NOTE: As of March, 2018, this draft manuscript[1] is still provisional; however, it has passed Peer Review, and it is now being prepared for technical edit and, ultimately, for formal publication.

NOTE: For the most current version of this draft manuscript, and for further information including example database and tools, see http://ngmdb.usgs.gov/Info/standards/GeMS/.

Please contact Ralph Haugerud and Dave Soller (USGS, gems@usgs.gov) with questions or comments, or to request access to the software tools.

GeMS (*Ge*ologic *M*ap *S*chema)—a standard format for digital publication of geologic maps[1]

By the USGS National Cooperative Geologic Mapping Program (NCGMP)[2]

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[1] This draft manuscript is intended to succeed *NCGMP09—draft standard format for digital publication of geologic maps, version 1.1* (USGS National Cooperative Geologic Mapping Program, 2010). Until it is formally published, please refer to the list of changes from version 1.1, included in Appendix E of this draft manuscript.

[2] Version 1.1 of this schema was prepared by (in alphabetical order) R.A. Haugerud, S.M. Richards, D.R. Soller, and E.E. Thoms. The version presented in this draft manuscript reflects significant input by numerous members of the USGS-Association of American State Geologists-Digital Mapping Techniques community, specifically the NCGMP09 Working Group (including Jennifer Athey (Alaska), Gregory Barker (New Hampshire), Seth Bassett (Florida), Jennifer Carrell (Illinois), Lorie Coiner (Virginia), Mary DiGiacomo-Cohen (USGS), John Dunham (Kansas), Tracey Felger (USGS), Trish Gallagher (Alaska), Jacqueline Hamilton (Minnesota), Jordan Hastings (UCSB), Mike Hendricks (Alaska), Lina Ma (Oregon), Phil Miller (New Mexico), Bethany Overfield (Kentucky), Jay Parrish (Pennsylvania), Kevin Russell (Indiana), Evan Thoms (USGS), Frederic Wilson (USGS), Jeremy Workman (USGS), and Mark Yacucci (Illinois)), and they should be considered contributors. Haugerud and Soller produced the final text of this draft manuscript. Correspondence should be addressed to gems@usgs.gov.

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INTRODUCTION

This draft manuscript defines a standard database schema—a database design—for digital publication of geologic maps funded by the National Cooperative Geologic Mapping Program (NCGMP) of the U.S. Geological Survey. It is intended to bridge between traditional geologic mapping and GIS communities at an operational level.

The schema was introduced at the Digital Mapping Techniques '09 meeting (May 2009), as version 0.8.2, in order to solicit preliminary comments and testing, and was named NCGMP09 to reflect the date and target audience. Subsequently, version 1.0 was released October 14, 2009, for presentation at the Geological Society of America's Annual Meeting. In the months following, more extensive evaluations were received. The design evolved in response and version 1.1 was published at the end of 2011 in USGS Open-File Report 2010-1335. Several more years of experience and discussion have led to this renamed version: GeMS[3] (for Geologic Map Schema). This and earlier versions of the schema are archived at *http://ngmdb.usgs.gov/Info/standards/GeMS/*.

GeMS provides for the encoding in digital form of 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[4] and because Esri's ArcGIS is the GIS most commonly used in the USGS, in the state geological surveys, and in the larger community for geologic maps. Migration to a nonproprietary format is a worthy goal and GeMS is designed with this in mind.

GeMS is also 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 content. The database design proposed herein will significantly promote that goal.

In our years of work prior to defining NCGMP09/GeMS we recognized that a single database design cannot suit all purposes. This has been underscored by our colleagues' evaluations of this design. A database most suited to the needs of a field geologist likely will not address the content and cartographic requirements of a single-map database published for use by other geologists and non-geologists, nor the requirements of a multi-map database maintained in perpetuity by a mapping agency. We further recognize that for any of these purposes a single design may be contentious, in part owing to varying requirements (e.g., for field systems, requirements imposed by local geology, or for particular hardware). Still, we have developed a design that should prove generally useful, recognizing that many will not find it their first and best choice or may need to extend it to suit their purposes. Compromise in design, without sacrificing the flexibility necessary for science-driven data and information management, is the path we have sought during development of the GeMS standard.

Objective

Geologic mappers, geologic mapping agencies, and geologic map users all benefit from a standard database design for digital representation of geologic maps. This draft manuscript describes such a design for the representation of a single geologic map. The design is focused on the transfer and archiving of map data, with less emphasis on the creation of map data, the visual representation of map

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[3] This name has been used before in a similar context: see Dohar (2004). We are pleased to reinforce GeMS as a useful acronym and think there is little likelihood of confusion.

[4] 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 is not now applicable).

data, or the compilation of data from many maps. With increased use of this design we anticipate reductions in the cost of map production and publication (data compilation and synthesis, review, editing, cartography, pre-press, training, and tool development).

For the purposes of this design ‘single map database’ means a package of data (bearing in mind that many geologic ‘data’ are inherently interpretations) that pertains to a particular portrayal of the geology of some area (the map extent), directly analogous to the traditional paper 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.

We focus on the design of a single map database for two reasons: this is the issue the geologic community understands best, and this is the problem that we perceive is most in need of a solution. The construction and maintenance of an enterprise, multi-map database brings several issues that we do not address here, including versioning, multiple-scale representations, vocabulary management, maintenance of the stratigraphic lexicon, and access control. The multi-map subject is under discussion in a separate working group; as the issues develop and mature, they may be addressed at the GeMS website.

Lessons learned in the last three decades

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

The distinction between map data and their 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 and its constituent data more easily used for various purposes. Similarly, maps should be more than vector graphic files (e.g., those produced in Adobe Illustrator). Map data are most usefully stored and analyzed in a 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 #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). Symbolization of these data via lines, colored areas, patterns, and markers, etc. results in a map portrayal on screen or on paper, analogous to a tabular report based on financial data in an accounting database.

Maps need metadata for both the overall database and for its individual features. Early GIS practices, largely shaped by limitations of storage space and database architecture, as well as paper-map precedents, led to the creation of a significant number of map databases in which key fields were populated with symbols (e.g., map unit = Ks) that were not defined within the database. This is inadequate. Most geologic maps have mixed sources and data qualities; map users benefit from feature-level metadata that describes data source and quality. Also, map data should be closely linked to authorship because maps are interpretations made by individuals or workgroups whose efforts require significant support from a governmental agency, academic institution, professional society, or private industry, all of whom need to be recognized.

Real-world database designs reflect compromises between the intrinsic complexity of geologic map data, the needs of geologists and GIS practitioners who work with the design, the capabilities of GIS and database software, and the limitations of the underlying computer systems. Database designs that do not make such compromises are unlikely to be widely used. Even the names of database 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 a schema and its associated vocabularies that extends 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 that tradition reflects prior compromises necessitated by the limitations of the paper-map format, which now may be alleviated in a digital world.

Finally, there is a perception among some geologists that comprehension of their maps, given their subtleties of layout, visual and textual vocabularies, and sometimes carefully ambiguous descriptions, is beyond the capabilities of the uninitiated; that these maps cannot be—and thus should not be expected to be—readily used by the public that needs and pays for them. This is unfortunate because, as noted by a former USGS Director, "…the maps are designed not so much for the specialist as for the people, who justly look to the official geologist for a classification, nomenclature, and system of convention so simple and expressive as to render his work immediately [understandable]…" (Powell, 1888).

We endeavored to honor these lessons in the GeMS design and hope that it contributes to a better understanding and wider use of geologic map data.

Acknowledgments

The GeMS 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 thank Peter Lyttle (former Program Coordinator, NCGMP) for his recommendation in 2008 that we undertake this work. We also thank our many colleagues who have given thoughtful comments and critiques of this design and trust that this iteration wins their engagement and, where still needed, improvement.

Under the authority of the Geologic Mapping Act of 1992 (and its subsequent reauthorizations), the NGMDB functions on behalf of the NCGMP as coordinator of database design changes and maintenance, in cooperation with the Association of American State Geologists. All questions or comments about GeMS should be directed via email to gems@usgs.gov.

DESIGN CONSIDERATIONS

With GeMS, we have attempted to:

- Encode the fundamental content of a single, traditional paper geologic map.
- Focus equally on the digital storage and digital transfer of the map.
- Facilitate editing of the map during production. For example, we put all lines that bound map-unit polygons in the same container to facilitate enforcement of topological constraints.
- Facilitate interactive display and query.
- Provide a foundation for publication-quality visualization of the map.
- Define data names and data types for all constituent elements of the map, both for the convenience of all users and as a springboard for development of software tools. Use names that have obvious meaning to geologists and GIS practitioners 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 by introducing standard terms and definitions.

- Preserve and facilitate the analysis of map feature topology.
- Normalize map data for robustness and compactness, but not to the extent that user comprehension is reduced.
- Allow queryable descriptions of map features with as much (or as little) granularity as desired.
- Accommodate both Esri and open file formats for flexibility, interoperability, and data longevity.
- Facilitate re-use of map data in later compilations by including feature-level metadata.

Content of a traditional geologic map

Traditional geologic maps have rich semantic content, fundamental aspects of which must be preserved in the digital database for it to be successful. This fundamental content appears in **bold** in the outline below, and is further discussed below where the GeMS schema is described in detail. Yellow backgrounding denotes secondary or supporting content for which a digital form is not specified.

1. Map graphic
    1. Base map
    2. **Map-unit polygons** (that cover the mapped area without gaps or overlaps. These 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. Special elements that are present as needed for idiosyncratic but significant content of a particular map:
        1. **Overlay polygons**, e.g., alteration zones, artificial fill, surface projection of mined-out areas. Because these polygons delimit features that are within, or beneath, the rocks and deposits represented by map-unit polygons, they commonly appear on the map as patterned overlays.
        2. **Miscellaneous 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 miscellaneous lines do not conform to the strict topological rules that constrain map-unit polygons and contacts and 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), sample locations, geochronologic results, fossils, chemical analyses, prospect locations, displacement (fault-slip) measurements, and points for map-unit polygons too small to show at scale.
2. **Cross sections**, as appropriate, each with elements analogous to map elements, except that the base map is replaced by a topographic profile.
3. **Correlation of Map Units** diagram ("CMU") that includes unit designators, grouping brackets, dividing lines, and free text.
4. **Symbolization** for above, including:
    1. Map-unit area fills (color and optional pattern) for map-unit polygons
    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 labels, and in some cases leaders, for some (but not necessarily all) polygons

   5. Line symbols (with variable color, weight, dot-dash pattern, repeated marker ornament, etc.) for some lines. Some lines also have point (marker or text) ornaments
   6. Point markers for some points
   7. Text labels, and in some cases leaders, for some lines and groups of lines and for some points. Examples are fault names and well identifiers
5. **Description of Map Units** (DMU), or a List of Map Units (LMU) with descriptions in an accompanying pamphlet. Traditionally, the DMU does not describe water, permanent snow and glaciers, unmapped area, and some geologic overlays. DMUs can be strongly hierarchical. Each unit shown on the map has area-fill color and pattern, label, unit name, age, description, and a paragraph style that (in part) denotes position in hierarchy. DMUs commonly include headings (e.g., "Unconsolidated Deposits") and some units not shown on the map, e.g., a Group or Formation that is entirely mapped as constituent subunits, or units that are shown only in a cross section. Headings and units not shown on the map lack area-fill colors, patterns, and labels.
6. **Explanation of map symbols**: overlay patterns, line symbols, and point symbols
7. **Miscellaneous map collar information**. 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, metadata for base map and other reference layers, and map scale. Content may vary from agency to agency, and from one map to another.
8. Figure(s)
9. Table(s)
10. Additional maps (e.g., sources of map data; distribution of facies in the Cambrian)
11. Extended text, as needed
12. References Cited, as needed.

Extensions to traditional geologic map content

GeMS includes several extensions to traditional geologic map content. Three of these extensions are required: 1) a glossary of terms, 2) a simple classification of map-unit materials, and 3) certain feature-level metadata. Optional extensions include supplemental standardized lithologic descriptions of map units and a simple table of miscellaneous map information.

Glossary of terms

Many published digital geologic map databases, and many paper geologic maps as well, provide definitions for few, if any, of the technical terms used to name and describe map features. Some producers of geologic map databases have remedied this with formal FGDC metadata that contains detailed entity and attribute descriptions that encapsulate definitions and definition sources for these terms. Unfortunately, such metadata can be difficult to access and nearly impossible to relate automatically to the relevant features in the database.

GeMS implements a Glossary that, for certain database fields, lists the terms that populate these fields along with their definitions and sources for these definitions. Terminology used in the map database must be defined in this Glossary. If this seems excessively laborious, consider that once terms are defined in this Glossary they are readily available for display within the map, on-screen and in print, and are easily searched and extracted for other publications. Glossary contents are accessed via a database join or relate based on the term itself, which serves as a primary key. Formal metadata for a feature class or table can reference the Glossary table for definitions and definition sources; re-listing of these within detailed entity and attribute metadata is not necessary.

In most cases, Glossary definitions can be copied or paraphrased from standard sources (e.g., AGI Glossary of Geology, with appropriate attribution), or from pre-existing Glossaries with minor amendments. Terms used only in the Description field of the DMU need not be defined. While building Glossaries for the first few maps produced by a workgroup will be a significant effort, subsequent Glossaries should be much easier to develop as content from previous Glossaries is reused.

Classification of geologic materials

The traditional Description of Map Units conveys essential information about each map unit. As such, it is a cornerstone of the GeMS design. However, descriptions in the DMU vary in their content and format and commonly use specialized terminology that is unfamiliar to the non-geologist. Also, terminology may, for valid reasons, be used inconsistently from map to map. Over time, many attempts have been made to organize and standardize descriptions of geologic map-unit materials with the goals of improving our abilities to make regional compilation maps and convey geologic information to the public. Of necessity, such attempts are compromises that only partially describe the near-infinity of map-unit ages, compositions, textures, genesis, and appearance.

The North American Data Model Steering Committee (*http://ngmdb.usgs.gov/www-nadm/*), sponsored by USGS, AASG, and the Geological Survey of Canada, in 2004 defined a general, conceptual data model for geologic maps and a “Science Language” for describing various characteristics of earth materials. The summary report on science language is available at *http://pubs.usgs.gov/of/2004/1451/nadm/index.html*. The classifications presented in that report have been evaluated and adapted for many purposes; for example, the IUGS-CGI Geoscience Concept Definitions Working Group incorporated that work into a limited set of lithology categories (“SimpleLithology”) for use in GeoSciML interchange documents (see *https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/ConceptDefinitionsTG*).

A similar list of terms, named “StandardLithology” accompanied the initial release of NCGMP09 (version 1.0, ca. Oct., 2009). As with SimpleLithology, the StandardLithology term list was designed to be used with a companion list of ProportionTerms to encode the relative amounts of the numerous lithologies that might be found in each map unit. This approach encourages multiple lithology entries for a map unit, thereby allowing description of map units in detail. However, the level of effort required to populate the StandardLithology and ProportionTerms tables was judged by many reviewers of version 1.0 to be too high. Therefore, this approach was abandoned for NCGMP09 version 1.1 and for GeMS.

Regardless, we remain convinced that standardized terminologies are beneficial, largely because of their potential to:

1) Allow more-uniform portrayal of rock and sediment types across multiple maps.
2) Facilitate queries for the presence of a particular rock type. For example, by using a hierarchical classification, both the queried rock type and related rock types can be found. If “Lava flows” is queried, “felsic-composition lava flows" and “Igneous rock” may also be returned.

Bearing in mind the importance of providing the public a simple and systematic view of the Nation’s geology, NCGMP09 v.1.1 included, and GeMS retains, a simplified classification of earth materials based on general lithologic and genetic character. This classification, named GeneralLithology in NCGMP09 but renamed in GeMS as GeoMaterial, applies a *single* term to each map unit, providing information that a non-expert can quickly use to identify map units that contain similar materials. Although GeoMaterial is a required field in GeMS, it is not intended as a substitute for more detailed and precise lithologic terminology that might be included in the Description of Map Units text or in more detailed and specialized controlled-term lists – rather, its purpose is as stated briefly above, and in detail in Soller (2009).

The GeoMaterial classification has been developed empirically, based on commonly-occurring geologic materials. It serves to organize the many and varied geologic terms found in the source maps, and the wide-ranging geologic conditions across the Nation, in order to provide a consistent means of displaying map-unit materials. It was initially developed for the NGMDB Data Portal, a prototype site (ca. 2008) intended to raise discussion with NGMDB partners in the state geological surveys regarding how to provide the public with an integrated view of regional-scale geologic maps, with links to the source map information. Documentation of the original term list, including rationale, is provided in Soller (2009; *http://pubs.usgs.gov/of/2009/1298/pdf/usgs_of2009-1298_soller4.pdf*). For version 1.1 of NCGMP09, the GeneralLithology classification was slightly modified from the original. Based on six years of evaluation and test implementation by the state geological surveys and USGS, this classification was further modified slightly and renamed GeoMaterial for inclusion in GeMS version 2. **Given the lengthy period of evaluation, and the inherent challenges in modifying a controlled-term list (e.g., reconciling new changes with previously-published databases that used the classification), we do not in the near future anticipate further modifications to this list**.

For some purposes a single standard earth materials classification may not adequately address the geology of a given region in sufficient detail. Therefore, scientists may wish to attach more detailed, structured terminology to their research databases than is stipulated in the GeMS schema. A more structured controlled-term list might, for example, be desired in order to query the database for minor lithologies within a map unit that are not adequately indicated by the map unit name, its GeoMaterial term, or its Description. In such cases, evaluation of the salary and programming costs versus the research and societal benefits of including supplemental data tables and vocabularies may motivate a mapping project to extend the GeMS schema; if so, we advocate using an optional table of the geologist's own design, or the optional StandardLithology table described in Appendix B.

Feature-level metadata

All features in a geologic map database should be accompanied by an explicit record of the data source. Many features should also be accompanied by explicit statements of scientific confidence—for example, how confident is the author that a feature exists? Or that it is correctly identified? How confidently are feature attributes known? These are challenging questions to which the field geologist may not be comfortable providing an answer, except in the most general sense. We recognize this. But we also recognize that geologic information commonly is used in a GIS, in conjunction with other types of information (e.g., cadastral surveys, road networks, pipelines), and that terms such as "accurately located" have a markedly different meaning for a pipeline or property line than for a geologic contact. Thus, in order to provide a general indication of the confidence and locational accuracy of geologic-map features, GeMS implements per-feature descriptions of scientific confidence and locational accuracy. For more discussion of this topic, please see Section 4 of the FGDC Digital Cartographic Standard for Geologic Map Symbolization, FGDC-STD-013-2006, *http://ngmdb.usgs.gov/fgdc_gds/*.

