Granitic rock that has a plagioclase to total feldspar ratio is less than 0.1. QAPF field 2 of LeMaitre et al. (2002).	LeMaitre et al., 2002	~00~04~01~03~00~03~
Aplite		Light colored intrusive igneous rock, characterized by a fine grained allotriomorphic-granular (aplitic, saccharoidal or xenomorphic) texture; typically granitic composition, consisting mostly of quartz, K-feldspar and sodic plagioclase.	Neuendorf et al. 2005	~00~04~01~03~00~03~
Syenitic rock	syenitoid	Phaneritic crystalline igneous rock with M less than 90, consisting mainly of alkali feldspar and plagioclase; minor quartz or nepheline may be present, along with pyroxene, amphibole or biotite. Ratio of plagioclase to total feldspar is less than 0.65, quartz forms less than 20 percent of QAPF fraction, and feldspathoid minerals form less than 10 percent of QAPF fraction. Includes rocks classified in QAPF fields 6, 7 and 8 and their subdivisions of LeMaitre et al. (2002).	LeMaitre et al. 2002	~00~04~01~03~01~
Monzonite		Syenitic rock with a plagioclase to total feldspar ratio between 0.35 and 0.65. A group of plutonic rocks intermediate in composition between alkali feldspar and plagioclase that contain little or no quartz, and commonly contain augite as the main mafic mineral. Includes rocks defined modally in QAPF fields 8, 8*, and 8' of LeMaitre et al. (2002).	LeMaitre et al. 2002	~00~04~01~03~01~00~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Syenite		Syenitic rock with a plagioclase to total feldspar ratio between 0.1 and 0.35. A group of plutonic rocks containing alkali feldspar, a small amount of plagioclase, one or more mafic minerals, and quartz, if present, only as an accessory. Includes rocks in QAPF fields 7, 7*, and 7' of LeMaitre et al. (2002).	LeMaitre et al. 2002	~00~04~01~03~01~01~
Dioritic rock	dioritoid	Phaneritic crystalline igneous rock with M less than 90, consisting of intermediate plagioclase, commonly with hornblende and often with biotite or augite. Plagioclase to total feldspar ratio is greater that 0.65, and anorthite content of plagioclase is less than 50 percent. Less than 10 percent feldspathoid mineral and less than 20 percent quartz in the QAPF fraction. Includes rocks defined modally in QAPF fields 9 and 10 and their subdivisions of LeMaitre et al. (2002).	LeMaitre et al. 2002	~00~04~01~03~02~
Diorite		A dioritic rock with a plagioclase to total feldspar ratio (in the QAPF fraction) greater than 0.9. Includes rocks defined modally in QAPF fields 10, 10' and 10* of LeMaitre et al. (2002).	LeMaitre et al. 2002	~00~04~01~03~02~00~
Monzodiorite		A dioritic rock with a plagioclase to total feldspar ratio in the QAPF fraction between 0.65 and 0.9. Includes rocks defined modally in QAPF field 9, 9' and 9* of LeMaitre et al. (2002).	LeMaitre et al. 2002	~00~04~01~03~02~01~
Gabbroic rock	gabbroid	Phaneritic crystalline igneous rock that contains less than 90 percent mafic minerals, and up to 20 percent quartz or up to 10 percent feldspathoid in the QAPF fraction. The ratio of plagioclase to total feldspar is greater than 0.65, and anorthite content of the plagioclase is greater than 50 percent. Includes rocks defined modally in QAPF fields 9 and 10 and their subdivisions of LeMaitre et al. (2002).	LeMaitre et al. 2002	~00~04~01~03~03~
Monzogabbro		Gabbroic rock with a plagioclase to alkali feldspar ratio between 0.65 and 0.9. Typical mafic minerals are biotite, hornblende, and pyroxene. QAPF field 9 and subdivisions.	LeMaitre et al. 2002	~00~04~01~03~03~00~
Gabbro	Gabbro (sensu stricto), Norite, Troctolite, Gabbronorite.	Gabbroic rock that has a plagioclase to total feldspar ratio greater than 0.9 in the QAPF fraction. Includes QAPF fields 10*, 10, and 10' of LeMaitre et al. (2002). This category includes the various categories defined in LeMaitre et al. (2002) based on the mafic mineralogy, but apparently not subdivided based on the quartz/feldspathoid content.	LeMaitre et al. 2002	~00~04~01~03~03~01~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Foid gabbroic rock	foid gabbroid	Phaneritic crystalline igneous rock in which M is less than 90, the Plagioclase to total feldspar ratio is greater than 0.5, feldspathoid minerals form 10-60 percent of the QAPF fraction, and plagioclase has anorthite content greater than 50 percent. These rocks typically contain large amounts of mafic minerals. Includes rocks defined modally in QAPF fields 13 and 14 of LeMaitre et al (2002). Equivalent to foid gabbroid of LeMaitre et al (2002) Fig 2.10 (p. 29), without denotation of field classification. Classify as exotic alkalic if melilite or kalsilite is more abundant than feldspathoid.	LeMaitre et al. 2002	~00~04~01~03~04~
Foid dioritic rock	foid dioritoid	Phaneritic crystalline igneous rock in which M is less than 90, the plagioclase to total feldspar ratio is greater than 0.5, feldspathoid minerals form 10-60 percent of the QAPF fraction, plagioclase has anorthite content less than 50 percent. These rocks typically contain large amounts of mafic minerals. Includes rocks defined modally in QAPF fields 13 and 14 of LeMaitre et al (2002). Equivalent to foid dioritoid of LeMaitre et al (2002) Fig 2.10 (p. 29), without denotation of field classification. Classify as exotic alkalic if melilite or kalsilite is more abundant than feldspathoid.	LeMaitre et al. 2002	~00~04~01~03~05~
Foid syenitic rock	foid syenitoid	Phaneritic crystalline igneous rock with M less than 90, contains between 10 and 60 percent feldspathoid mineral in the QAPF fraction, and has a plagioclase to total feldspar ratio less than 0.5. Includes QAPF fields 11 and 12 of LeMaitre et al (2002). Equivalent to foid syenitoid of LeMaitre et al (2002) Fig 2.10 (p. 29), without denotation of field classification. Classify as exotic alkalic if melilite or kalsilite is more abundant than feldspathoid.	LeMaitre et al. 2002	~00~04~01~03~06~
Anorthositic rock		Leucocratic phaneritic crystalline igneous rock consisting essentially of plagioclase, often with small amounts of pyroxene. By definition, color index M is less than 10, and plagioclase to total feldspar ratio is greater than 0.9. Less than 20 percent quartz and less than 10 percent feldspathoid in the QAPF fraction. QAPF field 10, 10*, and 10' of LeMaitre et al. (2002).	After LeMaitre et al. 2002	~00~04~01~03~07~
Feldspathoid-rich igneous rock	Foidolite, foidite, foiditoid	Igneous rock that contains more than 60 percent feldspathoid minerals in the QAPF fraction, with M < 90, irrespective of grain size. Equivalent to foidolite of LeMaitre et al (2002) Fig 2.10 (p. 29) or to foiditoid of LeMaitre et al (2002) Fig 2.19 (p. 39), without denotation of field classification.	LeMaitre et al. 2002	~00~04~01~03~08~
Quartz rich igneous rock	quartzolite, quartz rich granite	Igneous rock that contains greater than 60 percent quartz, fine and coarse grained varieties not differentiated.	Gillespie and Styles 1999; LeMaitre et al. 2002	~00~04~01~03~09~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Pegmatite		Exceptionally coarse grained crystalline rock with interlocking crystals; most grains are 1cm or more diameter; composition is generally that of granite, but the term may refer to the coarse grained facies of any type of igneous rock; usually found as irregular dikes, lenses, or veins associated with plutons or batholiths.	Neuendorf et al. 2005	~00~04~01~03~10~
Porphyry		An igneous rock of any composition that contains conspicuous phenocrysts. Denotes bimodal grain size (phenocrysts and groundmass) distribution, but not any specific size of phenocrysts or groundmass.	LeMaitre et al. 2002	~00~04~01~04~
Doleritic rock	dolerite, microdiorite, diabase, microgabbro	Dark colored gabbroic (basaltic) or dioritic (andesitic) rock intermediate in grain size between basalt and gabbro and composed of plagioclase, pyroxene, hornblende, and opaque minerals; often with ophitic texture. Typically occurs as hypabyssal intrusions.	LeMaitre et al. 2002	~00~04~01~05~
Fine grained igneous rock		Crystalline igneous rock in which the framework or groundmass of the rock consists of crystals that are too small to determine mineralogy with the unaided eye. A significant percentage of the rock by volume may be phenocrysts. Igneous rocks with 'exotic' composition are excluded from this concept.	Gillespie and Styles 1999	~00~04~01~06~
Andesitic rock	andesite	Fine-grained igneous rock with less than 20 percent quartz and less than 10 percent feldspathoid minerals in the QAPF fraction, in which the ratio of plagioclase to total feldspar is greater 0.65. Includes rocks defined modally in QAPF fields 9 and 10 or chemically in TAS field O2 as andesite. Basalt and andesite, which share the same QAPF fields, are distinguished chemically based on silica content, with basalt defined to contain less than 52 weight percent silica. If chemical data are not available, the color index is used to distinguish the categories, with basalt defined to contain greater than 35 percent mafic minerals by volume or greater than 40 percent mafic minerals by weight. Typically consists of plagioclase (frequently zoned from labradorite to oligoclase), pyroxene, hornblende and/or biotite. Fine grained equivalent of dioritic rock.	After LeMaitre et al. 2002	~00~04~01~06~00~
Dacitic rock	dacite	Fine grained crystalline rock that contains less than 90 percent mafic minerals, between 20 and 60 percent quartz in the QAPF fraction, and has a plagioclase to total feldspar ratio greater than 0.65. Includes rocks defined modally in QAPF fields 4 and 5 or chemically in TAS Field O3. Typically composed of quartz and sodic plagioclase with minor amounts of biotite and/or hornblende and/or pyroxene; fine-grained equivalent of granodiorite and tonalite.	LeMaitre et al. 2002	~00~04~01~06~01~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Trachytic rock		Fine-grained or porphyritic igneous rock defined in the QAPF diagram as having Q/(Q+A+P) less than 20 or F/(F+A+P) less than 10 percent, and A/(P+A) greater than 65. A fine-grained or porphyritic crystalline rock having alkali feldspar and minor mafic minerals (typically amphibole or mica) as the main components; typically porphyritic. Concept corresponds to trachytoid of LeMaitre et al (2002, p39, Fig 2.9), without denoting the categorization process. Includes rocks defined modally in QAPF fields 6, 7 and 8 or chemically in TAS Field T as trachyte or latite.	LeMaitre et al. 2002	~00~04~01~06~02~
Rhyolitic rock	rhyolitoid	Fine grained igneous rock that contains between 20 and 60 percent quartz in the QAPF fraction, and has a ratio of plagioclase to total feldspar is less than 0.65. Typically consisting of quartz and alkali feldspar, with minor plagioclase and biotite, in a microcrystalline, cryptocrystalline or glassy groundmass. Flow texture is common. Includes rocks defined modally in QAPF fields 2 and 3 or chemically in TAS Field R as rhyolite. Equivalent to rhyolitoid of LeMaitre et al (2002) Fig 2.19 (p. 39), without denotation of field classification.	LeMaitre et al. 2002	~00~04~01~06~03~
Phonolitic rock	phonolitoid	Fine grained igneous rock than contains less than 90 percent mafic minerals, between 10 and 60 percent feldspathoid mineral in the QAPF fraction and has a plagioclase to total feldspar ratio less than 0.5. Includes rocks defined modally in QAPF fields 11 and 12, and TAS field Ph. Equivalent to phonolitoid of LeMaitre et al (2002) Fig 2.19 (p. 39), without denotation of field classification.	LeMaitre et al. 2002	~00~04~01~06~04~
Basaltic rock	basalt, picrite, hawaiite, tholeite	Fine-grained igneous rock with less than 20 percent quartz, and less than 10 percent feldspathoid minerals, in which the ratio of plagioclase to total feldspar is greater 0.65. Typically composed of calcic plagioclase and clinopyroxene; phenocrysts typically include one or more of calcic plagioclase, clinopyroxene, orthopyroxene, and olivine. Includes rocks defined modally in QAPF fields 9 and 10 or chemically in TAS field B as basalt. Basalt and andesite are distinguished chemically based on silica content, with basalt defined to contain less than 52 weight percent silica. If chemical data are not available, the color index is used to distinguish the categories, with basalt defined to contain greater than 35 percent mafic minerals by volume or greater than 40 percent mafic minerals by weight.	After LeMaitre et al. 2002	~00~04~01~06~05~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Tephritic rock	basanite, tephrite	Fine grained igneous rock than contains less than 90 percent mafic minerals, between 10 and 60 percent feldspathoid mineral in the QAPF fraction and has a plagioclase to total feldspar ratio greater than 0.5. Includes rocks classified in QAPF field 13 and 14 or chemically in TAS field U1 as basanite or tephrite. Concept corresponds to tephritoid of LeMaitre et al 2002, p39, Fig 2.9, without denoting the categorization process.	LeMaitre et al. 2002	~00~04~01~06~06~
Acidic igneous rock		Igneous rock consisting of more than 63 percent SiO_2.	After LeMaitre et al. 2002	~00~04~01~07~
Intermediate composition igneous rock		Igneous rock with SiO_2 between 52 and 63 percent.	After LeMaitre et al. 2002	~00~04~01~08~
Basic igneous rock		Igneous rock with SiO_2 between 45 and 52 percent.	After LeMaitre et al. 2002	~00~04~01~09~
Ultrabasic igneous rock		Igneous rock with SiO_2 less than 45 percent.	After LeMaitre et al. 2002	~00~04~01~10~
Hornblendite		Ultramafic rock in which ol/(ol + px + hbl) is less than 40, and px/(hb + px) is less than 50 percent. Category includes all hornblendite varieties olivine hornblendite, olivine-pyroxene hornblendite, pyroxene hornblendite, and hornblendite) in the IUGS classification.	Gillespie and Styles, 1999; LeMaitre et al. 2002	~00~04~01~10~00~
Pyroxenite	olivine pyroxenite, olivine-hornblende pyroxenite, pyroxenite, orthopyroxenite, clinopyroxenite, websterite	Ultramafic rock in which ol/(ol + px + hbl) is less than 40, and px/(hb + px) is greater than 50 percent. Follows criteria laid out in Fig. 16 of Gillespie and Styles (1999) for pyroxenite.	LeMaitre et al. 2002	~00~04~01~10~01~
Komatiitic rock	Meimechite	Ultramafic extrusive rock crystallized from high temperature magmas with 18-32 percent MgO and TiO_2 less than 1 percent; they often form pillows and have chilled flow-tops and usually have well-developed spinifex textures, with intergrown skeletal and bladed olivine and pyroxene crystals set in abundant glass.	LeMaitre et al. 2002	~00~04~01~10~02~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Peridotite	dunite, harzburgite, lherzolite, wehrlite, olivinite, pyroxene peridotite, pyroxene hornblende peridotite, hornblende peridotite	Ultramafic rock with ol/(ol+opx+cpx) greater than 40 percent, ol/(ol+px+hbld) greater than 40 percent (LeMaitre et al. 2002 p. 28), and less than 10 modal percent melilite. A general term for a coarse-grained igneous rock composed chiefly of olivine with or without other mafic minerals, and containing little or no feldspar. Alteration to serpentinite is common.	LeMaitre et al. 2002	~00~04~01~10~03~
Composite (transformed) genesis rock		Rock formed by geological modification of pre-existing rocks outside the realm of igneous and sedimentary processes. Includes rocks formed by impact metamorphism, standard dynamothermal metamorphism, thermal metamorphism, brittle deformation, weathering, metasomatism and hydrothermal alteration (diagenesis is a sedimentary process in this context).	NADM SLTTm 2004	~00~04~02~
Impact metamorphic rock		Rock that contains features indicative of shock metamorphism, such as microscopic planar deformation features within grains or shatter cones; includes breccias and melt rocks. Include unconsolidated impact materials in this category.	Stoeffler and Grieve 2007; Jackson 1997	~00~04~02~00~
Metamorphic rock		Any rock formed by solid-state mineralogical, chemical and/or structural change to a pre-existing rock, in response to marked changes in temperature, pressure, differential stress, and chemical environment; generally at depth in the crust.	Jackson 1997	~00~04~02~01~
Migmatite		Metamorphic rock that is pervasively heterogeneous on a decimeter to decameter scale that typically consists of darker and lighter parts; commonly the lighter parts have igneous appearance and composition.	Fettes and Desmons, 2007	~00~04~02~01~00~
Granofels		Phaneritic metamorphic rock with granoblastic fabric and little or no foliation or lineation (less than 10 percent of the mineral grains in the rock are elements in a planar or linear fabric).	Fettes and Desmons, 2007	~00~04~02~01~02~
Hornfels		Granofels formed by contact metamorphism, composed of a mosaic of equidimensional grains in a characteristically granoblastic or decussate matrix; porphyroblasts or relict phenocrysts may be present. Typically fine grained.	Fettes and Desmons, 2007	~00~04~02~01~02~01