In some cases, default confidence and locational accuracy values for an entire map are appropriate. Although default values may seem meaningless, changes in default values from map to adjacent maps, and between geologic and other (e.g., pipeline route) GIS layers, are likely to be informative to map users. As software tools evolve, we anticipate changing workflows that produce more detailed metadata.

Data source (provenance). Typically, a single map database will have very few data source records, because 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 commonly are uncertain. This may be because of error in locating observation points (because of, for example, GPS error or an imprecise base map), or because features are subtle and difficult to locate, or because the locations of features are known by inference from the locations of other observations. Such uncertainty could be expressed as uncertainty in absolute location (geodetic accuracy). However, 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, we choose to focus on location confidence relative to other data in the database, with the understanding that with a sufficiently large database this is equivalent to location confidence relative to the base map. We define location confidence (database field LocationConfidenceMeters) as the combination of error in positioning of a known point relative to the base map (how precisely do I know where I am?) and the uncertainty in location of a geologic feature relative to that known point (i.e., how precisely, relative to where I am, can this contact be placed?). For a well-exposed sharp contact, the second factor is zero and location confidence becomes equivalent to positioning error.

This usage differs from that advocated by section 4.2 of the FGDC standard, which suggests that spatial accuracy be expressed as three attributes: (1) locatability (with values of *observable*, *inferred*, or *concealed*); (2) zone of confidence (a distance, for example, equivalent to 1/25th of an inch at map scale; may be the same for all parts of a map or may vary spatially); and (3) positioning (with values of *within zone of confidence* or *may not be within zone of confidence*). We depart from the FGDC recommendation in order to create databases that are simpler to understand, less dependent upon visualization scale, and more informative (if a feature is not positioned within the zone of confidence, the FGDC standard does not include guidance for quantitatively recording how precisely the feature is located).

LocationConfidenceMeters should be reported as the estimated 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. Values of LocationConfidenceMeters are recorded as floating-point numbers because they are real, measurable quantities, not because they are precisely known. The example picklist (below) may provide some insight into how this field can be populated.

Example picklist for LocationConfidenceMeters

Value	*Comments*
5	*Appropriate for well-defined features located by clear-sky GPS, or by inspection of high-resolution topography (e.g., 1m or 2m lidar DEMs), or by inspection of large-scale, well-rectified orthophotographs (e.g., NAIP images)*
10	
25	*Reasonable value for locations established by inspection of 1:24,000 scale map, or by digitizing paper source maps of that scale*
50	*May be appropriate for some “approximate” lines on 1:24,000 scale maps. Other “approximate” lines on the same map may have value of 100 meters, or larger*
100	*Appropriate value for features digitized from 1:100,000 scale paper source maps*

250	*You really don't know where a feature is! Or you captured its location from a 1:250,000 scale source map*

This picklist is merely a suggestion. Use of other, or additional, values for LocationConfidenceMeters is acceptable. Where location confidence changes along the length of a line, it may be appropriate to split the line and assign different values of LocationConfidenceMeters to different segments. Even with a factor-of-two uncertainty, author-assigned values of LocationConfidenceMeters are preferable to an unreported value or a value assigned by a third party, perhaps years after the map was made.

Visualization of LocationConfidenceMeters with a proportional symbol, wherein the half-widths of semi-transparent underlays are equal to values of LocationConfidenceMeters, is a powerful tool for evaluating the appropriateness of assigned values as the map is being prepared.

In some cases, it may be impossible to assign values to LocationConfidenceMeters, particularly when transcribing legacy maps. In such cases this schema can use traditional qualitative descriptors of line accuracy via line (or point) Type values such as "contact, approximate" and their definition in the Glosssary table. A null value (e.g., -9; discussed below) may then be assigned to LocationConfidenceMeters. However, in most cases an experienced geologist can estimate values for LocationConfidenceMeters with sufficient accuracy and thereby produce a more usable database.

The positions of certain lines, such as map boundaries, commonly are calculated, not observed; for these lines, there is no positional uncertainty and LocationConfidenceMeters should be assigned a value of 0.0.

Scientific confidence, identify confidence, and existence 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 or 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. Similarly, fold hinge surface traces, dikes, and marker beds may 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.

GeMS 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 separate them, 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 other situations, tools to efficiently assign varying confidence values can be developed.

For most databases it is likely that all ExistenceConfidence and IdentityConfidence values will be either "certain" or "questionable," though this Standard allows values and definitions other than those given here:

Example picklist for IdentityConfidence

Value	Definition from FGDC-STD-013-2006, p. 16-17

certain	Identity of a feature can be determined using relevant observations and scientific judgment; therefore, one can be reasonably confident in the credibility of this interpretation.
questionable	Identity of a feature cannot be determined using relevant observations and scientific judgment; therefore, one cannot be reasonably confident in the credibility of this interpretation. For example, IdentityConfidence = questionable is appropriate when a geologist reasons "I can see some kind of planar feature that separates map units in this outcrop, but I cannot be certain if it is a contact or a fault."

Values of ExistenceConfidence and IdentityConfidence must be defined in the Glossary table that is a part of each GeMS database. For some digital transcriptions of legacy paper geologic maps, it may not be possible for the transcriber to assign values of ExistenceConfidence or IdentityConfidence, and these should be coded as "unspecified." Such values in a database of new mapping should be questioned during the review process.

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 of the radius of the error circle similar to the alpha_{95} value often reported for paleomagnetic directions. The OrientationPoints feature class includes an OrientationConfidenceDegrees field to record this uncertainty.

Working with multiple feature attributes. Some users of this schema will have experience with databases in which features have a single significant attribute (e.g., LTYPE) that defines the feature type and describes confidence. The multiple feature attributes prescribed here for feature-level metadata appear to require a significant increase in the amount of work needed to create a database. While this draft manuscript is not the place for workflow suggestions, note that simple modifications of existing workflows can greatly ease the assignment of multiple attributes to features. Features may be digitized and attributed with a single proxy, or key, attribute that is later used to drive the scripted assignment of multiple attributes. In ArcGIS, feature templates may be used to create features with common clusters of attribute values. A workflow that tracks the genesis of features, perhaps via the DataSource attribute, can be useful for bulk assignment of confidence attributes.

Naming database elements

Standardized database field names that clearly convey their meaning are critical to a functional database design. Names in GeMS have been chosen according to the following rules:

- Names convey content to the geoscientist, to the GIS practitioner, and to the public
- Long names are acceptable and informative
- Names are easy to code and calculate
- Names reflect data type
- Names use uniform concatenation protocol (PascalCase, the first letter of each word is in upper case)
- 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
- Some names point to related tables. Field names which contain "SourceID" are reserved for

foreign keys to the DataSources table

- Field names which contain "_ID" are reserved for primary keys. These are of the form *TableName_ID* or *FeatureClassName_ID*. These primary keys are maintained by the database creator, not the GIS software, and are used mostly to relate attributes stored in non-spatial tables to spatial features, and—optionally—to relate spatial features to additional, feature-specific attributes stored in other tables.

We have chosen to not encode the publication identity (map name or map series number) in the names of feature datasets and feature classes. Doing so would simplify the joint display of multiple publications in an ArcMap project because each layer name automatically includes the map identifier for the layer; that is clearly a long-term goal for this schema. However, for this version, our choice to use the same 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 databases. Layer names in an ArcMap project are easily changed to reflect the source database.

Transparent identifiers

Identifiers in the database for map units, line types, and point feature types should all have obvious plain-English meaning. The map-unit identifier is used as a foreign key from the DMU table to various other tables, and this should correspond to (but may not be the same as; see the discussion of Labels below) the unique label for that unit in map displays (e.g., "Qal"). (Entries in the DMU—such as headings—that are not symbolized on the map, CMU, or in a cross-section may have null map-unit values.) The type identifiers for lines and points are references to terms in the Glossary table, and we recommend that these simply be the geologic term for the line or point type represented. This is in contrast to common practice which dictates that identifiers used as foreign keys in a database are best implemented as numbers or text strings that have no inherent meaning to users; these commonly are referred to as opaque identifiers. Though opaque identifiers may be more robust, we assert that to facilitate comprehension and use of information from a database of a published geologic map, the use of human-interpretable identifiers is preferable. Note, however, that this specification does not prohibit the use of opaque identifiers, particularly for primary key (table_ID) values.

File formats

In principle, we encourage the use of open file formats, because: (1) open formats facilitate writing and redistribution of third-party code; (2) open formats reduce the risk of losing data when the format becomes 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 Arc/Info coverages to shapefiles and from shapefiles to ArcGIS personal, or file, geodatabases.

Our desire to endorse open file formats is overshadowed 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 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.

Text not contained in the database should be stored as plain text (.txt), Web markup (.htm/.html), Open Document Format (.odt, ISO/IEC 26300:2006 or its successor), or publication-formatted (.pdf) files, and should be managed with the GIS data. Tables may be stored in a wide variety of text formats (.csv, .dat, .txt), or as XML (.xml) files, which most modern database software can import. The venerable dBASE III (.dbf) format, integral to Esri shapefiles, has been abandoned by software developers and so is unchanging, and thus a reliable choice; there appears to be no published standard but documentation of the format is readily available. For images, the patent on LZW compression (commonly used in .tif or .gif images) has expired and patents that may have restricted the use of JPEG compression (.jpg images) have been found invalid, thus the choice between .png, .tif, .jpg, and .gif files for raster images should depend on technical considerations. Vector, or mixed vector-raster, images can be stored as .pdf or .svg files.

REQUIRED, AS-NEEDED, AND OPTIONAL CONTENTS OF A DIGITAL GEOLOGIC MAP PUBLICATION

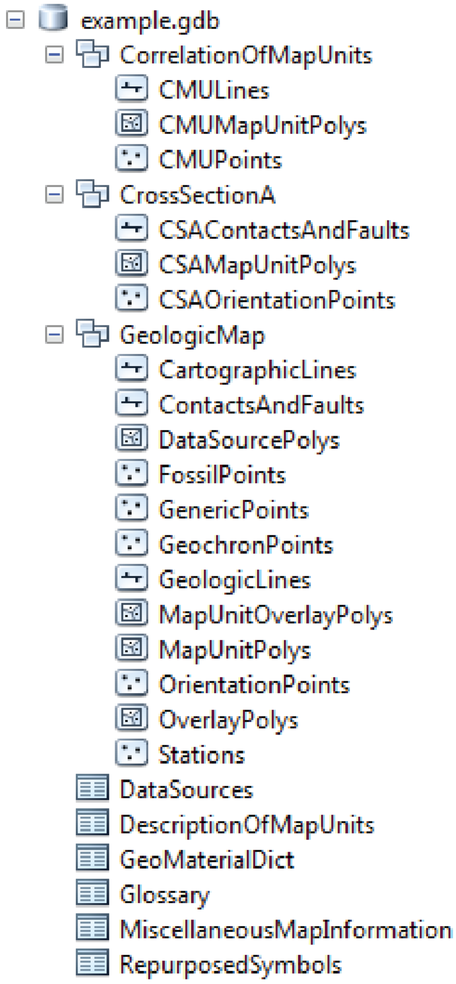
For a map publication named 'mapXYZ', the publication package should include the files described below. As-needed elements must be present if they are appropriate to the content of the map publication, e.g., if there is a Figure 1 in the map publication, then a file Figure1.png (or equivalent) must be 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; optional elements are not highlighted.

mapXYZ.pdf	*Reference map visualization. Publication quality*
mapXYZ-browse.png (.jpg, .tif)	*Browse graphic. A* ***small*** *file*
mapXYZ-pamphlet.pdf	*Map pamphlet*
mapXYZ-metadata.xml	*FGDC metadata. Metadata in a more readable form (e.g., .txt, .html) is recommended as a supplementary file*
mapXYZ-gdb.zip	*When unzipped, this file contains:*
mapXYZ.gdb *(file geodatabase folder)*	
mapXYZ.mxd	*ArcMap document stored with relative pathnames and including relevant macros*
mapXYZ.pmf	*ArcReader document*
resources (folder)	
figures (.png, .pdf, .tif)	
tables (.dbf, .ods, .xls)	
CMU (.pdf, .png, …)	Graphic representation of correlation of map units diagram. Note: eventually this may be superseded by required encoding of CMU within the map database
DMU (.pdf)	*Additional document for description of map units*

mapXYZ.style	*ArcGIS style file for area, line and marker symbols used in preferred symbolization of map. It is recommended that this be a subset of the FGDC geology symbol set. Please see the GeMS website for a suggested master style file and associated font files. Must include all symbols specified elsewhere in database. Include any non-standard font files referenced by the style file. Unnecessary if appropriate Esri Cartographic Representations are included in the database itself*
mapXYZ-pamphlet.pdf	*Map pamphlet; a copy of the file referenced above*
mapXYZ-base.gdb (folder or file)	*Base-map geospatial data; required if not published elsewhere*
mapXYZ-metadata.xml	*FGDC metadata; copy of file referenced above*
mapXYZ-simple.zip	*Simple version of database. See below for contents*
mapXYZ-open.zip	*Open version of database. See below for contents*

THE DATABASE DESIGN

As with the overall geologic map publication, there are required, as-needed, and optional elements in the single-map geologic map database (Figure 1). Required and as-needed elements are specified below. Optional elements are described in Appendix B. Note that additional optional elements are permitted by this schema. For each element (feature dataset, feature class, non-spatial table) we provide a name, identify the element type, and enumerate the fields (attributes) in the relevant table. Unless otherwise noted, all fields are of data type text (= string). 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.



example.gdb	
CorrelationOfMapUnits	optional
CMULines	optional
CMUMapUnitPolys	optional
CMUPoints	optional
CrossSectionA	optional
CSAContactsAndFaults	optional
CSAMapUnitPolys	optional
CSAOrientationPoints	optional
GeologicMap	**required**
CartographicLines	as needed
ContactsAndFaults	**required**
DataSourcePolys	as needed
FossilPoints	as needed
GenericPoints	as needed
GeochronPoints	as needed
GeologicLines	as needed
MapUnitOverlayPolys	as needed
MapUnitPolys	**required**
OrientationPoints	as needed
OverlayPolys	as needed
Stations	as needed
DataSources	**required**
DescriptionOfMapUnits	**required**
GeoMaterialDict	**required**
Glossary	**required**
MiscellaneousMapInformation	optional
RepurposedSymbols	as needed

Figure 1. Preliminary draft of ArcCatalog view of proposed GeMS-structured database, 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 can be more than one cross-section feature dataset, named CrossSectionA, CrossSectionB, etc.

General considerations

This design implies a relational database

This design relies on relations (joins or relationship classes) between various feature classes and non-spatial tables. These relations include:

- Feature class MapUnitPolys (via the field MapUnit) to DescriptionOfMapUnits (the field MapUnit) [many-to-one].
- All feature classes and some tables (via fields DataSourceID, LocationSourceID, AnalysisSourceID, DefinitionSourceID) to DataSources (field DataSource_ID) [many-to-one]
- All feature classes and some tables (via fields Type, ExistenceConfidence, IdentityConfidence, ScientificConfidence, …) to Glossary (field Term) [many-to-one]

Figure 2 shows the relationships among the elements of this design. The simple shapefile output version of the database (described below) provides a relate-free version of the data at the cost of truncation of long fields and omission of some database elements.

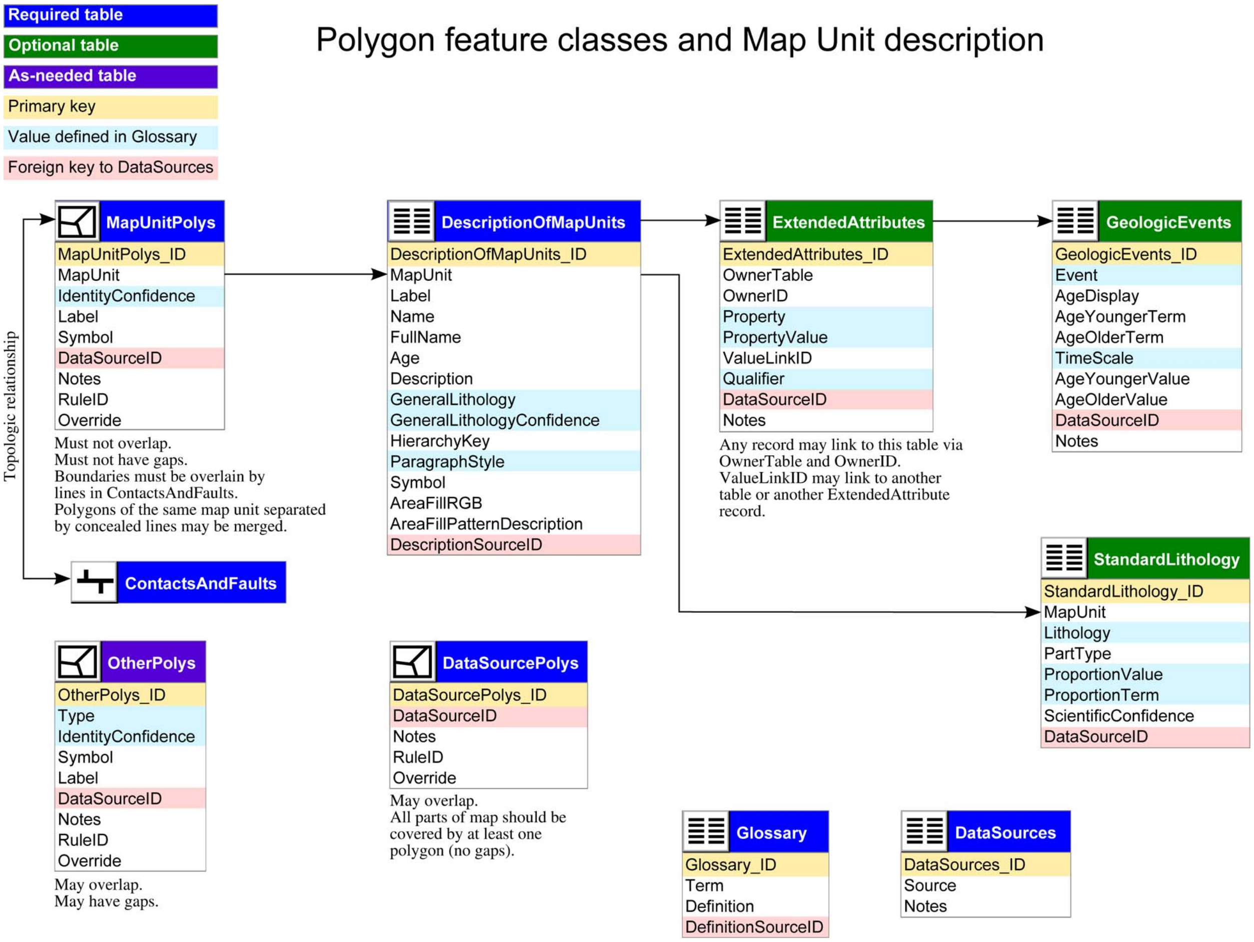


Figure 2A. Entity-relationship diagram NCGMP09 polygon feature classes and Map Unit description. (NOTE: this diagram has not yet been updated to the GeMS schema.)