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Foliated or lineated metamorphic rock		Metamorphic rock in which 10 percent or more of the contained mineral grains are elements in a planar or linear fabric. Does not include rocks with cataclastic or glassy character.	Based on NADM SLTTm	~00~04~02~01~03~
Schist		Metamorphic rock with well developed, continuous schistosity, meaning that half of the rock is mineral grains with a thin, tabular, lamellar, or acicular prismatic crystallographic habit, mineral grains are visible to the naked eye, and tabular, lamellar, and acicular grains are oriented in a continuous planar or linear fabric. May have any mineralogy or composition.	NADM SLTTm 2004; Neuendorf et al. 2005	~00~04~02~01~03~00~
Slate		Rock with well developed linear or planar metamorphic fabric in which individual mineral grains are too small to be discerned without a microscope (slaty cleavage). Slaty cleavage characteristically allows rock to be split into slabs or thin plates.	NADM SLTTm 2004; Neuendorf et al. 2005	~00~04~02~01~03~01~
Phyllite		Rock with a well developed, continuous schistosity in which individual phyllosilicate grains are just barely visible, typically with grain size between 0.1 and 0.5 millimeter, and produce a silvery sheen on cleavage surfaces. Rock becomes schist when individual phyllosilicate grains are easily visible with unaided eye, and slate when too fine-grained to discern constituent particles.	Fettes and Desmons, 2007	~00~04~02~01~03~02~
Mylonitic rock	protomylonite, mylonite, ultramylonite, phyllonite, blastomylonite	Foliated metamorphic rock formed by ductile deformation; greater than 10 percent of rock is fine-grained matrix caused by tectonic grain size reduction. Category includes protomylonite, mylonite and ultramylonite.	Marshak & Mitra 1988	~00~04~02~01~03~03~
Gneiss	granulite	A non-mylonitic foliated metamorphic rock that does not have well developed, continuous schistosity. NADM SLTTm (2002) defines well developed schistosity to mean that greater than 50 percent of the rock consists of mineral grains with a tabular, lamellar, or prismatic crystallographic habit that are oriented in a continuous planar or linear fabric. IUGS simply states a weak preferred orientation of inequant mineral grains or grain aggregates produced by metamorphic processes.	Fettes and Desmons, 2007; NADM SLTTm, 2004	~00~04~02~01~03~04~
Quartzite		Metamorphic rock consisting of at least 75 percent quartz; typically has granoblastic texture.	After Neuendorf et al. 2005	~00~04~02~01~04~00~
Serpentinite		Rock consisting of at least 75 percent serpentine-group minerals, e.g., antigorite, chrysotile or lizardite; accessory chlorite, talc and magnetite may be present.	Neuendorf et al. 2005	~00~04~02~01~04~01~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Eclogite		Metamorphic rock composed of at least 75 percent (by volume) omphacite and garnet, both of which are present as major constituents, the amount of neither of them being higher than 75 percent (by volume). Presence of plagioclase precludes classification as an eclogite.	Fettes and Desmons, 2007	~00~04~02~01~04~02~
Amphibolite		Metamorphic rock mainly consisting of green, brown or black amphibole and plagioclase (including albite), which combined form at least 75 percent of the rock, and both of which are present as major constituents. The amphibole constitutes 50 percent or more of the total mafic constituents and is at least 30 percent of the rock volume.	Fettes and Desmons, 2007	~00~04~02~01~04~03~
Marble		Metamorphic rock consisting of at least 75 percent fine- to coarse-grained recrystallized carbonate minerals (typically calcite or dolomite); usually with a granoblastic texture.	Fettes and Desmons, 2007	~00~04~02~01~04~04~
Metasomatic rock	skarn, tactite	Rock that has fabric and composition indicating open-system mineralogical and chemical changes in response to interaction with a fluid phase, typically water rich.	NADM SLTTm, 2004	~00~04~02~02~
Sedimentary rock		Rock formed by accumulation and cementation of solid fragmental material deposited by air, water or ice, or as a result of chemical processes, such as precipitation from solution, the accumulation of organic material, or from biogenic processes, including secretion by organisms.	NADM SLTTs 2004	~00~04~03~
Clastic sedimentary rock		Sedimentary rock in which at least 50 percent of the constituent particles were derived from erosion, weathering, or mass-wasting of pre-existing earth materials, and transported to the place of deposition by mechanical agents such as water, wind, ice and gravity.	NADM SLTTs 2004; Neuendorf et al. 2005	~00~04~03~00~
Mudstone	argillite	Clastic sedimentary rock consisting of less than 25 percent gravel-size clasts with a mud to sand ratio greater than 1. Equivalent to mudrock of NADM SLTTs.	Pettijohn et al. 1987 referenced in Hallsworth & Knox 1999; extrapolated from Folk, 1954, Figure 1a; based on Folk (1954, 1968, 1980); 25 percent cutoff for consistency within this vocabulary	~00~04~03~00~00~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Shale		A mudstone (mudrock of NADM SLTTs) that will part or break along thin, closely spaced layers parallel to stratification.	NADM SLTTs 2004; Neuendorf et al. 2005	~00~04~03~00~00~00~
Sandstone	arkose, arenite, calcarenite	Clastic sedimentary rock in which less than 25 percent of particles are greater than 2 mm in diameter (gravel) and the sand to mud ratio is at least 1. Equivalent to sandy rock of NADM SLTTs (2005).	Neuendorf et al. 2005; particle size from Wentworth grade scale	~00~04~03~00~01~
Conglomerate		Coarse grained sedimentary rock composed of at least 30 percent rounded to subangular fragments larger than 2 mm in diameter; typically contains finer grained material in interstices between larger fragments.	Neuendorf et al. 2005; NADM SLTTs 2004	~00~04~03~00~02~
Wackestone	graywacke	Clastic sedimentary rock that contains 15 to 75 percent matrix (undiscernible mud-size material) of unspecified or diagenetic origin. Distinguished from diamictite because mud-size material in diamictite is primary sediment.	CGI Simple Lithology vocabulary	~00~04~03~00~03~
Diamictite	tillite	Non-sorted or poorly sorted terrigenous sedimentary rock that consists of sand and /or larger particles in a muddy matrix. Particle size distribution is commonly bimodal or polymodal, with one or more modes in the coarse-grain range and one or more in the silt-clay size range. Biogenic materials that have such texture are excluded. Distinguished from conglomerate, sandstone, mudstone based on depositional fabric and structures that indicate genesis by glacier-related processes, sediment gravity flow, or explosive processes as indicated by chaotic mixing of clast sizes, mud-matrix enclosing larger clasts, and lack of structures related to transport and deposition of sediment by moving air or water. Distinguished from clastic wackestone based on interpretation that muddy matrix material is of primary sedimentary origin. Meant to be synonymous with CGI GeoSciML diamictite.	Flint et al., 1960	~00~04~03~00~04~