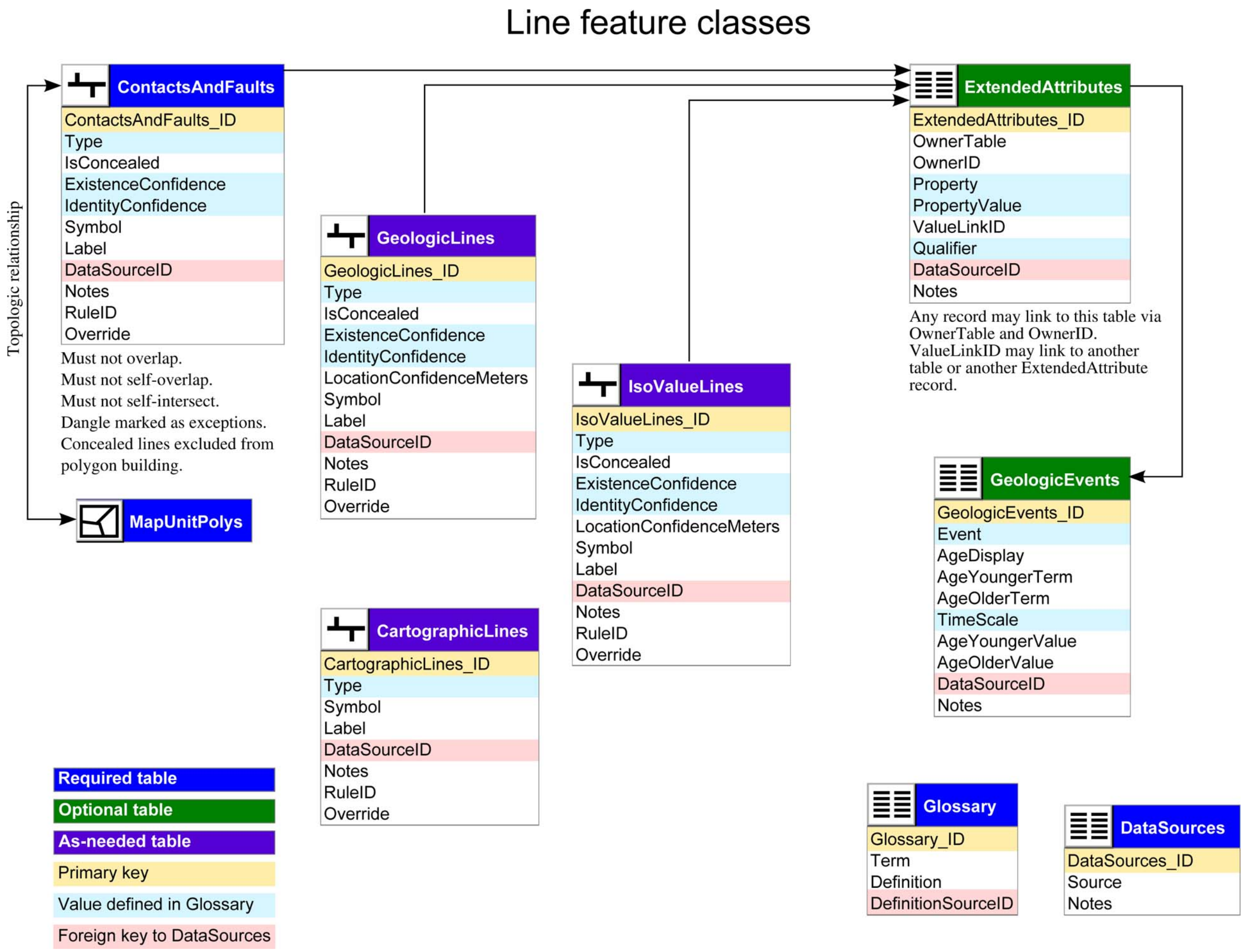


Figure 2B. Entity-relationship diagram NCGMP09 line feature classes. (NOTE: this diagram has not yet been updated to the GeMS schema.)

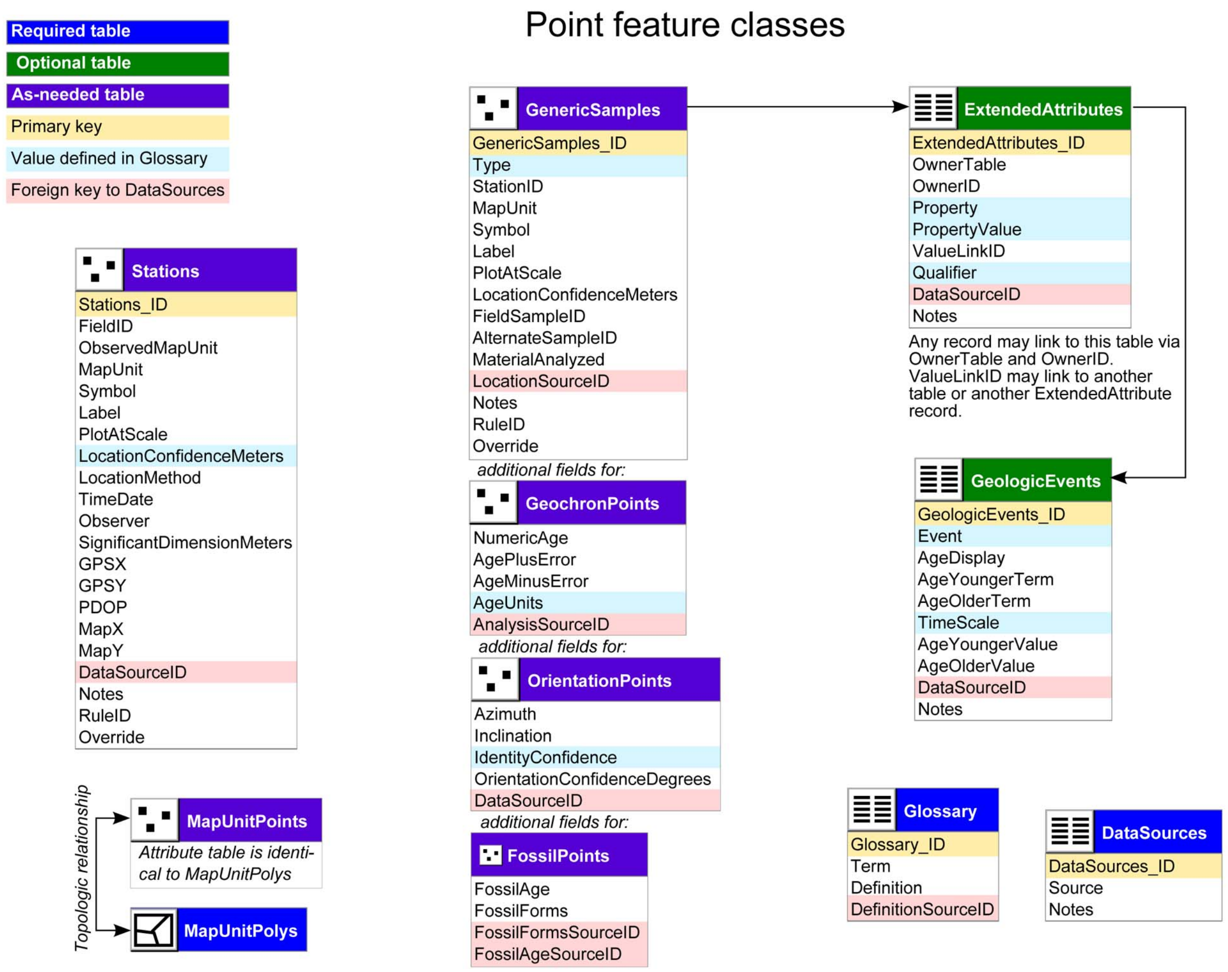


Figure 2C. Entity-relationship diagram for NCGMP09 point feature classes. (NOTE: this diagram has not yet been updated to the GeMS schema.)

Field hygiene

Required fields should not be deleted, even if all instances of the field are null (have no content). Deletion of required fields may create ambiguity: Is this a compliant database? Is the database incomplete or corrupted?

GeMS does not, in general, prescribe the lengths of text fields. Field lengths should be long enough to encompass all values and short enough to not unduly inflate database size.

Wherever a particular instance (row value) of a field is intended to have no content, this instance should be set to <null> if the underlying database software supports an explicit null value. Do not use an empty string for null values of text fields, or 0 for null values of numeric fields. If the database does not support <null>, use the text string “#null” for longer (≥5 character) text fields, “#” for short (<5 character) text fields, and -9 or -9999 for numeric fields. Be consistent: do not use both -9 and -9999 for null values of the same numeric field.

Fields should not be repurposed to hold other information. To store other attribute information in a table, you must add other fields. As noted below, such extensions to the database schema are encouraged.

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

For most feature classes, a Notes field is prescribed. This field is always optional and may be omitted if desired.

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

DataSources

Source	***Notes***	***DataSources_ID***
This report	<null>	DAS1
Smith, J.G., 1899, Geologic map of XYZ quadrangle: USGS GQ 9999, scale 1:125,000	Georeferenced and digitized by authors of this report	DAS2
Field work by A.B. Geolog, 2012-2015	<null>	DAS3
Field work by C.D. Nagt, 2014	<null>	DAS4

DescriptionOfMapUnits

MapUnit	***Name***	**…**	***DescriptionSourceID***	***DescriptionOfMapUnits_ID***
Qal	Alluvium	…	DAS1	DMU1
Qgd	Glacial drift	…	DAS1	DMU1

ContactsAndFaults

Type	***IsConcealed***	**…**	***DataSourceID***	***ContactsAndFaults_ID***
contact	N	…	DAS1	CAF001
thrust fault	Y	…	DAS2	CAF002

OrientationPoints

Type	***Azimuth***	**…**	***LocationSourceID***	***OrientationSourceID***	***OrientationPoints_ID***
bedding	73		DAS3	DAS3	ORP01
foliation	120		DAS4	DAS3	ORP02

Note that for ORP02, one worker determined the location, another the orientation of foliation, and the map author has chosen to distinguish these separate sources. Alternately, both OrientationSourceID and LocationSourceID could be DAS5, Source = “Field work, 2014, by A.B. Geolog and C.D. Nagt”

DataSources

If data loaded into the database do not already have user-managed primary keys, we suggest that primary key values be created from a three- or six-letter prefix based on the name of the containing table concatenated with an integer suffix unique to the containing table (e.g., for table MapUnitPolys, use prefix MUP; for ContactsAndFaults, use prefix CAF). The suffix could be the string representation of the Esri database-maintained ObjectID that is included in all feature classes and tables. This scheme provides unique identification across the database, as well as some human intelligibility of foreign keys.

Type, Label, and Symbol fields

Most feature classes contain fields *Type*, *Label*, and *Symbol*.

- *Type* is a classifier that specifies what kind of geologic feature is represented by a database element: for instance, a certain line within feature class ContactsAndFaults is a contact, or thrust fault, or water boundary; or a point in GeochronPoints represents a K-Ar date.
- *Label* is the plain-text equivalent of the desired annotation for a feature: for example “14 Ma”, or “^c” which (when used with the FGDC GeoAge font) results in the geologic map-unit label TRc .
- *Symbol* is a reference to a point marker, line symbol, or area-fill symbol that is used on the map graphic to denote the feature: perhaps a star for a K-Ar age locality, or a heavy black line for a fault.

This three-fold division of what at first glance may seem to be one entity is necessary because (1) values of Label commonly are very different from Type values or are formed by convolving Type and IdentityConfidence (e.g. “Qls” and “questionable” to show “Qls?”); (2) special characters, inappropriate for Type values, may be used to enable labeling; and (3) for line features, Symbol is determined by the combination of Type, LocationConfidenceMeters, ExistenceConfidence, and IdentityConfidence.

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, although faults may do so. Map-unit polygons may be partially bisected by a fault (i.e., using GIS jargon, the fault “dangles”).

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 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 database, and to facilitate topological queries when using a database.

Some maps 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 should be recorded in the feature class “ContactsAndFaults”, and be coded as IsConcealed = “Y”. Such concealed contacts and faults may not be involved in topology with MapUnit polygons. Concealed contacts and faults may dangle.

Many, but not all, geologic maps contain other classes of features that do not participate fully in map topology (e.g., fossil localities, fold axes, bedding orientation measurements). Feature classes for encoding such features are described below under “As-needed elements”.

Some producers of databases will choose to create polygons and edit linework in the absence of a topology relationship class. For instance, rather than using topology editing tools to synchronously edit shared boundaries between lines and polygons, many users prefer to create lines and then construct polygons as their bounding linesare finished, without the use of database topology rules. For the purposes of this data delivery design, 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 below.

Directional lines

Many geologic lines have directionality, equivalent to handedness. Examples are thrust and normal faults, which by convention have ornaments (teeth, tics, bar-and-ball markings) that point toward the upper (overlying) plate. We prescribe the right-hand rule to store this directionality: such lines should be created or edited so that any ornament, or the upper direction in the case of U-D labels on faults, is to the right of the line while traveling from the start of the line to the end of the line.

Required elements

GeologicMap (feature dataset)

This is equivalent to the map graphic: it contains all the geologic content within the neatline, without the basemap. All elements share a single spatial reference framework. Blue highlighting indicates fields whose content must be defined in the Glossary table.

MapUnitPolys (polygon feature class)

Fields:

MapUnit	*Short plain-text key (identifier) for the map unit. Example values: "Qal", "Tg", "Kit", "water", "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 "certain", "questionable", or "unspecified". Null values not permitted. Suggest setting default value to "certain"*
Label	*Determined from the appropriate value of the Label in the DescriptionOfMapUnits table and IdentityConfidence: if IdentityConfidence = "questionable", then append "?" to Label value from the DescriptionOfMapUnits table. Allows for subscripts and special characters. Null values permitted*
Symbol	*References an area fill symbol (background color + optional pattern). Area fill symbols must be defined in an accompanying style file. If Esri Cartographic Representations are used to symbolize map units, the value may be null or blank. Null values permitted*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*
Notes	*Optional field. Free text for additional information specific to this polygon. Null values permitted*

MapUnitPolys_ID	*Primary key. Example Values = MUP1, MUP2, MUP3, etc. Values must be unique in database. Null values not permitted*

Topology rules:

- Polygons must not overlap
- No gaps between polygons
- Boundaries must be overlain by lines in ContactsAndFaults

Note that not all lines in ContactsAndFaults necessarily bound polygons: polygons separated by concealed contacts or faults may have been merged during construction of the database; also some faults, concealed contacts, and concealed faults may dangle (terminate within polygons) and thus not separate polygons. Note also that open water (lakes, double-line rivers), glaciers, and unmapped areas are polygons, and so must have non-null MapUnit values (e.g., water, glacier, unmapped). Water and glacier areas commonly are not labeled (Label=null).

ContactsAndFaults (line feature class)

Fields:

Type	*Specifies the kind of feature represented by the line. Values could be, for example, 'contact', 'fault', 'waterline', 'glacier boundary', 'map boundary'. Values must be defined in Glossary. Null values not permitted*
IsConcealed	*Values = 'N', 'Y'. This is a flag for contacts and faults covered by an overlying map unit. Null values not permitted*
LocationConfidenceMeters	*Data type = float. Half-width in meters of positional uncertainty envelope; position is relative to other features in database. Null values not permitted. Recommend value of -9 if value is not available. See discussion in "Feature-level metadata", above*
ExistenceConfidence	*Values = 'certain', 'questionable', 'unspecified'. Null values not permitted. Suggest setting default value = 'certain'*
IdentityConfidence	*Values: 'certain' , 'questionable, 'unspecified''. Null values not permitted. Suggest setting default value = 'certain'*
Label	*Can be used to store fault name, or human-readable name for a line feature. To group line segments into a specific structure trace, e.g."San Andreas Fault", use optional Extended Attributes table. Typically null*
Symbol	*References a symbol in the accompanying style file. Calculated from Type, LocationConfidenceMeters, ExistenceConfidence, IdentityConfidence, and most appropriate map display scale. Null values permitted*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*
Notes	*Optional field. Free text for additional information specific to this feature. Null values permitted*
ContactsAndFaults_ID	*Primary key. Example values = CAF1, CAF2, etc. Values must be unique in database*

Topology rules:

- Must not overlap.
- Must not self-overlap.
- Must not self-intersect.
- Must not have dangles, with certain exceptions. Most dangling-line exceptions should be Type=’fault’ or be Type=’contact’ and IsConcealed = ‘Y’.

Map boundaries, open water boundaries, and snowfield and glacier boundaries delineate the edge of certain map unit polygons and in this sense are contacts. Therefore, they are included in this feature class. Map-unit-bounding fault lines are legitimate elements of this feature class and should not be coincident with contacts.

Lines symbolized as “contact”, “contact inferred” and “contact approximately located” are Type = “contact”, but have differing LocationConfidenceMeters, ExistenceConfidence, and (or) IdentityConfidence. Their symbolization may change with map scale.

We recommend using “blank” as the value of Symbol for scratch boundaries (where no line is drawn between adjoining polygons, also known as wash boundaries); scratch boundaries are occasionally used for contacts with exceptionally large values of LocationConfidenceMeters.

Suggested values for Type include:

contact
contact, internal
contact, gradational
contact, unconformable
fault
fault, normal
fault, reverse
fault, thrust
scratch boundary
glacier boundary
waterline
map boundary (or, map neatline)

This list is derived from the FGDC standard, sections 1, 2, 30, and 31. Other values certainly are possible (e.g., see FaultType and ContactType vocabularies at *https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/ConceptDefinitionsTG*). In all cases, note that modifiers such as “approximate”, “certain”, “concealed”, and “queried” are not encoded in Type. These modifiers reflect the convolution of LocationConfidenceMeters, ExistenceConfidence, IdentifyConfidence, and the scale. The description of a contact as “approximate” is not literally preserved in a GeMS database; this information is preserved with the appropriate value of LocationConfidenceMeters. When migrating an existing map into the GeMS schema it is often convenient to store “contact, approximate” in a temporary field (e.g., LTYPE) that is later parsed to calculate values of Type, LocationConfidenceMeters, etc.