Carbonate sedimentary rock		Sedimentary rock in which at least 50 percent of the primary and/or recrystallized constituents are composed of one (or more) of the carbonate minerals calcite, aragonite and dolomite, in particles of intrabasinal origin.	NADM SLTTs 2004	~00~04~03~01~
Calcareous carbonate sedimentary rock	chalk, limestone	Carbonate sedimentary rock with a calcite (plus aragonite) to dolomite ratio greater than 1. Includes limestone and dolomitic limestone.	Based on NADM SLTTs 2004; Hallsworth & Knox 1999	~00~04~03~01~00~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Dolomitic or magnesian sedimentary rock	dolostone	Carbonate sedimentary rock with ratio of magnesium carbonate to calcite (plus aragonite) greater than 1 to 1. Includes dolostone, lime dolostone and magnesite-stone.	Based on NADM SLTTs 2004	~00~04~03~01~01~
Carbonate boundstone		Sedimentary carbonate rock with preserved biogenic texture, whose original components were bound and encrusted together during deposition by the action of plants and animals during deposition and remained substantially in the position of growth.	Hallsworth and Knox 1999; NADM SLTTs 2004	~00~04~03~01~02~00~
Carbonate mudstone		carbonate sedimentary rock with recognizable depositional texture and matrix supported fabric, in which more than 75 percent of original sedimentary grains are mud-sized (smaller than 32 microns).	Dunham, 1962; Hallsworth & Knox 1999; NADM SLTTs	~00~04~03~01~02~01~
Grainstone		Carbonate rock with grain supported depositional fabric and contains little or no (less than 1 percent) originally mud-sized particles.	Dunham, 1962; Hallsworth and Knox 1999; NADM SLTTs	~00~04~03~01~02~02~
Packstone		Carbonate sedimentary rock with discernible grain-supported depositional texture, containing greater than 10 percent grains; intergranular spaces are filled by matrix.	NADM SLTTs 2004	~00~04~03~01~02~03~
Crystalline carbonate		Carbonate rock of indeterminate mineralogy in which diagenetic processes have obliterated any original depositional texture. Sparstone and microsparstone of Hallsworth and Knox (1999).	NADM SLTTs 2004	~00~04~03~01~02~04~
Framestone		Carbonate reef rock consisting of a rigid framework of colonies, shells or skeletons, with internal cavities filled with fine sediment; usually created through the activities of colonial organisms.	Hallsworth & Knox 1999; NADM SLTTs, 2004, Table 15-3-1	~00~04~03~01~02~05~
Carbonate wackestone		Carbonate rock with preserved depositional fabric that is mud-supported, and rock contains greater than 10 percent allochems (NADM SLTTs 2004).	Dunham 1962; Hallsworth & Knox 1999; NADM SLTTs	~00~04~03~01~02~06~
Organic rich sedimentary rock	lignite	Sedimentary rock with color, composition, texture and apparent density indicating greater than 50 percent organic content by weight on a moisture-free basis.	NADM SLTTs 2004	~00~04~03~02~
Coal	anthracite	Hard, black, organic rich sedimentary rock that yields greater than 8,300 Btu on a moist, mineral-matter-free basis, or contains greater than 69 percent fixed carbon on a dry, mineral-matter-free basis; formed from the compaction or induration of plant remains similar to those of peaty deposits.	ASTM 2002; Schopf 1956	~00~04~03~02~00~
Non-clastic siliceous sedimentary rock	chert	Sedimentary rock that consists of at least 50 percent silicate mineral material, deposited directly by chemical or biological processes at the depositional surface, or in particles formed by chemical or biological processes within the basin of deposition.	CGI Simple Lithology vocabulary	~00~04~03~03~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Biogenic silica sedimentary rock	radiolarite, diatomite	Sedimentary rock that consists of at least 50 percent silicate mineral material deposited directly by biological processes at the depositional surface, or in particles formed by biological processes within the basin of deposition.	Based on NADM SLTTs; Hallsworth & Knox 1999	~00~04~03~03~00~
Iron rich sedimentary rock		Sedimentary rock that consists of at least 50 percent (by volume) iron-bearing minerals (hematite, magnetite, limonite-group, siderite, iron-sulfides), as determined by hand-lens or petrographic analysis; corresponds with a rock typically containing at least 15 percent iron by weight.	Hallsworth and Knox 1999; NADM SLTTs 2004	~00~04~03~04~
Phosphorite		Sedimentary rock in which at least 50 percent of the primary or recrystallized constituents are phosphate minerals.	Hallsworth and Knox 1999	~00~04~03~05~
Igneous material		Earth material formed as a result of igneous processes, eg. intrusion and cooling of magma in the crust, volcanic eruption.	CGI Simple Lithology vocabulary	~00~05~
Acidic igneous material		Igneous material consisting of more than 63 percent SiO_2.	After LeMaitre et al. 2002	~00~05~00~
Basic igneous material		Igneous material with SiO_2 between 45 and 52 percent.	After LeMaitre et al. 2002	~00~05~01~
Intermediate composition igneous material		Igneous material with SiO_2 between 52 and 63 percent.	After LeMaitre et al. 2002	~00~05~02~
Fragmental igneous material		Igneous material of unspecified consolidation state in which greater than 75 percent of the rock consists of fragments produced as a result of igneous rock-forming process.	CGI concepts task group	~00~05~03~
Pyroclastic material		Material that consists of greater than 75 percent by volume of fragments produced as a direct result of volcanic processes. Volcanic processes are those associated with the extrusion of magma from within the earth onto its surface. Includes pyroclastic rock of Gillespie & Styles (1999) and LeMaitre et al. (2002). LeMaitre et al. (2002) explicitly exclude autobreccia related to lava flows. This is rejected here because of the difficulty it would present with fragmental deposits associated with silicic lava flows or exogenous domes (e.g. block and ash deposits). Autobreccia associated with lava flows is thus included here as a kind of pyroclastic rock.	LeMaitre et al. 2002	~00~05~03~00~
Sedimentary material		A material that is an aggregation of particles that have sedimentary genesis; consolidation state is not specified; subsumes sediment and sedimentary rock.	NADM SLTTs 2004	~00~06~

Display Name	Synonyms, narrower match terms	Description	Source	Hierarchy Key
Clastic sedimentary material		Sedimentary material of unspecified consolidation state in which at least 50 percent of the constituent particles were derived from erosion, weathering, or mass-wasting of pre-existing earth materials, and transported to the place of deposition by mechanical agents such as water, wind, ice and gravity.	NADM SLTTs 2004; Neuendorf et al. 2005	~00~06~00~
Organic-rich sedimentary material		Sedimentary material with color, composition, texture and apparent density indicating greater than 50 percent organic content by weight on a moisture-free basis.	NADM SLTTs 2004	~00~06~01~
Phosphate-rich sedimentary material		Sedimentary material in which at least 50 percent of the primary and/or recrystallized constituents are phosphate minerals.	NGMDB	~00~06~02~
Iron-rich sedimentary material		Sedimentary material that consists of at least 50 percent (by volume) iron-bearing minerals (hematite, magnetite, limonite-group, siderite, iron-sulfides), as determined by hand-lens or petrographic analysis; corresponds with a rock typically containing 15 percent iron by weight.	CGI Simple Lithology vocabulary	~00~06~03~
Carbonate sedimentary material		Sedimentary material in which at least 50 percent of the primary and/or recrystallized constituents are composed of one (or more) of the carbonate minerals calcite, aragonite and dolomite, in particles of intrabasinal origin.	NADM SLTTs 2004	~00~06~04~
Calcareous carbonate sedimentary material		Carbonate sedimentary material of unspecified consolidation state with a calcite (plus aragonite) to dolomite ratio greater than 1 to 1. Includes lime-sediments, limestone and dolomitic limestone.	Based on NADM SLTTs 2004; Hallsworth & Knox 1999	~00~06~04~00~
Dolomitic or magnesian sedimentary material		Carbonate sedimentary material of unspecified consolidation degree with a ratio of magnesium carbonate to calcite (plus aragonite) greater than 1 to 1. Includes dolomite sediment, dolostone, lime dolostone and magnesite-stone.	Based on NADM SLTTs 2004	~00~06~04~01~
Non-clastic siliceous sedimentary material		Sedimentary material that consists of at least 50 percent silicate mineral material, deposited directly by chemical or biological processes at the depositional surface, or in particles formed by chemical or biological processes within the basin of deposition.	CGI Simple Lithology vocabulary	~00~06~05~
Evaporite	Halite, gypsum	A sedimentary material composed of at least 50 percent non-carbonate (chloride, sulfate, or borate) salts.	Jackson 1997; NADM SLTTs	~00~06~06~
Anthropogenic material		Material known to have artificial (human-related) origin; insufficient information to classify in more detail.	CGI Simple Lithology vocabulary	~00~07~