DescriptionOfMapUnits (non-spatial table)

This table captures the content of the Description of Map Units or equivalent List of Map Units (LMU) and associated descriptions in a pamphlet, if that is included in a geologic map.

Fields:

MapUnit	*Short plain-text key (identifier) for the map unit. Example values: “Qal”, “Tg”, “Kit”, “water”, “Trc3”, etc. Values in this field are the link (foreign key) between this table and the MapUnitPolygon table. Null values permitted, and are commonly associated with headings or headnotes. Use of special characters is not*

	recommended in this field
Name	*Boldface name in traditional DMU, identifies the unit within its hierarchical context. Examples: 'Chinle Formation', 'Shnabkaib Member'. Text in the Name field should have initial capitalization only and no font specification—these are given by ParagraphStyle and Glossary. Formal 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. Place headings in this field and place accompanying headnote text, if any, in the Description field. Null values permitted*
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 permitted (e.g., for headings, headnotes, geologic units not shown on map)*
Age	*As shown in traditional DMU (commonly as bold text within parentheses). Use null values for headings and headnotes*
Description	*Free-format text description of map unit. Commonly terse and structured according to one or more accepted traditions (e.g., lithology, thickness, color, weathering and outcrop characteristics, distinguishing features, genesis, age constraints). Allows markup (e.g., HTML) specification of new paragraphs, superscripts and subscripts, and geologic-age font (sans-serif and with special characters). Place headnote text in this field. Null values permitted*
HierarchyKey	*Text string with form nn-nn-nn, nnn-nnn, or similar. Each fragment is numeric, of the same length, left-padded with zeros, and dash-delimited. 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. Appendix C illustrates the use of HierarchyKey to describe the structure of Description of Map Units for several maps*
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*
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=FGDCGeoAge>#n". Null values permitted for units that do not appear on map or are not labeled, e.g., headings, headnotes, water, glacier, some overlay units*
Symbol	*References an area fill symbol in the accompanying style file that is used for symbolizing the unit on the map.*
AreaFillRGB	*{Red, Green, Blue} tuples that specify the suggested color (e.g., '255,255,255', '124,005,255') of area fill for symbolizing this MapUnit. Use of consistent syntax is important to enable computer programs to read this field and display intended color. Each color value is an integer between 0 and 255; values are zero-padded so that there are 3 digits to each R, G, and B value; and color values are separated by commas with no space: NNN,NNN,NNN. Especially important to non-Esri users unable to use the .style file. Null values permitted (e.g., for 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 permitted (e.g., for headings, headnotes, unpatterned map units)*
DescriptionSourceID	*Foreign key to DataSources. Identifies source of DescriptionOfMapUnits entry. Null values not permitted*
GeoMaterial	*Term to categorize the map unit based on lithologic and genetic character, from NGMDB standard term list (*Appendix A*); see also discussion in "Extensions to traditional geologic map content", above. Null values permitted for headings and unmapped units*
GeoMaterialConfidence	*Describes appropriateness of GeoMaterial term for describing the map unit (Appendix A). Null values permitted for headings and unmapped units*
DescriptionOfMapUnits_ID	*Primary key: DMU1, DMU2, DMU3. 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. This table encodes the traditional DMU as specified in Suggestions to Authors (Hansen, 1991, p. 49-52) without loss of information and—with one exception (GeoMaterial)—without imposing additional structure or content.

Note on contents of Description field

The text in the Description field in the DMU is an essential part of this database schema, just as it has always been an essential part of the printed map. This schema does not prescribe the form or content of such descriptions; however, there is a long tradition that may be useful to describe here. *Suggestion to Authors of the Reports of the United States Geological Survey* (Hansen, 1991) states:

> The "Description of Map Units" is an abbreviated account of the lithology, color, and thickness of the rocks in each unit. (p. 49)
>
> Where space is available, an expanded "Description of Map Units" giving stratigraphic detail is desirable. Detail may include information such as lithologic content, color, grain size, bedding characteristics, porosity, permeability, fracture characteristics, mineral or fossil content, remanent magnetization, and thickness. Correlation with other units, nature of contacts, radiometric or other age determinations, and sources of specific information (citations) may be provided. (p. 187).
>
> Stratigraphic details … should be limited to data from within the map area, although brief correlations with rock units in adjacent areas may be appropriate. References may be included. Descriptions should use telegraphic style; nonessential articles ("a," "an," "the") may be deleted; complete sentences are unnecessary. To separate ideas, periods or semicolons may be better than conjunctions. Let brevity and good judgment decide. The description may be paragraphed. Periods are omitted at the end of each entry or paragraph.
>
> The order of describing lithology may differ from map to map, but it should be consistent within a given "Description of Map Units." If entries are fairly short and no lithology predominates, normal word order reads more smoothly than inverted order ("Sandy green shale and silty gray sandstone"), but if an entry is long and has a string of modifiers, inverted sentence structure is easier to follow:

> **Curtis Formation (Jurassic)**—Interbedded sandstone, shale, and limestone. Sandstone, light-gray, fine- to coarse-grained, poorly sorted, and thickly bedded. Shale, pale- green…
>
> Features that characterize a unit, such as color, permeability, or gradations in grain size, also modify the lithologic term; other information follows (magnetization, fossil or mineral content, age, and so on). The order in which these subsidiary features are listed may depend on their significance in the mind of the author, but usage should be consistent throughout the description. (p. 187)

R.E. Wells (USGS, written communication 2010) suggests the following basic order for descriptions in the DMU: lithology (dominant and subordinate); color; induration; grain size; mineralogy; bedding characteristics; interpreted facies; unit thickness; nature of contacts; fossil content/stage/zone; magnetic polarity; correlation with other units; radiometric age; data sources where needed. Not all DMUs need all of these; volcanic rocks, plutonic rocks, metamorphic rocks, and surficial deposits require somewhat different approaches, but the main features articulated by Wells are relevant for most map units.

We further note that DMU descriptions should emphasize the essential character of each unit and how it is distinguished in the field from nearby units. In poorly exposed terrain it can be a challenge to write a map unit description that accurately expresses no more than what little is known about a map unit.

We have added GeoMaterial and GeoMaterialConfidence fields to the DMU table in order to provide a foundation for simple, regional, lithologic queries. GeoMaterial is not a replacement for the free-text Description described above.We see no benefit in segregating this summary lithologic information from the "source" information (i.e., the Description); including both in this Table permits users to more readily assess the GeoMaterial term selected for each map unit. Additional lithologic information may be included in a user-defined table or in the optional StandardLithology table (see Appendix B. Optional Elements).

Implementation

All map units and overlay units assigned to polygons on the map (or in any of the cross sections), and all headings and headnotes beneath "DESCRIPTION OF MAP UNITS" (or LIST OF MAP UNITS) have an entry in this table. 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 should be stored in the Name field. Any accompanying headnote text should be placed in the accompanying Description field. An example translation of part of a traditional DESCRIPTION OF MAP UNITS text into the DMU table is given in Appendix C.

Order and hierarchy in a Description of Map Units carry a significant amount of information. In the DMU table this is expressed by values of HierarchyKey. Examples of HierarchyKey and its construction are given in Appendix C.

As a practical matter, paragraph styles and values of the ParagraphStyle field should correspond to the styles prescribed by an organization's publication group. If templates for these styles are available, they may incorporated into a script that automates much—if not all—of the construction of a traditional text DMU or LMU from DescriptionOfMapUnits. ParagraphStyle values can usually be calculated from HierarchyKey, text in the Description field, and feature class MapUnitPolys. An exception is the use of group or formation terms as headings or, alternately, as unmapped map units of which only the constituent formations or members are mapped; ParagraphStyle is necessary to describe which use is the author's intent. 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>'.

DataSources (non-spatial table)

Fields:

Source	*Terse, plain-text description that identifies the data source. By convention, for DataSources_ID = DAS1, Source = 'This report'. Null values not permitted*
Notes	*Optional field. Notes on source, providing more complete description of processing or data acquisition procedure. Can include a full citation. Null values permitted*
URL	*Optional field. Link, either an online URL or Digital Object Identifier (DOI) to the data source or a full description of the data source. Null values permitted*
DataSources_ID	*Primary key. Example values = DAS1, DAS2, DAS3, ... Null values not permitted*

Some example DataSources records:

Source	**Notes**	**DataSources_ID**
This report	Field compilation automated by A. Digitdroid, using georeferenced scan of green-line mylar, Esri ArcScan tools, and manual editing	DAS1
This report, interpreted from 6ft lidar DEM	Data acquired winter 2003-2004 by Puget Sound Lidar Consortium	DAS2
This report, Ralph Haugerud field data, 2005		DAS3
USGS Open-file Report 2004-197		DAS4
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	DAS5
Beta Laboratories, Report 1999-451.	K-Ar dates determined using constants from Dalrymple, 1985.	DAS6
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.	DAS7
Modified from DAS4	S. Richard digitized 3 new large landslides based on 2006 air photography.	DAS8

All features and table entries must 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 that have been edited and (or) reinterpreted so that the data source has effectively been changed, this table becomes longer and more useful.

GeoMaterialDict (non-spatial table)

Fields:

HierarchyKey	*Text string with form nn-nn, nn-nn-nn, or similar. Each fragment is numeric, of the same length, left-padded with zeros, and dash-delimited. These strings document hierarchical relationships within this table*
GeoMaterial	*Name of a GeoMaterial; values used to populate GeoMaterial field in DescriptionOfMapUnits table*
IndentedName	*GeoMaterial name with indentation, useful for understanding the hierarchy of GeoMaterial terms*
Definition	*Plain-language definition of GeoMaterial*

This table provides definitions and a hierarchy for GeoMaterial names prescribed by the GeMS database schema. The table is available at http://ngmdb.usgs.gov/Info/standards/GeMS/, and is installed in any database created with the GeMS CreateDatabase script. Users of the GeMS schema do not create this table. This table need not, and should not, be modified by authors and publishers of individual maps.

Glossary (non-spatial table)

Fields:

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

Some example Glossary records:

Term	Definition	DefinitionSourceID	Glossary_ID
contact	Line denoting unfaulted boundary (depositional, intrusive, metamorphic...) between two geologic map units	DAS1	GL001
Biotite isograd	Line marking first appearance, going up-grade, of newly formed biotite in metamorphosed siltstones and shales	DAS1	GL002

Terms that require definition include all values of Type, ExistenceConfidence, IdentityConfidence, ScientificConfidence, ParagraphStyle, and AgeUnits. 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 for definitions via the DefinitionSourceID. If such restrictions preclude including a definition in the glossary, the term should still be present, with a note in the definition field to refer the reader to the publication cited in the definition-source record. 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.

As-needed elements

Some geologic maps contain types of features that do not directly participate in map topology. If such features are present in a geologic map report, they should be digitally encoded in the map database. If such elements are not present, the corresponding feature classes need not be part of the database, thus these feature classes are *as-needed* elements. Such features include foliation, lineation, and bedding measurements; sample localities; various sample-based fossil, geochemical, and geochronological analyses; localities of field photographs; fold axes (more precisely, traces of fold hinge surfaces); structure contours; concentration contours; cross-section lines; former ice limits and ice flow lines; and areas of mineralization or manmade fill (both commonly depicted as overprints).

There are many such feature types and there are many ways to partition these types into feature classes. At one extreme, each feature type can be represented by a separate feature class—in which case, the Type attribute of the feature class becomes redundant. At the other extreme, all feature types with the same geometry (point, line, polygon) can be assigned to a single feature class and differentiated by the Type attribute. In this case, there is a temptation to add a plethora of attributes to the feature class, many of which are likely to be unpopulated for many features. In discussions with colleagues we have been unable to agree on a “best” partitioning: different database use-cases suggest different partitioning. For this reason we do not prescribe such as-needed feature classes. Instead we present guidelines for designing and naming feature classes, discuss principles that govern the structure of point data, and describe several examples of as-needed feature classes. All of these feature classes reside within the GeologicMap feature dataset.

Guidelines for naming and designing additional feature classes

- The feature class name should emphasize the identity of the class.
- The feature class name will include “Points”, “Lines”, or “Polys” except where this is redundant (Stations, not StationPoints).
- Feature class names and attribute names will commonly be compound words. Compound words will be written in PascalCase, without spaces or underscores.
- Every feature class will have a primary key field named *FeatureClassName*_ID. This is the sole exception to the “no underscores” guideline.
- Every feature class will have at least one sourceID field. If each feature has a single source, this field will typically be named “DataSourceID”. If the data source is compound (e.g., sample analyses, for which the sample location commonly has a different source than the associated sample analysis), there should be multiple sourceID fields, (e.g., LocationSourceID and AnalysisSourceID).
- ExistenceConfidence, IdentityConfidence, LocationConfidenceMeters, and similar confidence fields will be included as appropriate.
- Measured attributes, or attributes that represent real-world quantities (strike, dip, concentration, location confidence) will be data type = float. It may be necessary to define, and document in the feature-class metadata, conventions for representing null values, e.g., -9 = “Not available”.
- All attributes of a feature class should be populated for most features. If a feature class has one or

more attributes that are not applicable to some subset of features in the class, consider splitting the class into multiple classes, each with a more appropriate subset of attributes. If some attributes have many null values because the information is not available, consider representing this attribute using the ExtendedAttributes table, which is described in the documentation for NCGMP09 v.1.1.

- Consider combining small feature classes that have common attribute structures.

The remainder of this section describes the as-needed feature classes OrientationPoints, GeochronPoints, Stations, GeologicLines, CartographicLines, IsoValueLines, and OtherPolys. Other possible as-needed feature classes include GeochemPoints, PhotoPoints, FieldNotePoints, SamplePoints, FossilPoints, FoldLines, and DikeLines. We request your comments on this set of feature classes and names, in order to help converge on standard naming conventions; please send comments to gems@usgs.gov.

Structure of point data

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

1. A normalized mode, in which a “Stations” feature class stores location information and data specific to the station, 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.
2. A denormalized mode, in which there is a separate feature class for each type of observation or analysis that requires a special attribute structure and that in some cases duplicates station location and sample information.

Each mode has advantages. The first allows error-resistant editing of location and sample information (the station data is recorded in only one place) and is well suited for a data management and archiving system. The second facilitates symbolization and organization of data in map layers in a GIS viewing environment with no joins or filtering required, and is more convenient for exporting analytical information from a source database by simply copying the relevant feature class.

Because GeMS is designed primarily for publishing, not creating, geologic map data, we endorse the second mode. We note that to create a compliant database it may be useful to start in the first mode, creating a Stations point feature class with related 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. Below, we recommend 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.

Point feature classes in general

Each point feature class shall contain the following fields:

Type	*Values must be defined in Glossary or by reference to external glossary. Null values not permitted*

Symbol	*References a symbol in the accompanying style file. Null values permitted*
Label	*Text to accompany the symbol. For structure data this is typically the dip or plunge of the measured orientation. Null values permitted*
LocationConfidenceMeters	*Data type = float. Radius in meters of positional uncertainty envelope for location of the observation or sample locale. Null values not permitted. Recommend value of -9 if value is not available*
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, default value is 0 (display at all scales)*
StationID	*Foreign key to* Stations *point feature class. If the table represents stations, this field is not required—it would duplicate the Stations_ID primary key field. Null values permitted*
MapUnit	*It is useful to know the map unit to which an analysis or observation pertains. Value obtained by intersection with feature class MapUnitPolys. Foreign key to* DescriptionOfMapUnits. *Null values permitted*
Notes	*Optional field. Null values permitted. Free text for additional information specific to this feature*
TableName_ID	*Primary Key. Substitute actual table name for 'TableName'. Null values not permitted*

MapUnit, obtained by overlay with feature class MapUnitPolys, is included so that a point feature classes may be taken from its host database and used elsewhere while retaining some context for the point features. Values should not be null, except for points that lie outside the extent of MapUnitPolys.

Sample-oriented point feature classes shall also have the fields:

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

Some examples of as-needed feature classes

OrientationPoints (point feature class)

Point structure data (bedding attitudes, foliation attitudes, slip vectors measured at a point, etc.) may be recorded in OrientationPoints, one point per measurement. This table has fields:

Type	*Values must be defined in* Glossary *or by reference to external glossary. 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 to 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) should have Inclination=0. Null values not permitted*
Symbol	*References a symbol in the accompanying style file. Null values permitted*
Label	*Text to accompany displayed symbol, typically the dip or plunge value for the measured orientation. Null values permitted*
LocationConfidenceMeters	*Data type = float. Radius in meters of positional uncertainty envelope for the observation locale. Null values not permitted. Recommended value is -9 if value is not otherwise available*
IdentityConfidence	*Values = 'certain', 'questionable', 'unspecified'. 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*
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, default value is 0 (display at all scales)*
StationID	*Foreign key to* Stations *point feature class. If the table represents stations, this field is not required—it would duplicate the Stations_ID primary key field. Null values permitted*
MapUnit	*It is useful to know the map unit to which an analysis or observation pertains. Value obtained by intersection with feature class MapUnitPolys. Foreign key to* DescriptionOfMapUnits. *Null values permitted*
LocationSourceID	*Foreign key to DataSources. Identifies source of location of this point. Null values not permitted*
OrientationSourceID	*Foreign key to DataSources. Identifies source of orientation data at this point. Null values not permitted*
Notes	*Optional field. Free text for additional information specific to this feature. Null values permitted*
OrientationPoints_ID	*Primary Key. Example values = ORP1, ORP2, ORP3, … 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 and dip, trend and plunge, dip direction and dip, etc.). Data creators should ensure that multiple measurements at a single station (e.g., bedding and cleavage) have the same StationID.