Scientific confidence

(NGMDB, v. 1.0)

Term	Definition
std	The attribute is considered by mapper to be assigned with an acceptably reliable level of confidence
low	The associated attribute assignment is uncertain
unk	Unknown reliability, generally for use with legacy data

Property Value qualifiers

(NGMDB, v. 1.0)

Terms that may be used to qualify property values in ExtendedAttributes.

Term	Definition
Always	Denotes that property value or relationship applies at all observed locations, and is expected to apply everywhere.
Common	Denotes that property value or relationship applies at most observed locations, and is expected to apply at most locations.
Sometimes	Denotes that property value or relationship is observed at less than 25 percent of locations, and is expected to apply at less than a quarter of locations.
Rare	Denotes that property value or relationship is observed at less than 1 percent of locations, and is expected to apply only rarely.
Never	Denotes that property value or relationship has not been observed, and is not expected to apply at any location or under any condition.

Uncontrolled vocabularies

LocationMethod

(NGMDB, v. 1.0)

The method by which a geologic feature is identified, and then located on a map, is important both to map users and to geologists in the future who choose to revisit our observations and interpretations. We suggest these terms for describing various identification and location methods. We would greatly appreciate comments and suggestions for additions.

HKey	Term	Guidance
1	Observed	Feature located on basis of observations at locales that are separated by distances that are insignificant at the scale of mapping
1.1	Observed on ground	Feature located on basis of visual observations from a distance of less than 10 meters. The observed phenomena may include changes in soil color, vegetation, or slope that are inferred to be a direct result of the mapped feature
1.2	Observed on ground from a distance	Feature located on basis of visual observations from a distance of more than 10 meters. The observed phenomena may include changes in soil color, vegetation, or slope that are inferred to be a direct result of the mapped feature
1.3	Observed in remotely-sensed imagery	Feature located on basis of observations and interpretation of aerial

		photographs or other remotely sensed reflectance data, including non-visible wavelengths and possible digital enhancement. The observed phenomena may include changes in soil color, vegetation, or surface character that are inferred to be a direct result of the mapped feature
1.4	Observed in topographic model	Feature located on basis of a representation of topography (scale model, digital elevation model, contour map, et cetera). Includes topography from all sources, including photogrammetry, lidar, IFSAR, plane table, ...
1.5	Observed in subsurface data	
1.5.1	Observed in excavation	Feature located on basis of observations made in a trench, pit, or other excavation
1.5.2	Observed in borehole core	Feature located on basis of observations in core obtained from a borehole.
1.5.3	Observed in borehole cuttings	Feature located on basis of observation of cuttings obtained from a borehole.
1.5.4	Observed in geophysical log of bore hole	Feature located on basis of measurements made by electronic bore hole logging device(s) that measure geophysical properties.
1.6	Observed by geophysical survey	Feature located on basis of instrumental measurements of physical properties of in-situ earth materials. Such properties include density, acoustic velocity, magnetic susceptibility, radioactivity, etc.
1.6.1	Observed by seismic survey	Feature located on basis of seismic reflection and (or) seismic refraction survey
1.6.2	Observed by aeromagnetic survey	Feature located on basis of magnetic field data acquired by airborne sensor.
1.6.3	Observed by gravity survey	Feature located on basis of measured variations in the acceleration of gravity related to mass of underlying Earth material.
1.6.4	Observed by ground magnetic survey	Feature located on basis of magnetic field data acquired by sensor on the earth surface, either at manually occupied stations, or by a vehicle-based continuously collected sensor data.
1.6.5	Observed by radiometric survey	Feature located on basis of measured flux or intensity of radiation related to the decay of radioactive elements in Earth material. Use for both airborne and ground-surface based sensor.
1.7	Observed by sample analyses	Feature located on basis of analyses of samples. Analytical method(s) may include staining and point counting, thin-section petrography, chemical analysis, physical analysis (density, magnetization, etc.), geochronological analysis
2	Inferred	Feature does not have observed manifestation for significant intervals at the scale of observation.
2.1	Inferred by projection from observed locations	Feature located on basis of continuity with observed locations and assumption of continuity of the feature.
2.1.1	Inferred by projection beneath unmapped surficial material	Feature located on basis of continuity with observed locations and assumption of continuity of the feature. Not observable because of covering mantle of soil, talus, loess, or colluvium that are not mapped as separate geologic units.
2.1.2	Inferred by projection beneath vegetation	Feature located on basis of continuity with observed locations, and assumption of continuity of the feature. Not observable because of obscuring vegetation, but inferred to crop out at surface.
2.4	Inferred on basis of geological interpretation	Feature location basis of geologic reasoning from surrounding observations and inferred earth history. True of many faults, e.g., missing or duplicated stratigraphic section leads to inference of a fault, change in facing direction may lead to inference of a fold.