GeochronPoints (point feature class)

Type	*The geochronological method (K-Ar, radiocarbon, mineral - whole-rock Rb-Sr isochron,*

	etc.) used to estimate the age. Values must be defined in Glossary *or by reference to external glossary. Null values not permitted*
FieldSampleID	Null values permitted
AlternateSampleID	Null values permitted
MapUnit	*Map unit from which the analyzed sample was collected. Value obtained by intersection with feature class MapUnitPolys. Foreign key to* DescriptionOfMapUnits. *Null values not permitted*
Symbol	*References a symbol in the accompanying style file. Null values permitted*
Label	*What text should accompany the symbolization? Null values permitted*
LocationConfidenceMeters	*Data type = float. Radius in meters of positional uncertainty envelope. How well located is the observation or sample locale? Null values not permitted. Recommend value of -9 if value is not available*
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, default value is 0 (display at all scales)*
MaterialAnalyzed	*Null values permitted*
NumericAge	*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 permitted*
AgeMinusError	*Data type = float. Record type of error (RMSE, 1 sigma, 2 sigma, 95% confidence limit) in Notes field. Null values permitted*
AgeUnits	*Units for numeric values in NumericAge, AgePlusError, and AgeMinusError. Values = years, Ma, ka, radiocarbon ka, calibrated ka, etc. These values shall be defined in* Glossary. *Null values not permitted*
StationID	*Foreign key to Stations point feature class. Null values OK*
LocationSourceID	*Foreign key to DataSources. Identifies source of location for this point. Null values not permitted*
AnalysisSourceID	*Foreign key to DataSources. Identifies source of analytical data for this sample. Null values not permitted*
Notes	*Optional Field. Free text for additional information specific to this feature. Null values permitted*
GeochronPoints_ID	*Primary key. Values = GCR1, GCR2, GCR3, … Null values not permitted*

Analytical data may be represented using the ExtendedAttributes table (see NCGMP09 v.1.1), or in an analysis-specific table such as KArPoints if there are many data with a single analysis type.

Stations (point feature class)

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

Fields:

FieldID	*Identifier assigned by person who originally located the station, e.g., DRS09-234. Commonly a key to a field sheet and (or) field notebook*
LocationConfidenceMeters	*Data type = float. Radius in meters of positional uncertainty envelope. Null values not permitted. Recommend value of -9 if value is not available*
ObservedMapUnit	*The map unit identified in the field (or interpreted from remote sensing) as outcropping at the station. Foreign key to* DescriptionOfMapUnits. *Null values permitted*
MapUnit	*Unit on map in which the station is located. Value obtained by intersection with feature class MapUnitPolys. Foreign key to* DescriptionOfMapUnits. *Null values not permitted*
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. Null values OK*
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. Default value is 0 (display at all scales)*
DataSourceID	*Foreign key to* DataSources *table, to track provenance of each data element. Null values not permitted*
Notes	*Optional field. FreeText; any observation narrative associated with station. Null values permitted*
Stations_ID	*Primary Key. Example values = STA1, STA2, STA3 ... Unique in database. Null values not permitted*

ObservedMapUnit is provided because occasionally a station is in a geologic-unit exposure that is too small to map as distinct from the surrounding map unit, or is identified as in one map unit in the field and later reinterpreted as in another map unit, or because stations and samples are at depth (e.g., in pit exposure, borehole, or bluff) and the observed geologic unit is not that which is shown on the geologic map (i.e., the MapUnit).

A stations point feature class might also include these fields:

TimeDate	*Time and date of observation at station*
Observer	*Name and affiliation of the person who located station*
SignificantDimensionMeters	*Significant dimension of exposure (e.g., thickness of stratigraphic section or depth of auger hole), in meters. Null values permitted*
LocationMethod	*Term that categorizes technique used to determine station location. Example values = 'Recreational GPS', 'Survey grade GPS', 'By inspection', 'By offset', ... Terms must be defined in Glossary table.*
GPSX	Measured GPS coordinate (easting). *May differ from map coordinate because of GPS error or (more likely) base map error*
GPSY	Measured GPS coordinate (northing). *May differ from map coordinate because of GPS error or (more likely) base map error*

PDOP	*Data type=float. Predicted Dilution Of Precision; an estimator of GPS accuracy*
MapX	*Station coordinate (easting) as compiled on the base map; base map should be identified in the* DataSources *record*
MapY	*Station coordinate (northing) as compiled on the base map; base map should be identified in the* DataSources *record*

GeologicLines (line feature class)

Dikes, coal seams, ash beds, other kinds of key beds, anticline and syncline hinge-surface traces, and isograds commonly are shown on geologic maps as lines that share three properties:

(a) They do not participate in map-unit topology

(b) They correspond to features that exist within the Earth and may be concealed beneath younger, covering material; and

(c) They are likely to be located with an accuracy that can be estimated.

Feature class GeologicLines suffices to store such features. It has fields:

Type	*Values for example could be 'syncline hinge surface trace', 'biotite isograd', ... Values must be defined in Glossary or by reference to external glossary. Null values not permitted*
IsConcealed	*Values = 'N', 'Y'. Identifies lines covered by overlying map unit. Null values not permitted*
LocationConfidenceMeters	*Data type = float. Half width in meters of positional uncertainty envelope. Null values not permitted. Recommend value of -9 if value is not available*
ExistenceConfidence	*Values = 'certain', 'questionable', 'unspecified'. Null values not permitted. Suggest setting default value = 'certain'*
IdentityConfidence	*Values: 'certain', 'questionable', 'unspecified'. Null values not permitted. Suggest setting default value = 'certain'*
Symbol	*References a symbol in the accompanying style file. Determined from Type, IsConcealed, LocationConfidenceMeters, ExistenceConfidence, IdentityConfidence, and expected visualization scale*
Label	*Typically blank, can be used to store name of fold, or other human-readable name for each line feature. To group line segments (e.g., concealed and not-concealed segments) into a specific structure trace, the optional* ExtendedAttributes *table (see documentation for NCGMP09 v1.1) can be used. Null values permitted*
DataSourceID	*Foreign key to* DataSources *table, to track provenance of each data element. Null values not permitted*
Notes	*Optional field. Free text for additional information specific to this feature. Null values permitted*
GeologicLines_ID	*Primary key. Values = GEL1, GEL2, GEL3, ... Values must be unique in database as a whole. Null values not permitted*

Topology rules:

- Must not self-overlap.

- Must not self-intersect.

'Anticline', 'approximately located anticline', 'concealed anticline', and 'inferred anticline' are all Type = 'anticline' but have differing values of IsConcealed, LocationConfidenceMeters, ExistenceConfidence, and (or) IdentityConfidence.

Note that these features could be divided thematically into several feature classes, e.g., into FoldLines, KeyBedLines, DikeLines, and IsogradLines.

CartographicLines (line feature class)

Some lines on maps (e.g., cross-section lines) have no real-world physical existence, such that LocationConfidenceMeters, ExistenceConfidence, and IdentityConfidence attributes are meaningless. Further, they are never shown as concealed beneath a covering unit, and do not participate in map-unit topology. These lines can be stored in a CartographicLines feature class with fields:

Type	*Term that categorizes what the line represents. Values must be defined in* Glossary *table. Null values not permitted*
Symbol	*References a symbol in the accompanying style file. May be determined from Type*
Label	*Typically blank, can be used to store cross-section designation (e.g., "A-A'"), or other human-readable name for a line feature. Null values permitted*
DataSourceID	*Foreign key to DataSources table, to track provenance of each data element. Null values not permitted*
Notes	*Optional field. Free text for additional information specific to this feature. Null values permitted*
CartographicLines_ID	*Primary key. Values = CAL1, CAL2, CAL3, … Values must be unique in database. Null values not permitted*

IsoValueLines (line feature class)

Structure contours, concentration isopleths, and hydraulic head contours share the properties of (a) having an associated value (elevation, concentration, hydraulic potential) that is a real number, (b) having a definable uncertainty in their location, and (c) describing an idealized surface that need not be shown as concealed beneath covering map units. Such lines could be stored in feature class IsoValueLines with fields:

Type	*Term that specifies the represented feature. Example values= 'top of Big Muddy seam', 'ppm Sr', 'hydraulic potential in Stoneyard aquifer'. Values must be defined in* Glossary *table and definition must include the units for associated Value and ValueConfidence fields; Value and ValueConfidence must have same units. Definition must give units for associated Value field. E.g., for Type = "ppm_As", Definition = "Arsenic concentration in unconfined aquifer; Value is in parts per million; ValueConfidence is estimated 1-sigma uncertainty, also in parts per million". Null values not permitted*
Value	*Date type=float. Null values not permitted*
ValueConfidence	*Data type=float. Half width of value uncertainty. Recommend value of -9 if value is not available. Null values not permitted.*
Symbol	*References a symbol in the accompanying style file. Typically determined from Type*
Label	*Typically blank, can be used to store human-readable name for a line feature. Null*

	values permitted
DataSourceID	*Foreign key to* DataSources *table, to track provenance of each data element. Null values not permitted*
Notes	*Optional field. Free text for additional information specific to this feature. Null values permitted*
IsoValueLines_ID	*Primary key. Values = IVL1, IVL2, IVL3, … Values must be unique in database. Null values not permitted*

Note the use of ValueConfidence instead of LocationConfidenceMeters. Either could be used to specify the real-world uncertainty, but in the case of structure contours (or concentration contours), the "vertical" uncertainty is generally more useful than the horizontal uncertainty.

Overlay polygons

Geologic maps occasionally show 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 such as diagonal lines, scattered red dots, and so forth, displayed ("overprinted") on the map-unit color and (optional) map-unit pattern. The overlay polygons do not participate in the map tessellation—that is, they are not in the set of polygons that cover the map area without gaps or overlaps—thus they do not belong in feature class MapUnitPolys. The topological relations of these overlays are likely to be complicated (e.g., alteration zone boundaries do not coincide with most bedrock map-unit boundaries, but do coincide with some faults and with unconsolidated-deposit boundaries) and are not easily prescribed by a simple set of rules. On some published maps the edges of overlay polygons are shown without a bounding line (i.e., they have a scratch boundary).

On some paper maps, overlay polygons delimit units described in the Description of Map Units. For example, in USGS SIM 3065 (Booth and others, 2009) the first four units in the Description of Map Units (modified land m, graded areas gr, artificial fill af, and landfill debris afl) are shown as overlays. In the GeMS schema, such overlay polygons should be described in feature class MapUnitOverlayPolys, with field MapUnit that references the appropriate entry in table DescriptionOfMapUnits.

On some paper maps, overlay polygons are described with other symbols such as contacts and strike and dip of beds. For example, in Nevada Bureau of Mines and Geology Map 180 (Castor and others, 2013), "Phyllosilicate alteration" is shown as a stipple overlay that is identified in an explanation of symbols table along with contacts, faults, various vein types, and strike and dip symbols. Unlike modified land in SIM 3065, phyllosilicate alteration in Map 180 is not treated as a map unit. In the GeMS schema, such overlay polygons should be described in feature class OverlayPolys, with field Type that references an entry in table Glossary.

If some but not all types of overlay polygon have additional attributes, it may be useful to divide these into multiple feature classes with the division based on the necessary attribute structure.

MapUnitOverlayPolys, fields:

MapUnit	*Term that categorizes the kind of overlaying feature. Values must be defined in the DescriptionOfMapUnits table. Null values not permitted*
IdentityConfidence	*How confidently is this polygon identified as MapUnit? Value is usually 'certain', 'questionable', or 'unspecified'. Null values not permitted. Suggest setting default value to 'certain'*
Label	*May be determined from MapUnit and IdentityConfidence. Allows for subscripts*

	and special characters. Null values permitted
Symbol	*References an area fill symbol (background color + optional pattern) in the accompanying style file. May or may not be the Symbol value defined for MapUnit in table DescriptionOfMapUnits. Null values permitted*
DataSourceID	*Foreign key to* DataSources *table, to track provenance of each data element. Null values not permitted*
Notes	*Optional field. Free text for additional information specific to this feature. Null values permitted*
MapUnitOverlayPolys_ID	*Primary key. Values = MUOP1, MUOP2, MUOP3, … Values must be unique in database. Null values not permitted*

Topology rules: None prescribed.

OverlayPolys, fields:

Type	*Term that categorizes the kind of overlaying feature. Values must be defined in the Glossary table. Null values not permitted*
IdentityConfidence	*How confidently is this polygon identified as Type? Value is usually 'certain', 'questionable', or 'unspecified'. Null values not permitted. Suggest setting default value to 'certain'*
Label	*May be determined from Type and IdentityConfidence. Allows for subscripts and special characters. Null values permitted*
Symbol	*References an area fill symbol (background color + optional pattern) in the accompanying style file. Null values OK*
DataSourceID	*Foreign key to* DataSources *table, to track provenance of each data element. Null values not permitted*
Notes	*Optional field. Free text for additional information specific to this feature. Null values permitted*
OverlayPolys_ID	*Primary key. Values = OVP1, OVP2, OVP3, … Values must be unique in database. Null values not permitted*

Topology rules: none prescribed.

DataSourcePolys (polygon feature class)

It is useful to provide an index map that shows polygons identifying the sources of data and interpretations for various parts of the map. Examples of such sources are a previously published map, new mapping, mapping by one of several authors, and mapping with a certain technique (e.g., "compiled by A.N. Author from 1:40,000-scale air photos"). For a map with one data source, for example all new mapping, this feature class would contain one polygon that encompasses the map area.

Fields:

DataSourceID	*Foreign key to DataSources table, indicating source for map data within polygon. Null values not permitted*
Notes	*Optional field. Free text for additional information specific to this feature. Null values permitted*
DataSourcePolys_ID	*Primary key. Values = DSP1, DSP2, DSP3, … Values must be unique in database*

Topology rules:

- Polygons may overlap
- Polygon boundaries may in part be coincident
- All parts of map area should be encompassed by at least one polygon (no gaps).

RepurposedSymbols (non-spatial table)

Line and point symbolization should follow the FGDC Digital Cartographic Standard for Geologic Map Symbolization (FGDC-STD-013-2006). If the FGDC Standard does not define a suitable symbol required for a geologic map, the Standard may be supplemented with custom symbols or with FGDC symbols that are "repurposed" for the map. Such repurposed symbols should be identified in this table, which becomes a required table if FGDC symbols are repurposed.

Fields:

FgdcIdentifier	*Zero-padded identifier string from FGDC standard, e.g., 01.01.03. Null values not permitted*
OldExplanation	*Explanatory text from FGDC standard for meaning of symbol, e.g., "Contact—Identity and existence certain, location approximate'. Null values not permitted*
NewExplanation	*Explanation of usage of symbol in this map portrayal, e.g., "Limit of tephra deposits from Holocene eruptions of Glacier Peak'. Null values not permitted*
RepurposedSymbol_ID	*Primary key. Example values = RSY1, RSY2, RSY3, … Null values not permitted*

SYMBOLIZATION

Symbolization is a critical aspect of a geologic map. It illustrates the geologist's interpretation and may depict (via color, type size, and other graphical elements) subtleties of interpretation and emphasis that are otherwise not obvious in the database. 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.

Symbolization instructions may include a single Esri .style file for all symbols (area, line, marker) used in the preferred visualization and an Esri map composition (.mxd) file. Alternatively, authors may choose to use Esri's cartographic representations to symbolize one or more map layers. For each feature class, values of either the Symbol attribute or the RuleID attribute should be non-null. At this time, a subset of the FGDC Standard's library of symbols is available as Cartographic Representations through Esri's Geologic Mapping Template ("GMT", http://www.arcgis.com/home/item.html?id=bb02aa75305f40ff87fb6106aa297da9 or see the GeMS Web site for any updated links or information). Esri's GMT stores the symbols in feature classes organized according to the sections of the FGDC standard. This organization is not compliant with GeMS and we hope to renew work with Esri on methods to facilitate use of the GMT representations within the GeMS design.

For the convenience of users without access to an ArcGIS license, we suggest provision of an

ArcReader document (.pmf file), and descriptions of the symbolization in order for it to be replicated in other GISs (e.g., for map unit areas, the AreaFillRGB and AreaFillPatternDescription fields in the DescriptionOfMapUnits non-spatial table).

Line and point symbolization should follow the FGDC Digital Cartographic Standard for Geologic Map Symbolization (FGDC-STD-013-2006). These symbols are implemented in an ArcGIS style and associated font files created by staff at the Geological Survey of Canada (see *http://ngmdb.usgs.gov/Info/standards/GeMS/* for links and latest version). Note that to use this style it will be necessary to zero-pad the FGDC symbol identifiers so that each part of the identifier has a two- or three-character width: 1.1.3 becomes 01.01.03; 1.1.25 becomes 01.01.25. 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. Such repurposed symbols should be identified in the RepurposedSymbols table, which is required if FGDC symbols have been repurposed.

SHAPEFILE VERSIONS OF THE DATABASE

We require that two shapefile versions of the database be provided: (1) 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 (2) an open version that uses well-documented file formats to supply as much of the database content as possible. Script GeMS_TranslateToShape.py (available at *http://ngmdb.usgs.gov/Info/standards/GeMS/*) translates a GeMS-style database 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. Various other line- and point-feature shapefiles from the GeologicMap feature dataset are optional additions. Most attribute data are included with every shape record, thus no related tables or joins are required to browse the data. If you choose to not use the GeMS TranslateToShape.py script, we offer the following guidance.

To create the MapUnitPolys shapefile, join DescriptionOfMapUnits (via the MapUnit field) and DataSources (via DataSourceID field) tables to the MapUnitPolys feature class. Map long field names from the database to short (10 characters or less), DBF-compatible names and export to a polygon shapefile. In the exported table, delete the OBJECTID_ID, Source, and Notes fields from the DescriptionOfMapUnits and DataSources tables (see Table 2). If the DescriptionOfMapUnits source field contains important information that is not conveyed by the MapUnitPolys source, consider updating the MapUnitPolys source. 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 unfortunate, but acceptable.

To create the ContactsAndFaults shapefile, join Glossary (Type field joins to Term in Glossary) and DataSources (via the DataSourceID field) tables to the ContactsAndFaults feature class. Delete OBJECTID_ID, RuleID, Override, DataSourceID, Glossary_ID, Glossary DefinitionSourceID, and DefinitionSource Notes fields (Table 3). Map long field names from the database to short, DBF-compatible names and export to a line shapefile. Other feature classes may be exported to shapefiles following similar procedures.

Table 2. Fields in denormalized Esri shapefile export of MapUnitPolys feature class.