3	Concealed beneath covering mapped unit	Feature is covered by mapped younger geologic unit. Location method not otherwise specified.
4	Location method not specified	Locatability is not specified; use for normative descriptions where locatability may take any value
5	Location method not applicable	Use for lines and points that are not located by a mapping process. Location may defined *a priori* or be arbitrary. Examples include quadrangle boundaries and cross-section lines

Property terms (for ExtendedAttributes)

(NGMDB, v. 1.0)

The following table lists some properties that might be associated with a map unit through the ExtendedAttributes table. These have been extracted from the GeoSciML version 2 model and from NGMDB vocabulary compilations. Vocabularies for populating these properties have been compiled but are not included with this package. The NGMDB vocabularies are available at http://ngmdb.usgs.gov/Info/standards/NGMDBvocabs/. Please note that these are draft unpublished documents, offered to the community in order to provide terminology lists and definitions that may be found useful by projects and agencies, and to improve the vocabulary content. Please send comments to Dave Soller and Steve Richard (drsoller@usgs.gov, steve.richard@azgs.az.gov).

Property	**Explanation**
bedding pattern	Term(s) specifying patterns of bedding thickness or relationships between bedding packages, Examples: thinning upward, thickening upward.
bedding style	Term(s) specifying the style of bedding in a stratified geologic unit, e.g.,lenticular, irregular, planar, vague, massive.
bedding thickness	Term(s) or numeric values characterizing the thickness of bedding in the unit.
body morphology	The geometry or form of a Geologic Unit. Examples include: dike (dyke), cone, fan, sheet, etc. Morphology is independent of the substance (Earth Material) that composes the Geologic Unit. The described morphology is based on the conceptualization of what the original shape of the mapped geologic unit was when originally formed.
clast weathering degree	The degree of weathering intensity of clasts in sedimentary surficial deposits. Classification is based on degree of weathering of clasts that were originally indurated material.
clast weathering style	The weathering style of clasts on a surface. Examples: pitted, etched, weathering rinds.
composition category	Term to specify the gross chemical character of geologic unit. Examples: silicate, carbonate, ferromagnesian, . Chemical classification terms for igneous rocks also go here (including total alkali silica (TAS) categories). Examples: alkalic, subaluminous, peraluminous, mafic, felsic, intermediate.
contained structure	Geologic structures that are present in and characterize a geologic unit, e.g. ripple cross lamination, soft-sediment deformation structures.
exposure color	Typical color at the outcrop of a geologic unit. Notes should indicate observation conditions, e.g.,wet, dry, sunlight, overcast…
genesis	A term that represents a summary geologic history of a geologic unit. (ie, a genetic process classifier term) Examples include igneous, sedimentary, metamorphic, shock metamorphic, volcanic, pyroclastic.
magnetic susceptibility	The ratio of induced magnetization to the strength of the magnetic field causing the magnetization, customarily measured in SI units. Note that volume magnetic susceptibility is dimensionless, being magnetization (magnetic dipole moment) in amperes per meter (SI) divided by the applied field, also in amperes per meter. However, many tables of magnetic susceptibility and some instruments give cgs values that rely on different definitions of the permeability of free space than SI values. The cgs value of susceptibility is multiplied by 4pi to give the SI susceptibility value. For example, the cgs volume magnetic susceptibility of water at 20°C is -7.19x10-7 which is -9.04x10-6 in SI. Glossary notes for this property should explicitly explain the units and constants used.
metamorphic	Characteristic mineral assemblages developed in metabasaltic rocks that are indicative of certain

Property	Explanation
facies	metamorphic P-T conditions: greenschist facies, amphibolite facies, granulite facies. More generally, mineralogic associations diagnostic or suggestive or metamorphism at particular P-T conditions. Glossary definitions for terms should clearly explain how the facies described are defined.
metamorphic grade	A term to indicate the intensity or rank of metamorphism applied to an Earth Material, commonly very low, low, medium, or high grade; commonly used to refer in a general way to the temperature of metamorphism, as the occurrences of typical grade indicators (mostly, Barrovian index minerals) are relatively insensitive to pressure.
outcrop character	Describes the nature of outcrops formed by a geologic unit. Examples: bouldery, cliff-forming, ledge-forming, slope-forming, poorly exposed, crumbly, rugged.
permeability	The measure of the capacity of a porous material to transmit a fluid. Customary unit of measure: millidarcy.
porosity	The percentage of the bulk volume of a material that is occupied by interstices, whether isolated or connected.
protolith	An interpretation of the Earth Material that constituted the pre-metamorphic lithology for a metamorphic or metasomatic rock.
stratigraphic rank	Rank provides an ordering by relative magnitude. For strata, the ordering is typically from fewest/least beds to most beds, or from lest time to most time, or from small volume/outcrop area to large volume/regional extent. Examples: group, subgroup, formation, member, bed, intrusion, complex, batholith.
soil development	Characterization of soil formed from a rock or unconsolidated deposit.
surface morphology	The form of the surface developed on a unit.
surface dissection	The degree and pattern of erosional dissection of the earth's surface. Depends on the character of substrate, and on the geomorphic evolution of the landscape.
surface armoring	Characterization of the development of pavement or other surface armor on a surficial deposit.
surface varnish	The degree of development of rock varnish on clasts or a bedrock surface.
weathering degree	Term to specify degree of modification from original material, e.g.,slightly weathered, strongly weathered, weathered rock grade III.
unit thickness	Typical thickness of the geologic unit. Measured normal to bedding on stratified rocks and deposits. For other kinds of unit morphology (e.g.,sills, dikes) the relationship of thickness to the morphology should be described in the Glossary.
weathering product	Earth material produced by weathering of a pre-existing, different material, e.g.,saprolite, ferricrete, clay, calcrete.
weathering environment	Terms to specify the climatic context of weathering.
peak metamorphic temperature	Maximum temperature of metamorphism.
peak metamorphic pressure	Maximum pressure of metamorphism.
density	Material mass per unit volume.
weathering process	Characteristic weathering process, e.g.,leaching, accumulation.