Original field name	**Short field name**	**Notes on usage**
MapUnit	MapUnit	*Short plain-text identifier for the map unit. Example values: Qal, Tg, Kit, Trc3, etc. Null values not permitted—a mapped polygon must have an assigned map unit. In order to avoid corruption of text strings in transformation between formats, only lower and upper case letters and numerals in standard ASCII encoding should be used in these identifier strings. Null values not permitted*
IdentityConfidence	IdeConf	*How confidently is this polygon identified as MapUnit? Value is usually "certain", "questionable", or "unspecified". Null values not permitted. Suggest setting default value to "certain"*
Label	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=FGDCGeoAge>#n". Calculated from the appropriate value of the Label in the DescriptionOfMapUnits table and IdentityConfidence: if IdentityConfidence = "low", then append "?" to Label value from the DescriptionOfMapUnits table. Allows for subscripts and special characters. Null values permitted*
Symbol	Symbol	*References an area fill symbol (background color + optional pattern). Area fill symbols should be defined in an accompanying file. Null values permitted*
Notes	Notes	*Optional field. Free text for additional information specific to this polygon. Null values permitted*
MapUnitPolys_ID	MUPs_ID	*Primary key. Example Values = MUP1, MUP2, MUP3, etc. Values must be unique in database. Null values not permitted*
Name	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 Web site. Null values permitted*
FullName	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 permitted (e.g., for headings, headnotes, geologic*

Original field name	Short field name	Notes on usage
		units not shown on map)
Age	Age	*As shown in traditional DMU (commonly as bold text within parentheses). Null values may be used for map units that inherit Age from a parent unit, or for headings, headnotes, or overlay units.*
Description	Descr	*Free-format text description of map unit. Commonly terse, structured according to one or more accepted traditions (e.g., lithology, thickness, color, weathering and outcrop characteristics, distinguishing features, genesis, age constraints). Allows markup (e.g., HTML) specification of new paragraphs, superscripts and subscripts, and geologic-age font (sans-serif and with special characters). Place headnote text in this field. Null values permitted*
HierarchyKey	HKey	*Text string with form nn-nn-nn, nnn-nnn, or similar. Each fragment is numeric, of the same length, left-padded with zeros, and dash-delimited. 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. Appendix C illustrates the use of HierarchyKey to describe the structure of Description of Map Units for several maps*
ParagraphStyle	ParaSty	*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	RGB	*{Red, Green, Blue} tuples that specify the suggested color (e.g., '255,255,255', '124,005,255') of area fill for symbolizing this MapUnit. Use of consistent syntax is important to enable computer programs to read this field and display intended color. Each color value is an integer between 0 and 255; values are zero-padded so that there are 3 digits to each R, G, and B value; and color values are separated by commas with no space: NNN,NNN,NNN. Especially important to non-Esri users unable to use the .style file. Null values permitted (e.g., for headings, headnotes)*
AreaFillPatternDescription	PatDes	*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 permitted (e.g., for headings, headnotes, unpatterned map units)*
GeoMaterial	GeoMat	*Term to categorize the map unit based on lithologic and genetic character, from NGMDB standard term list*

Original field name	Short field name	Notes on usage
		(Appendix A). Null values permitted for headings and unmapped units
GeoMaterialConfidence	GeoMatConf	*Describes appropriateness of GeoMaterial term for describing the map unit (Appendix A). Null values permitted for headings and unmapped units*
Source	Source	*Plain-text short description to identify the data source, from MapUnitPolys.DataSource_ID join. If the DescriptionOfMapUnits source field contains important information that is not conveyed by the MapUnitPolys source, consider updating this source text with information from the DMU source as well. Null values not permitted*

Table 3. Fields in denormalized Esri shapefile format for ContactsAndFaults.

Original field name	Short field name	Notes on usage
Type	Type	*Specifies the kind of feature represented by the line. Values could be, for example, 'contact', 'fault', 'waterline', 'glacier boundary', 'map boundary'. Values must be defined in Glossary. Null values not permitted*
IsConcealed	IsCon	*Values = 'N','Y'. This is a flag for contacts and faults covered by overlying map unit. Null values not permitted*
LocationConfidenceMeters	LocConfM	*Half-width in meters of positional uncertainty envelope; position is relative to other features in database. Data type = float. Recommend value of -9 if value is not available. Null values not permitted*
ExistenceConfidence	ExiConf	*Values = 'certain', 'questionable', 'unspecified'. Suggest setting default value = 'certain'. Null values not permitted*
IdentityConfidence	IdeConf	*Values: 'certain' , 'questionable, 'unspecified''. Suggest setting default value = 'certain'. Null values not permitted*
Symbol	Symbol	*References a symbol in the accompanying style file. Calculated from Type, LocationConfidenceMeters, ExistenceConfidence, IdentityConfidence, and expected map display scale. Null values permitted*
Label	Label	*Can be used to store fault name, or human-readable name for a line feature. To group line segments into a specific structure trace, e.g. "San Andreas Fault", use the optional Extended Attributes table. Typically null*
Notes	Notes	*Free text for additional information specific to this feature. Null values permitted*
ContactsAndFaults_ID	CAFs_ID	*Primary key for database record. Example values = COF1, COF2, ... Values must be unique in database. Null values not permitted*

Original field name	**Short field name**	**Notes on usage**
Definition	Definition	*Plain-language definition of ContactAndFault Type. Null values not permitted*
Source	Source	*Plain-text short description to identify the data source from the ContactsAndFaults DataSourceID field joined to DataSources. If the Definition source information from the Glossary table adds important information, this source field text should be updated to include it. Null values not permitted*

Open version

The open shapefile version of the database 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.

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APPENDIX A. TERMS FOR GEOMATERIAL AND GEOMATERIALCONFIDENCE

Much of the benefit from a defined database schema depends on use of clearly defined vocabularies. Based on many discussions within the geoscience community over the past three decades, it seems to be the consensus and logical conclusion that users of geologic map databases are best served if some vocabularies, particularly lithology, are consistent from one database to another. These commonly are referred to as controlled-term lists or vocabularies. GeoMaterial is a controlled-term list. Other lists in GeMS (e.g., Type terms) are uncontrolled vocabularies. Terms in uncontrolled lists should be defined in the Glossary table. Terms for the controlled GeoMaterial list described below are encapsulated in a database table generated by GeMS CreateDatabase script, and in an Excel file provided at the GeMS website. General metadata should fully specify, under Supplemental Information, the sources and versions of all vocabularies used in the database.

GeoMaterial

The lithologic terms and definitions in this draft manuscript are provided in an indented format for clarity. An accompanying spreadsheet (see *http://ngmdb.usgs.gov/Info/standards/GeMS/*) also includes the LithHierarchy Key to facilitate sorting. Documentation of this classification, including rationale for its development, is provided in Soller (2009; *http://pubs.usgs.gov/of/2009/1298/pdf/usgs_of2009-1298_soller4.pdf*); some terms and definitions in that classification were updated for version 1.1 of GeneralLithology (see Archive section at *http://ngmdb.usgs.gov/Info/standards/GeMS/*). In the six years of test implementation among the state geological surveys and USGS, this classification was slightly modified for GeMS. The current version of this classification is maintained at the GeMS Web site.

This classification is intended to characterize a map unit with a generalized category based on lithologic and genetic criteria; it applies to the map unit as a whole. The purpose of this classification is to provide a basis for quickly integrating map data from different sources, and to convey to the public a simple, general sense of each map unit's lithology and genesis. Such a classification cannot adequately address the immense variety of map units occurring on a national level, and we expect that other regionally specific map unit classifications will also be developed that are more appropriate to local conditions. The appropriateness of a selected term for describing a map unit is specified by the GeoMaterialConfidence field. This provides the map user with a potentially useful qualifier term. Please refer to the Geologic Materials discussion in "Design Considerations", above.

GeoMaterial terms and definitions are:

- **Sedimentary material** -- An aggregation of particles deposited by gravity, air, water, or ice, or as accumulated by other natural agents operating at Earth's surface such as chemical precipitation or secretion by organisms. May include unconsolidated material (sediment) and (or) sedimentary rock. Does not include sedimentary material directly deposited as a result of volcanic activity.
    - **Sediment** -- Unconsolidated material (sediment) composed of particles deposited by gravity, air, water, or ice, or as accumulated by other natural agents operating at Earth's surface such as chemical precipitation or secretion by organisms. Does not include sedimentary material directly deposited as a result of volcanic activity.
        - **Clastic sediment** -- Sediment formed by the weathering and erosion of preexisting rocks or minerals; the eroded particles or "clasts" are transported and deposited by gravity, air, water, or ice.
            - **Sand and gravel of unspecified origin** -- A sediment composed mostly of sand and (or) gravel, formed by the weathering and erosion of preexisting rocks or minerals; the eroded particles or "clasts" are transported and deposited by gravity, air, water, or ice.

- **Silt and clay of unspecified origin** -- A sediment composed mostly of silt and (or) clay, formed by the weathering and erosion of preexisting rocks or minerals; the eroded particles or "clasts" are transported and deposited by gravity, air, water, or ice.
- **Alluvial sediment** -- Unconsolidated material deposited by a stream or other body of running water, as a sorted or semi-sorted sediment in the bed of the stream or on its floodplain or delta, or as a cone or fan at the base of a mountain slope. Grain size varies from clay to gravel.
    - **Alluvial sediment, mostly coarse-grained** -- Unconsolidated material deposited by a stream or other body of running water, as a sorted or semi-sorted sediment in the bed of the stream or on its floodplain or delta, or as a cone or fan at the base of a mountain slope. This sediment is mostly sand, gravel, and coarser material, but may contain some silt and clay.
    - **Alluvial sediment, mostly fine-grained** -- Unconsolidated material deposited by a stream or other body of running water, as a sorted or semi-sorted sediment in the bed of the stream or on its floodplain or delta, or as a cone or fan at the base of a mountain slope. This sediment is mostly silt and clay, but may contain some sand and gravel.
- **Glacial till** -- Mostly unsorted and unstratified material, generally unconsolidated, deposited directly by and underneath or adjacent to a glacier without subsequent reworking by meltwater, and consisting of a heterogeneous mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape.
    - **Glacial till, mostly sandy** -- Mostly unsorted and unstratified material, generally unconsolidated, deposited directly by and underneath or adjacent to a glacier without subsequent reworking by meltwater, and consisting of clay, silt, sand, gravel, and boulders ranging widely in size and shape. Relatively sandy in texture.
    - **Glacial till, mostly silty** -- Mostly unsorted and unstratified material, generally unconsolidated, deposited directly by and underneath or adjacent to a glacier without subsequent reworking by meltwater, and consisting of a heterogeneous mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape. Relatively loamy (silty) in texture.
    - **Glacial till, mostly clayey** -- Mostly unsorted and unstratified material, generally unconsolidated, deposited directly by and underneath or adjacent to a glacier without subsequent reworking by meltwater, and consisting of a heterogeneous mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape. Relatively clayey in texture.
- **Ice-contact and ice-marginal sediment** -- Mostly sand, silt, and gravel-sized particles or "clasts" derived from rock or preexisting sediment eroded and transported by glaciers. As the glacier melted, this material was deposited by running water essentially in contact with glacial ice, or was transported and deposited by glacially fed streams. Includes sediment deposited into water bodies adjacent to the glacier.
    - **Ice-contact and ice-marginal sediment, mostly coarse-grained** -- Mostly sand and gravel-sized particles or "clasts," with lesser silt and clay, derived from rock or preexisting sediment eroded and transported by glaciers. As the glacier melted, this material was deposited by running water essentially in contact with glacial ice, or was transported and deposited by glacially fed streams. Includes sediment deposited into water bodies adjacent to the glacier.

    - **Ice-contact and ice-marginal sediment, mostly fine-grained --** Mostly silt and clay-sized particles or "clasts," with lesser sand and gravel, derived from rock or preexisting sediment eroded and transported by glaciers. As the glacier melted, this material was deposited by running water essentially in contact with glacial ice, or was transported and deposited by glacially fed streams. Includes sediment deposited into water bodies adjacent to the glacier.
- **Eolian sediment** -- Silt- and sand-sized sediment deposited by wind.
    - **Dune sand** -- Mostly sand-sized sediment deposited by wind. Typically characterized by various dune landforms.
    - **Loess** -- Silty material deposited by winds, commonly near a glacial margin.
- **Lacustrine sediment** -- Mostly well sorted and well bedded material ranging in grain size from clay to gravel, deposited in perennial to intermittent lakes. Much of the sediment is derived from material eroded and transported by streams. Includes deposits of lake-marginal beaches and deltas.
    - **Lacustrine sediment, mostly coarse-grained** -- Mostly well-sorted and well-bedded material, generally sand- and gravel-sized with lesser silt and clay, deposited in perennial to intermittent lakes. Much of the sediment is derived from material eroded and transported by streams. Mostly deposits of lake-marginal beaches and deltas.
    - **Lacustrine sediment, mostly fine-grained** -- Mostly well-sorted and well-bedded material, generally silt- and clay-sized with lesser sand, deposited in perennial to intermittent lakes.
- **Playa sediment** -- Fine-grained clastic sediment and evaporitic salts deposited in ephemeral lakes in the centers of undrained basins. Includes material deposited in playas, mud flats, salt flats, and adjacent saline marshes. Generally interbedded with eolian sand and with lacustrine sediment deposited during wetter climatic periods; commonly intertongues upslope with sediment deposited by alluvial fans.
- **Coastal zone sediment** – Mud, sand, and lesser gravel deposited in beach, barrier island, nearshore marine deltaic, or in various low-energy shoreline (mud flat, tidal flat, sabka, algal flat) settings.
    - **Coastal zone sediment, mostly coarse-grained** -- Mostly sand, silt, and gravel deposited on beaches and dunes, and in shallow marine and related alluvial environments.
    - **Coastal zone sediment, mostly fine-grained** -- Mostly clay and silt deposited in lagoons, tidal flats, backbarriers, and coastal marshes.
- **Marine sediment** -- Mud and sand deposited in various marine settings. Sediment may originate from erosion of rocks and sediments on land, or from marine organisms (of carbonate or siliceous composition).
    - **Marine sediment, mostly coarse-grained** -- Mud and sand derived from erosion of rocks and sediment on land, transport by streams, and deposition in marine deltas and basins. Sediment is mostly siliceous in composition.
    - **Marine sediment, mostly fine-grained** – Mostly clay- and silt-sized sediment deposited in relatively deep, quiet water, far removed from areas where coarser-grained clastic sediments are washed into the marine environment. Includes sediment derived from marine organisms.
- **Mass movement sediment** – Sediment formed by downslope transport of particles or "clasts" produced by weathering and breakdown of the underlying rock, sediment, and (or) soil. Composed of poorly sorted and poorly stratified

material ranging in size from clay to boulders. Includes colluvium, landslide deposits, talus, and rock avalanche deposits.

            - **Colluvium and other widespread mass-movement sediment** -- Sediment formed by relatively widespread and slow downslope transport of particles or "clasts" produced by weathering and breakdown of the underlying rock, sediment, and (or) soil. Composed of poorly sorted and poorly stratified material ranging in size from clay to boulders.
            - **Debris flow, landslide, and other localized mass-movement sediment** -- Sediment formed by relatively localized downslope transport of particles or "clasts" produced by weathering and breakdown of the underlying rock, sediment, and (or) soil. Composed of poorly sorted and poorly stratified material ranging in size from clay to boulders. The speed of downslope transport ranges from rapid to imperceptible.
        - **Residual material** – Unconsolidated material developed in place by weathering of the underlying rock or sediment. Usually forms a relatively thin surface layer that conceals the unweathered or partly altered source material. The material from which soils are formed.
        - **Carbonate sediment** -- Sediment formed by the biotic or abiotic precipitation from aqueous solution of carbonates of calcium, magnesium, or iron; e.g., limestone, dolomite.
        - **Peat and muck** -- Unconsolidated material principally composed of plant remains, with lesser amounts of fine-grained clastic sediment. Deposited in a water-saturated environment such as a swamp, marsh, or bog. With lithification such material becomes coal.
    - **Sedimentary rock** -- Consolidated material (rock) composed of particles transported and deposited by gravity, air, water, or ice, or accumulated by other natural agents operating at Earth's surface such as chemical precipitation or secretion by organisms. Does not here include sedimentary material directly deposited as a result of volcanic activity.
        - **Clastic sedimentary rock** -- Sedimentary rock composed predominantly of particles or "clasts" derived by erosion, weathering, or mass-wasting of preexisting rock, and deposited by gravity, air, water, or ice.
            - **Conglomerate** -- Sedimentary rock composed predominantly of particles or "clasts" derived by erosion and weathering of preexisting rock, and containing more than 30 percent gravel-sized particles.
            - **Sandstone** -- Sedimentary rock composed predominantly of particles or "clasts" derived by erosion and weathering of preexisting rock, consisting mostly of sand-sized particles, with or without a fine-grained matrix of silt or clay.
            - **Mostly sandstone** -- Mostly sandstone, interbedded with other sedimentary rocks which locally may include conglomerate and finer grained clastics (mudrock), carbonates, and (or) coal.
            - **Sandstone and mudstone** -- Sandstone and mudstone (including shale and siltstone) in approximately equal (or unspecified) proportion.
            - **Mudstone** -- Sedimentary rock composed predominantly of particles or "clasts" derived by erosion and weathering of preexisting rock, consisting mostly of mud (silt- and clay-sized particles). Includes shale and siltstone.
            - **Mostly mudstone** -- Mostly mudstone, interbedded with other sedimentary rocks which locally may include coarser grained clastics (sandstone, conglomerate), carbonates, and (or) coal.
        - **Carbonate rock** -- Sedimentary rock consisting chiefly of carbonate minerals, such as limestone or dolomite.

      - **Limestone** -- Carbonate sedimentary rock consisting chiefly of the mineral calcite.
      - **Dolomite** -- Carbonate sedimentary rock consisting chiefly of the mineral dolomite. Although "dolostone" is the proper analog to “limestone”, it has not often been applied to dolomitic units; historically, the literature used "dolomite”.
    - **Mostly carbonate rock** -- Mostly carbonate rock interbedded with other sedimentary rock types.
    - **Chert** -- Sedimentary rock composed chiefly of microcrystalline or cryptocrystalline quartz.
    - **Evaporitic rock** -- Sedimentary rock composed primarily of minerals produced by evaporation of a saline solution. Examples include gypsum, anhydrite, other diverse sulfates, halite (rock salt), primary dolomite, and rocks composed of various nitrates and borates.
    - **Iron-rich sedimentary rock** -- Sedimentary rock in which at least half (by volume) of the observed minerals are iron-bearing (hematite, magnetite, limonite-group, siderite, iron sulfides).
    - **Coal and lignite** -- Organic-rich sedimentary rock formed from the compaction and alteration of plant remains. Coal is a consolidated, harder, black rock. Lignite is a semiconsolidated brown to black, earthy material which may contain large particles of recognizable plant parts and tends to crack upon drying.
- **Sedimentary and extrusive igneous material** -- Either (1) sedimentary rock and (or) unconsolidated material (sediment) and extrusive igneous material (volcanic rock and (or) sediment) or (2) volcanic rock and (or) sediment and such material after erosion and redeposition.
- **Igneous rock** -- Rock and fragmental material that solidified from molten or partly molten material (magma).
  - **Extrusive igneous material** -- Molten material that was erupted onto the surface of the Earth, fusing into rock or remaining as unconsolidated particles. Includes pyroclastic flows, air-fall tephra, lava flows, and volcanic mass flows.
    - **Volcaniclastic (fragmental) material** -- Rock and unconsolidated material consisting of particles or "clasts" that were formed by volcanic explosion or aerial expulsion from a volcanic vent.
      - **Pyroclastic flows** -- Hot ash, pumice, and rock fragments erupted from a volcano or caldera. This material moves downslope commonly in chaotic flows. Once deposited, the hot fragments may compact under their own weight and weld together.
        - **Felsic-composition pyroclastic flows** -- Hot ash, pumice, and rock fragments erupted from a volcano or caldera. This material moves downslope commonly in chaotic flows. Once deposited, hot fragments may compact under their own weight and weld together. Composed of light-colored rocks (e.g., rhyolite, dacite, trachyte, latite) which, because of their high-silica content and resulting high viscosity, tend to erupt explosively.
        - **Intermediate-composition pyroclastic flows** -- Hot ash, pumice, and rock fragments erupted from a volcano. This material moves downslope commonly in chaotic flows. Once deposited, hot fragments may compact under their own weight and weld together. Composed of rocks (e.g., andesite) intermediate in color and mineral composition between felsic and mafic rocks. Andesite magma commonly erupts from stratovolcanoes as thick lava flows but also can generate strong explosive eruptions to form pyroclastic flows.
        - **Mafic-composition pyroclastic flows** -- Hot ash, pumice, and rock fragments erupted from a volcano. This material moves downslope

commonly in chaotic flows. Once deposited, hot fragments may compact under their own weight and weld together. Composed of dark-colored rocks (e.g., basalt) which, because of their low silica content and resulting low viscosity, tend to erupt gently as lava flows rather than more forcefully as pyroclastic flows.

  - **Air-fall tephra** -- Fragments of volcanic rock and lava of various sizes are known as "tephra." This material is carried into the air by explosions and by hot gases in eruption columns or lava fountains. As tephra falls to the ground with increasing distance from a volcano, the average size of the individual rock particles and the thickness of the resulting deposit decrease. Fine tephra deposited at some distance from a volcano is known as volcanic ash.
    - **Felsic-composition air-fall tephra** -- Fragments of volcanic rock and lava, of various sizes, are known as "tephra." This material is carried into the air by explosions and by hot gases in eruption columns or lava fountains. As tephra falls to the ground with increasing distance from a volcano, the average size of the individual rock particles and the thickness of the resulting deposit decrease. Composed of light-colored rocks (e.g., rhyolite, dacite, trachyte, latite) which, because of their high silica content and resulting high viscosity, tend to erupt explosively, readily forming pumice and volcanic ash.
    - **Intermediate-composition air-fall tephra** -- Fragments of volcanic rock and lava, of various sizes, are known as "tephra." This material is carried into the air by explosions and by hot gases in eruption columns or lava fountains. As tephra falls to the ground with increasing distance from a volcano, the average size of the individual rock particles and the thickness of the resulting deposit decrease. Composed of rocks (e.g., andesite) intermediate in color and mineral composition between felsic and mafic rocks. Andesite magma commonly erupts from stratovolcanoes as thick lava flows but also can generate strong explosive eruptions, readily forming pumice and volcanic ash.
    - **Mafic-composition air-fall tephra** -- Fragments of volcanic rock and lava, of various sizes, are known as "tephra." This material is carried into the air by explosions and by hot gases in eruption columns or lava fountains. As tephra falls to the ground with increasing distance from a volcano, the average size of the individual rock particles and the thickness of the resulting deposit decrease. Composed of dark-colored rocks (e.g., basalt) which, because of their low silica content and resulting low viscosity, tend to erupt gently as lava flows rather than more forcefully, and so these deposits are uncommon.

- **Lava flows** -- Lateral, surficial outpourings of molten lava from a vent or a fissure, and the solidified bodies of rock that form when they cool. Composed generally of fine-grained, dark-colored rocks (e.g., basalt), which tend to form extensive sheets with generally low relief except in the vent areas where cinder cones or shield volcanoes may form. Includes basaltic shield volcanoes, which may become very large (e.g., Hawaii).
  - **Felsic-composition lava flows** -- Lateral, surficial outpourings of molten lava from a vent or a fissure, and the solidified bodies of rock that form when they cool. Composed of fine-grained, light-colored rocks which, because of their high-silica content and resulting high viscosity, tend to erupt explosively, and so these deposits are uncommon. Includes rhyolitic, dacitic, trachytic, and latitic rock.
  - **Intermediate-composition lava flows** -- Lateral, surficial outpourings of molten lava from a vent or a fissure, and the solidified bodies of rock that form when they cool. Composed of fine-grained rocks intermediate in color and

mineral composition between felsic and mafic rocks, and commonly erupts from stratovolcanoes as thick lava flows. Includes andesitic rock.

        - **Mafic-composition lava flows** -- Lateral, surficial outpourings of molten lava from a vent or a fissure, and the solidified bodies of rock that form when they cool. Composed of fine-grained, dark-colored rocks, and tends to form extensive sheets with generally low relief. Includes basaltic shield volcanoes, which may become very large (e.g., Hawaii). Includes basaltic rock.
    - **Volcanic mass flow** – Deposit formed by mass movement, i.e., debris avalanches, debris flows, or lahars. In many cases these are triggered by volcanic eruption. Debris avalanches occurring on volcanoes clearly without an eruptive trigger may be classified as sedimentary mass movement.
- **Intrusive igneous rock** -- Rock that solidified from molten or partly molten material (magma), forming below the Earth's surface.
    - **Coarse-grained intrusive igneous rock** -- Rock that solidified from molten or partly molten material (magma). It formed at some depth beneath the Earth's surface, thereby cooling slowly enough for mineral crystals to grow to a size large enough to be visible to the naked eye.
        - **Coarse-grained, felsic-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (magma). It formed at some depth beneath the Earth's surface, thereby cooling slowly enough for mineral crystals to grow to a size large enough to be visible to the naked eye. Composed mostly of light-colored minerals, e.g., feldspar, quartz. Includes granitic, syenitic, and monzonitic rock.
        - **Coarse-grained, intermediate-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (magma). It formed at some depth beneath the Earth's surface, thereby cooling slowly enough for mineral crystals to grow to a size large enough to be visible to the naked eye. Intermediate in color and mineral composition between felsic and mafic igneous rock. Includes dioritic rock.
        - **Coarse-grained, mafic-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (magma). It formed at some depth beneath the Earth's surface, thereby cooling slowly enough for mineral crystals to grow to a size large enough to be visible to the naked eye. Composed mostly of feldspar and dark-colored minerals. Includes gabbroic rock.
        - **Ultramafic intrusive igneous rock** -- Rock that solidified from molten or partly molten material (magma). It formed at some depth beneath the Earth's surface, thereby cooling slowly enough for mineral crystals to grow to a size large enough to be visible to the naked eye. Composed almost entirely of mafic minerals, e.g., hypersthene, augite, olivine.
    - **Fine-grained intrusive igneous rock** -- Rock that solidified from molten or partly molten material (magma). It formed at shallow depths beneath the Earth's surface, thereby cooling quickly. These rocks generally are fine-grained, but may contain large mineral crystals (phenocrysts), and they mostly occur as tabular dikes or sills.
        - **Fine-grained, felsic-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (magma). It formed at shallow depths beneath the Earth's surface, thereby cooling quickly. These rocks generally are fine-grained, but may contain large mineral crystals (phenocrysts), and they occur mostly as tabular dikes or sills. Composed mostly of light-colored minerals. Includes rhyolitic, dacitic, trachytic, and latitic rock.
        - **Fine-grained, intermediate-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (magma). It formed at shallow depths beneath the Earth's surface, thereby cooling quickly. These rocks

generally are fine-grained, but may contain large mineral crystals (phenocrysts), and they occur mostly as tabular dikes or sills. Intermediate in color and mineral composition between felsic and mafic igneous rock. Includes andesitic rock.

      - **Fine-grained, mafic-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (magma). It formed at shallow depths beneath the Earth's surface, thereby cooling quickly. These rocks generally are fine-grained, but may contain large mineral crystals (phenocrysts), and they occur mostly as tabular dikes or sills. Composed mostly of dark-colored minerals. Includes basaltic rock.
    - **Exotic-composition intrusive igneous rock** -- Rock that solidified from molten or partly molten material (magma), forming below the Earth's surface and having exotic mineralogical, textural, or field setting characteristics. These rocks typically are dark-colored with abundant phenocrysts. Includes kimberlite, lamprophyre, lamproite, and foiditic rocks.
- **Igneous and metamorphic rock** -- Consists of coarse-grained intrusive igneous rocks and generally medium to high grade metamorphic rocks.
- **Metamorphic rock** -- Rock derived from preexisting rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, deformation, and chemical environment, generally at depth in the Earth's crust.
  - **Regional metamorphic rock of unspecified origin** -- Rock derived from preexisting rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked regional changes in temperature, pressure, deformation, and (or) chemical environment, generally at depth in the Earth's crust. Origin of the preexisting rock is mixed (e.g., igneous and sedimentary) or is not known.
    - **Lower-grade metamorphic rock of unspecified origin** -- Rock derived from preexisting rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to relatively mild regional changes in temperature, pressure, deformation, and chemical environment, generally at depth in the Earth's crust. Origin of the preexisting rock is mixed (e.g., igneous and sedimentary) or is not known. Includes slate and phyllite.
    - **Higher-grade regional metamorphic rock of unspecified origin** -- Rock derived from preexisting rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to relatively intense regional changes in temperature, pressure, deformation, and (or) chemical environment, generally at depth in the Earth's crust. Origin of the preexisting rock is mixed (e.g., igneous and sedimentary) or is not known. Includes amphibolite, granulite, schist, and gneiss.
    - **Contact-metamorphic rock** -- Rock that originated by local processes of thermal metamorphism, genetically related to the intrusion and extrusion of magmas and taking place in rocks at or near their contact with a body of igneous rock. Metamorphic changes are effected by the heat and fluids emanating from the magma and by some deformation because of emplacement of the igneous mass.
    - **Deformation-related metamorphic rock** -- Rock derived from preexisting rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to strong deformation, commonly in association with marked changes in temperature, pressure, and (or) chemical environment. Generally forms in narrow, planar zones of local deformation (e.g., along faults) and characterized by foliation or alignment of mineral grains. Includes mylonite and cataclasite.
  - **Metasedimentary rock** -- Rock derived from preexisting sedimentary rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, deformation, and (or) chemical environment, generally at depth in the Earth's crust.

        - **Slate and phyllite of sedimentary rock origin** -- Fine-grained rock derived from preexisting sedimentary rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, deformation, and (or) chemical environment, generally at depth in the Earth's crust. Includes phyllite and slate, which is a compact, fine-grained rock that possesses strong cleavage and hence can be split into slabs and thin plates. Mostly formed from fine-grained material such as mudstone.
        - **Schist and gneiss of sedimentary rock origin** -- Foliated rock derived from preexisting sedimentary rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, deformation, and (or) chemical environment, generally at depth in the Earth's crust. Includes schist (characterized by such strong foliation or alignment of minerals that it readily splits into flakes or slabs) and gneiss (characterized by alternating, irregular bands of different mineral composition). Mostly formed from fine-grained material such as mudstone.
        - **Meta-carbonate rock** -- Rock derived from preexisting carbonate sedimentary rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, deformation, and chemical environment, generally at depth in the Earth's crust. Characterized by recrystallization of the carbonate minerals in the source rock. Includes marble, for which the preexisting rock was dominantly limestone or other rock composed of the mineral calcite, and dolomitic marble, meta-dolostone, or meta-dolomite, for which the preexisting rock contained appreciable magnesium.
        - **Quartzite** -- Rock derived from preexisting (commonly sandstone) sedimentary rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shear stress, and (or) chemical environment, generally at depth in the Earth's crust. Characterized by recrystallization of quartz in the source rock.
    - **Metaigneous rock** -- Rock derived from preexisting igneous rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shear stress, and (or) chemical environment, generally at depth in the Earth's crust.
        - **Meta-ultramafic rock** -- Rock derived from preexisting ultramafic rocks and altered by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, deformation, and chemical environment, generally at depth in the Earth's crust. Composed mostly of Mg-bearing minerals, e.g., serpentine, talc, and magnesite.
        - **Meta-mafic rock** -- Rock derived from preexisting mafic rocks and altered by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, deformation, and chemical environment, generally at depth in the Earth's crust. Composed mostly of Fe- and Mg-bearing dark-colored and green minerals. Includes greenstone, amphibolite, and metagabbro.
        - **Meta-felsic and -intermediate rock** -- Rock derived from preexisting felsic and intermediate rocks and altered by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, deformation, and chemical environment, generally at depth in the Earth's crust. Composed mostly of light-colored minerals and relatively enriched in silica. Includes metagranite, metadiorite, and meta-andesite.
        - **Meta-volcaniclastic rock** -- Rock derived from preexisting volcaniclastic rocks and altered by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, deformation, and chemical environment, generally at depth in the Earth's crust. Composed of deformed but recognizable particles or "clasts" of volcanic explosive material.
- **Other materials:**

- **Rock and sediment** -- Various rocks and sediment, not differentiated.
- **Rock** -- Various rock types, not differentiated.
- **"Made" or human-engineered land** -- Modern, unconsolidated material known to have human-related origin.
- **Water or ice**
- **Unmapped area**

These definitions were adapted from a variety of published and unpublished works, including:

Blatt, Harvey, Tracy, R.J., and Owens, B.E., 2006, Petrology – Igneous, sedimentary, and metamorphic, 3rd ed.: W.H. Freeman and Company, New York, 530 p.

Hyndman, D.W., 1985, Petrology of igneous and metamorphic rocks, 2nd ed.: McGraw-Hill, Inc., New York, 576 p.

Neuendorf, K.K.E., Mehl, J.P., Jr., and Jackson, J.A., 2005, Glossary of geology, 5th ed.: American Geological Institute, Alexandria, VA., 779 p.

North American Geologic Map Data Model Steering Committee Science Language Technical Team, 2004, Report on Progress to Develop a North American Science-Language Standard for Digital Geologic-Map Databases, *in* Soller, D.R., ed., Digital Mapping Techniques '04 -- Workshop Proceedings: U.S. Geological Survey Open-File Report 2004-1451, p. 85-94 and 4 appendices containing the science terminologies, http://pubs.usgs.gov/of/2004/1451/nadm/.

National Geologic Map Database Project, 2007, Science vocabulary to support the National Geologic Map Database project: Lithology terms: U.S. Geological Survey unpublished document, 218 p.

Soller, D.R., and Reheis, M.C., compilers, 2004, Surficial materials in the conterminous United States: U.S. Geological Survey Open-File Report 03-275, scale 1:5,000,000, http://pubs.usgs.gov/of/2003/of03-275/.

USGS Photo glossary of volcanic terms, 2008, USGS Volcano Hazards Program Web site, http://volcanoes.usgs.gov/images/pglossary/index.php.

GeoMaterialConfidence

Term	Definition
High	The term and definition adequately characterize the overall lithologic nature of rocks and sediments in the map unit. Regarding the subjective term "adequately characterize", we refer to context and objectives of this classification as described in the documentation.
Medium	The term and definition generally characterize the overall lithology of the map unit, but there are one or more significant minor lithologies that are not adequately described by the selected term.
Low	The overall lithology of this map unit is not adequately classifiable using this list of terms and definitions, but the term selected is the best available. Or this map unit is

	insufficiently known to confidently assign a GeoMaterial term.

NOTE: Please refer to the introductory note of this appendix, particularly the scope and intent, before assigning confidence values.

APPENDIX B. OPTIONAL ELEMENTS

Some parts of a geologic map publication (e.g., cross sections, CMU) may, if present, be encoded as image files. At present, this is the conventional approach, and quite reasonable. Alternatively, these could be encoded within the database as described below. In this Appendix, we also define two non-spatial tables (MiscellaneousMapInformation and StandardLithology) that some map publishers may find useful. These are *optional elements*.

Cross Sections (feature datasets)

Cross sections should be identified as cross-section A, cross-section B, cross-section C, and so on, and abbreviated as CSA, CSB, CSC in the dataset and feature class names. Each cross section exists in a separate map-space, and thus there should be 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 otherwise identical with those for ContactsAndFaults and MapUnitPolys. If lines that do not participate in MapUnit topology or point-based data are depicted on the cross-section, the appropriate feature classes (e.g., CSAGeologicLines, CSAOrientationPoints) should be created.

Correlation of Map Units (feature dataset)

The Correlation of Map Units (CMU) diagram found on many geologic maps can be encoded as a feature dataset in a database. Doing so makes it easier to match symbolization of the CMU to that 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:

MapUnit	*Foreign key to DescriptionOfMapUnits. Null values not permitted*
Label	*Value = the appropriate value of the Label in the DescriptionOfMapUnits table. Null values permitted*
Symbol	*References a symbol in accompanying style file. Null values permitted*
CMUMapUnitPolys_ID	*Primary key. Example values = CMUMUP1, CMUMUP2, CMUMUP3, ... Null values not permitted*

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 = ‘blank’. Or, the box outline alone can be stored in CMULines.

CMULines (line feature class)

Fields:

Type	*Term to classify meaning of lines. Example values = 'contact', 'ghost contact', 'CMU leader', 'CMU rule', 'CMU bracket', or '<MapUnit> line'. Values must be defined in Glossary. Null values not permitted*
Symbol	*References a symbol in accompanying style file. Null values permitted*
CMULines_ID	*Values are CMULIN1, CMULIN2, CMULIN3, ... Null values not permitted*

CMUText (annotation feature class)

Fields:

ParagraphStyle	*Null values not permitted*
Text	*Text to display*
Additional fields as implemented by GIS software	
CMUText_ID	*Primary key. Example values = CMUTEX1, CMUTEX2, CMUTEX3, ... 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)

Fields:

Type	*Values are '<MapUnit> point'. Values must be defined in Glossary. Null values not permitted*
Label	*Text string to display in association with symbol at this point*
Symbol	*References a symbol in accompanying style file. Null values permitted*
CMUPoints_ID	*Primary key. Example values = CMUPNT1, CMUPNT2, CMUPNT3, ... Null values not permitted*

MiscellaneousMapInformation (non-spatial table)

Most paper maps have significant miscellaneous information printed in the collar region around the map graphic. This includes such map properties as the title, authorship, scale, geologic mapping credit, editing credit, cartography credit, date of approval, local magnetic declination, publication series and number, and base map information. These properties are commonly necessary for full comprehension of the information in an associated digital database and can usefully reside in a table in the database. Information may be harvested from this table to populate formal metadata. A common element of all these properties is that they are single statements that apply to the map as a whole.