References

ASTM, 2002, Annual Book of ASTM Standards, Petroleum Products, Lubricants, and Fossil Fuels: American Society of Testing Materials, 522 p.

CGI Simple Lithology vocabulary, in review 2008, Draft vocabularies for GeoSciML Web services, https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/ConceptDefinitionsTG.

Dunham, R.J., 1962, Classification of carbonate rocks according to depositional texture, in Ham, W.E., ed., Classification of carbonate rocks: American Association of Petroleum Geologists Memoir, p. 108-121.
Taylor, G., and Eggleton, R.A., 2001, Regolith Geology and Geomorphology: Nature and Process: New York, John Wiley and Sons, 375 p.
Fettes, D., and Desmons, J., eds., 2007, Metamorphic Rocks: A Classification and Glossary of Terms, Cambridge University Press, Cambridge, UK, ISBN 13.9780521868105, 256 p.
Flint, R.F., Sanders, J.E., and Rodgers, J., 1960, Diamictite, a substitute term for symmictite: Geological Society of America Bulletin, vol. 71, p. 1809.
Folk, R.L., 1954, The distinction between grain size and mineral composition in sedimentary-rock nomenclature: Journal of Geology, v. 62, p. 344-359.
Folk, R.L., 1968, Petrology of Sedimentary Rocks: Austin, TX, Hemphill, 170 p.
Folk, R.L., 1980, Petrology of Sedimentary Rocks: Hemphill Publishing, Austin, TX, 184 p.
Gillespie, M.R., Styles, M.T., 1999, BGS Rock Classification Scheme, Volume 1: Classification of igneous rocks: British Geological Survey Research Report, RR 99-06, 52 p.
Hallsworth, C.R., Knox, R.W.O'B., 1999, BGS Rock Classification Scheme, Volume 3: Classification of sediments and sedimentary rocks: British Geological Survey Research Report, RR 99-03, 44 p.
Jackson, J.A., 1997, Glossary of Geology (Fourth edition): Alexandria, VA, American Geological Institute, 769 p.
LeMaitre, R.W., (ed.)., Streckiesen, A., Zanettin, B., LeBas, M.J., Bonin, B., Bateman, P., Bellieni, G., Dudek, A., Efremova, S., Keller, J., Lameyre, J., Sabine, P.A., Schmid, R., Sorensen, H., and Woolley, A.R., 2002, Igneous Rocks, A Classification and Glossary of Terms: Cambridge, U.K., Cambridge University Press, 236 p.
Marshak, S., and Mitra, G., 1988, Basic Methods of Structural Geology: Englewood Cliffs, Prentice-Hall, 446 p.
McMillan, A.A., Powell, J.H., 1999, BGS Rock Classification Scheme, Volume 4: Classification of artificial (man-made) ground and natural superficial deposits—applications to geological map and datasets in the UK: British Geological Survey Research Report, RR 99-04, 65 p.
North American Geologic Map Data Model Steering Committee Science Language Technical Team (SLTT), 2004, Report on Progress to Develop a North American Science-Language Standard for Digital Geologic-Map Databases, in D.R. Soller, ed., Digital Mapping Techniques '04—Workshop Proceedings: U.S. Geological Survey Open-File Report 2004–1451, http://pubs.usgs.gov/of/2004/1451/nadm/ (includes all science language documents).
North American Geologic Map Data Model Steering Committee (NADM C1), 2004, NADM Conceptual Model 1.0, A Conceptual Model For Geologic Map Information: U.S. Geological Survey Open-file Report 2004-1334, 58 p., http://pubs.usgs.gov/of/2004/1334/. Simultaneously released as Geological Survey of Canada, Open File 4737, 1 CDROM.
North American Geologic-map Data Model Science Language Technical Team (NADM SLTTs), 2004a, Sedimentary materials: science language for their classification, description, and interpretation in digital geologic-map databases, Version 1.0 (12/18/2004), in D.R. Soller, ed., Digital Mapping Techniques '04—Workshop Proceedings: U.S. Geological Survey Open-File Report 2004–1451, Appendix C to SLTT report, 595 p., http://pubs.usgs.gov/of/2004/1451/nadm/.
North American Geologic-map Data Model Science Language Technical Team (NADM SLTTm), 2004b, Classification of metamorphic and other composite-genesis rocks, including hydrothermally altered, impact-metamorphic, mylonitic, and cataclastic rocks, Version 1.0 (12/18/2004), in D.R. Soller, ed., Digital Mapping Techniques '04—Workshop Proceedings: U.S. Geological Survey Open-File Report 2004–1451, Appendix B to SLTT report, 56 p., http://pubs.usgs.gov/of/2004/1451/nadm/.

Neuendorf, K.K.E., Mehl Jr., J.P., and Jackson, J.A., Eds., 2005, Glossary of Geology, Fifth Edition: Alexandria, Virginia, American Geological Institute, 779 p.
Pettijohn, F.J., Potter, P.E., and Siever, R., 1987, Sand and Sandstone (Second edition): New York, Springer-Verlag, 553 p.
Richard, S.M., and Soller, D.R., in preparation, Vocabularies for Geoscience Information Exchange, in D.R. Soller, ed., Digital Mapping Techniques ’08 – Workshop Proceedings: U.S. Geological Survey Open-File Report, 7 manuscript pages.
Schmid, R., 1981, Descriptive nomenclature and classification of pyroclastic deposits and fragments: Recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks: Geology, v. 9, p. 41-43.
Schopf, J.M., 1956, A definition of coal: Economic Geology, v. 51, p. 521-527.
Stoeffler, D., and Grieve, R.A.F., 2001, IUGS classification and nomenclature of impact metamorphic rocks: Towards a final proposal [indexed as: Towards a unified nomenclature of metamorphism: IUGS classification and nomenclature of impact metamorphic rocks. A proposal on behalf of the IUGS Subcommission on the Systematics of Metamorphic Rocks, Web version of 14.01.2001], 3 p., http://www.bgs.ac.uk/SCMR.
Streckeisen, A., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1-33.