The details of this information vary from map to map and agency to agency, thus we do not prescribe what properties should be encoded nor what they should be named.

Fields:

MapProperty	*Name of map property. Examples = "Scale", "Authors and*

	affiliations", "Magnetic declination", "Date of Approval", … Null values not permitted
MapPropertyValue	*Value of map property. Examples = "1:24,000", "G.S. Smith1 and J. Doe2 1-Division of Geology, Some State, 2-Big University", "16.5 degrees", "Approved for publication on 23 September 2017", … Null values not permitted*
MiscellaneousMapInformation_ID	*Primary key. Example values are MCI01, MCI03, … Null values not permitted*

StandardLithology (non-spatial table)

StandardLithology provides a simple structure for describing the various constituents that occur in geologic map units. It can be used to extend and supplement the unstructured free text descriptions and GeoMaterial terms found in the DescriptionOfMapUnits table. Please also note that you may wish to instead create your own table for a lithologic classification that best suits the geology of the map area and the intended audience.

The StandardLithology table represents the lithologic composition of map units by associating with the unit one or more lithology categories from the CGI SimpleLithology controlled vocabulary (https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/ConceptDefinitionsTG; see discussion in GeoMaterial section, above). Descriptions for 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. 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:

MapUnit	*Unit abbreviation, foreign key to DescriptionOfMapUnits. Null values not permitted*
PartType	*Domain is CGI GeologicUnitPartRole vocabulary (https://www.seegrid.csiro.au/wiki/bin/view/CGIModel/ConceptDefinitionsTG). Terms used should be included in the Glossary, along with their URI. Use 'Not available' if information is not available*
Lithology	*Domain is CGI SimpleLithology vocabulary (see URL above). Values used should be defined in Glossary, along with their URI. Null values not permitted*
ProportionTerm	*Domain is CGI ProportionTerm list (see URL above). Users may wish to restrict this list of 10 terms to a shorter, less expressive but easier to use list (e.g., see discussion, below). Values of ProportionTerm must be defined in the Glossary. Either ProportionTerm or ProportionValue should be non-null. Null values allowed*
ProportionValue	*Data type = float. Range 0–1.0. Must not sum to more than 1.0 for a given MapUnit. Either ProportionValue or ProportionTerm should be non-null. Null values allowed.*
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*
StandardLithology_ID	*Primary key. Example values = STL1, STL2, STL3, … Null values not permitted*

Regarding ProportionTerm, the CGI list is recommended. But for parsing certain map descriptions into a controlled term list, especially those already compiled and published, a simpler list whose definitions are less precise may be found more appropriate. This is particularly the case where the percentage proportions, especially among the dominant lithologic constituents, cannot readily be determined. Such a list might be:

- all – the lithology constitutes all of the map unit
- major – lithology is a major or significant component of the map unit
- minor – lithology is a minor or relatively insignificant component of the map unit
- trace – lithology is present, but is a very small component of the map unit.

Below are examples of StandardLithology records. Field names are at the top of each column and each row represents a separate data instance. Use ProportionTerm or ProportionValue as appropriate; we recommend that the ProportionTerm be included for all entries. For a given record, only one may be null. ProportionValue terms are fractional values between 0.0 and 1.0, and for a single map unit these should sum to 1.0 or less. 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.

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	Dominant	.55
STL770	KJz	beds	Mudstone	Subordinate	.45

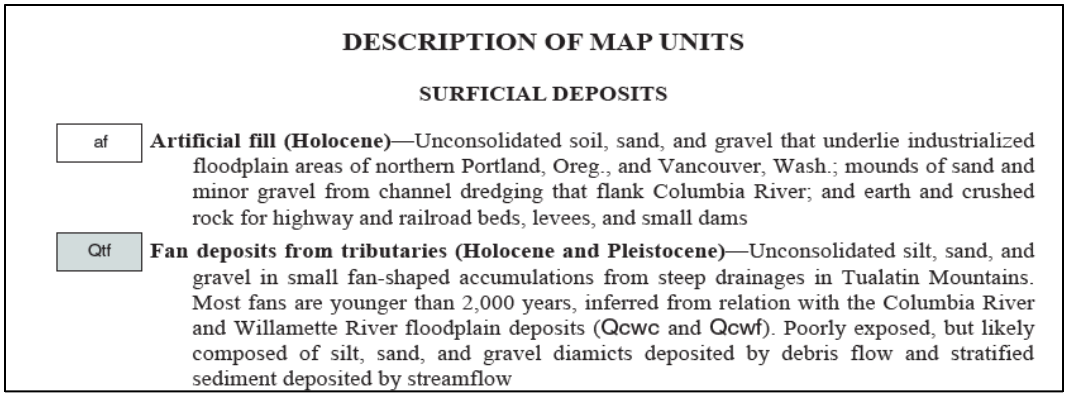
Deprecated non-spatial tables

The NCGMP09v1.1 specification described optional non-spatial tables ExtendedAttributes and GeologicEvents which could be used to specify arbitrary properties and their values for any feature with the map database, and to attach multiple ages to map units or map features. To our knowledge these tables were rarely, if ever, implemented and they are thus omitted from this draft manuscript's specification. If map authors or publishers wish to encode multiple ages, or link otherwise unspecified attributes to some items within the database, they may wish to consult the v1.1 specification.

APPENDIX C. PARSING THE DESCRIPTION OF MAPUNITS AND HIERARCHYKEY

Description of Map Units

Parsing the Description of Map Units on a recently published geologic map into the fields of the DescriptionOfMapUnits table is straightforward.



DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

af **Artificial fill (Holocene)**—Unconsolidated soil, sand, and gravel that underlie industrialized floodplain areas of northern Portland, Oreg., and Vancouver, Wash.; mounds of sand and minor gravel from channel dredging that flank Columbia River; and earth and crushed rock for highway and railroad beds, levees, and small dams

Qtf **Fan deposits from tributaries (Holocene and Pleistocene)**—Unconsolidated silt, sand, and gravel in small fan-shaped accumulations from steep drainages in Tualatin Mountains. Most fans are younger than 2,000 years, inferred from relation with the Columbia River and Willamette River floodplain deposits (Qcwc and Qcwf). Poorly exposed, but likely composed of silt, sand, and gravel diamicts deposited by debris flow and stratified sediment deposited by streamflow

The fragment above, from USGS SIM 3349, is parsed into table

DescriptionOfMapUnits

MapUnit	Label	Name	Age	Description	ParagraphStyle
<null>	<null>	Surficial deposits	<null>	<null>	DMUHeading2
af	af	Artificial fill	Holocene	Unconsolidated soil, sand, and gravel that underlie industrialized floodplain areas of northern Portland, Oreg., and Vancouver, Wash.; mounds of sand and minor gravel from channel dredging that flank Columbia River; and earth and crushed rock for highway and railroad beds, levees, and small dams	DMUUnit1
Qtf	Qtf	Fan deposits from tributaries	Holocene and Pleistocene	Unconsolidated silt, sand, and gravel in small fan-shaped accumulations from steep drainages in Tualatin Mountains. Most fans are younger than 2,000 years, inferred from relation with the Columbia River and Willamette River floodplain deposits (Qcwc and Qcwf). Poorly exposed, but likely composed of silt, sand, and gravel diamicts deposited by debris flow and stratified sediment deposited by streamflow	DMUUnit1

Notes: (1) MapUnit and Label are commonly, but not always, identical. Label allows for the use of special characters such as ^ *] that may be translated into ^ * } with the FGDC GeoAge font. (2) Unused fields (e.g., MapUnit, Label for heading rows) are filled with explicit null values, not empty strings. (3) Formatting such as the bolding of unit names and ages and parentheses around the unit age is not carried into the DMU table. (4) Some formatting cannot be readily stored in the quasi-ASCII Name and Description fields. If it is important to preserve such formatting, e.g., superscripts or paragraph breaks, use HTML-style markup.

Several fields are missing from this example. When translating an existing map into the GeMS schema, the translator will have to determine, for example, appropriate values of FullName, GeoMaterial, Symbol, Pattern, and AreaFillRGB. For the most part this should be straightforward. Assigning values of HierarchyKey is discussed at length below.

Older geologic maps and maps published by other agencies may not have Description of Map Units text formatted as shown above. But we have found no map-unit explanations that cannot be translated into this schema.

HierarchyKey

Explanations of units on geologic maps commonly are ordered and hierarchical. Map units are listed in an intentional sequence, map units may be listed under headings and subheadings, and some map units may be subdivisions of other map units. The sequence of map units shown in the Description of Map Units generally corresponds to the relative ages of map units. Hierarchy may express closeness in genesis, closeness in age, paleogeography, relative certainty of map-unit identification, and (or) other relations. In the **Description of Map Units** (DMU) or **List of Map Units** (LMU) text of a USGS geologic map, hierarchy is shown by paragraph style (font, alignment, indentation) of successive elements. This hierarchy is also shown by the spatial arrangement of map-unit polygons, headings, and brackets in the associated **Correlation of Map Units** (CMU) diagram.

We record these relations in the DescriptionOfMapUnits table with the HierarchyKey attribute, which (1) allows the table to be sorted into its proper sequence, and (2) records parent-child relations. Values of HierarchyKey are text strings with the form *nn-nn-nn*. Each fragment (*nn*) of HierarchyKey is numeric, left-padded with zeros to the same length, and hyphen-delimited. Different values of HierarchyKey may comprise different numbers of fragments. A DMU row with HierarchyKey = 03-11 is the eleventh child of the row with HierarchyKey = 03

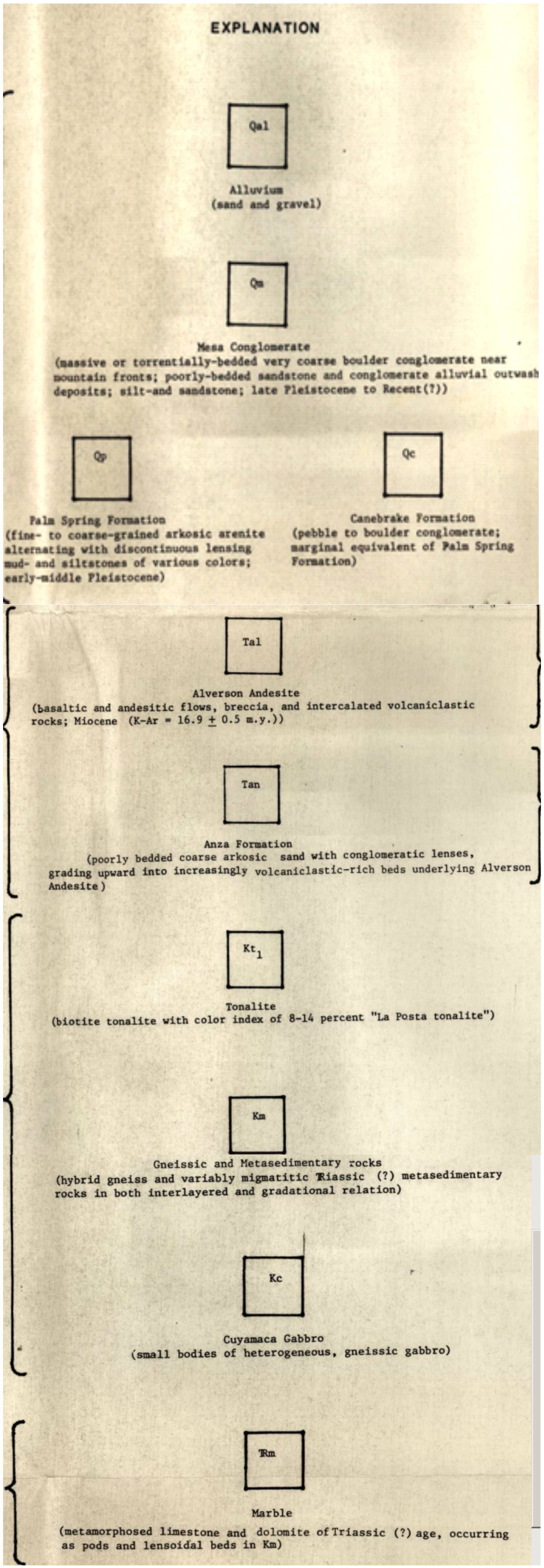
Some general rules for construction of HierarchyKeys are:

- Within siblings, elements are numbered youngest to oldest, left to right, first to last.
- A parent may have 0, 1, or many children.
- The length (*n* vs *nn* vs *nnn*) of the HierarchyKey fragments is determined by the size of the family with the largest number of siblings. It is not an error to have extra zeros (e.g., largest fragment value is *003*, instead of *3*) but this is discouraged as it reduces the readability of HierarchyKey values.
- Headings are not children of map units. Map units may be children of headings or of other map units.
- Values of HierarchyKey within a single DescriptionOfMapUnits table must be unique.
- If an ascending alphanumeric sort on HierarchyKey does not put DescriptionOfMapUnits in the correct order, one or more HierarchyKey values are incorrect.
- After sorting, an element may be the same length as its preceding element (a sibling), one fragment longer than its preceding element (a child, generations shall not be omitted), or shorter than its preceding element (aunt, great-aunt, etc.; not in the immediate family).

It is typically easier to decipher hierarchy from DMU or LMU text than from a CMU diagram.

There are published maps in which the LMU (or DMU) and CMU do not agree on the hierarchy of headings and map units. When encoding such maps, choose the hierarchy which you think best expresses the author’s intentions and will best serve users of the database.

The following examples illustrate the use of HierarchyKeys. Each example reproduces part of an Explanation or Correlation of Map Units diagram for a published map and part (some columns, relevant rows) of a corresponding DescriptionOfMapUnits table. *In a database the Name field is* *unformatted ASCII. In the tables below the Name fields are formatted (alignment, font) for purposes of illustration only, to match the List of Map Units or Description of Map Units text on the analog source map; the formatting should be recorded in ParagraphStyle.*



EXPLANATION

Qal

Alluvium
(sand and gravel)

Qm

Mesa Conglomerate
(massive or torrentially-bedded very coarse boulder conglomerate near mountain fronts; poorly-bedded sandstone and conglomerate alluvial outwash deposits; silt-and sandstone; late Pleistocene to Recent(?))

Qp

Palm Spring Formation
(fine- to coarse-grained arkosic arenite alternating with discontinuous lensing mud- and siltstones of various colors; early-middle Pleistocene)

Qc

Canebrake Formation
(pebble to boulder conglomerate; marginal equivalent of Palm Spring Formation)

Tal

Alverson Andesite
(basaltic and andesitic flows, breccia, and intercalated volcaniclastic rocks; Miocene (K-Ar = 16.9 ± 0.5 m.y.))

Tan

Anza Formation
(poorly bedded coarse arkosic sand with conglomeratic lenses, grading upward into increasingly volcaniclastic-rich beds underlying Alverson Andesite)

Kt_1

Tonalite
(biotite tonalite with color index of 8-14 percent "La Posta tonalite")

Km

Gneissic and Metasedimentary rocks
(hybrid gneiss and variably migmatitic Triassic (?) metasedimentary rocks in both interlayered and gradational relation)

Kc

Cuyamaca Gabbro
(small bodies of heterogeneous, gneissic gabbro)

TRm

Marble
(metamorphosed limestone and dolomite of Triassic (?) age, occurring as pods and lensoidal beds in Km)

From USGS Open-File Report 79-754, *Geologic map of the Sweeney Pass quadrangle, San Diego County, California*, by W.C. Hoggatt, 1979. Map accessed via National Geologic Map Database Mapview.

Hierarchy-Key	*Paragraph-Style*	*Map-Unit*	*NAME*
01	DMU1	Qal	Alluvium
02	DMU1	Qm	Mesa Conglomerate
03	DMU1	Qp	Palm Spring Formation
04	DMU1	Qc	Canebrake Formation
05	DMU1	Tal	Alverson Andesite
06	DMU1	Tan	Anza Formation
07	DMU1	Kt_1	Tonalite
08	DMU1	Km	Gneissic and metasedimentary rocks
09	DMU1	Kc	Cuyamaca Gabbro
10	DMU1	TRm	Marble

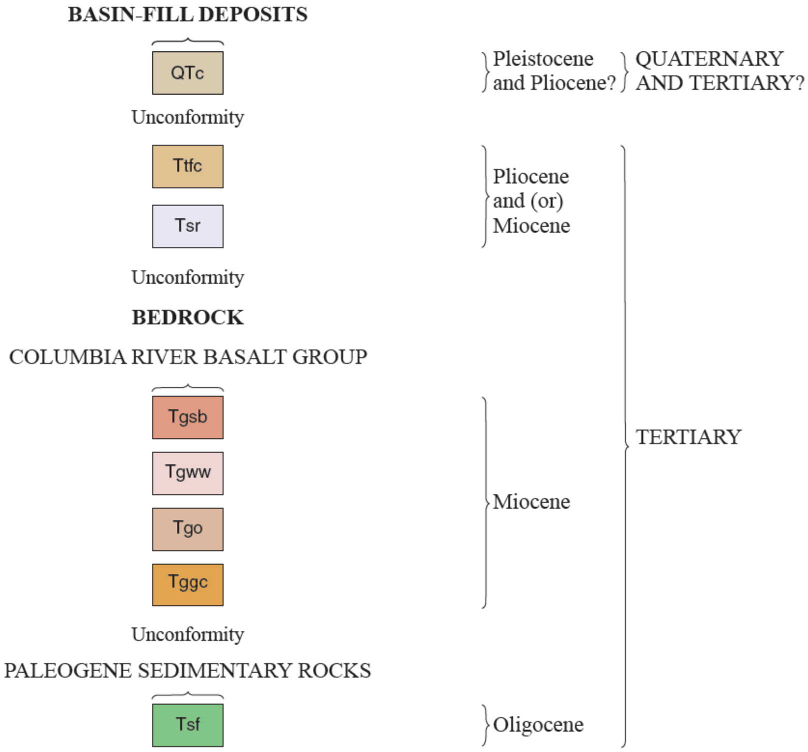
NOTES

This Explanation has no headings and no subunits.

Map-unit description is integrated with the Explanation; there is no separate Description of Map Units text accompanying this report.

There is a sequence (top to bottom, left to right) that is in order of geologic age, with Palm Spring and Canebrake Formations having the same age. Every entry has the same rank. HierarchyKey thus has sequential values 1 to 10, zero-padded so that an alphanumeric sort on HierarchyKey puts the rows of DescriptionOfMapUnits in the correct sequence.

The last entry (Marble, HierarchyKey = 10) has *MapUnit* value of **TRm**. This is an ASCII substitution for the unit label. The value "**^m**" for *Label* and symbolization of *Label* values with the FGDC GeoAge font produces the desired effect.



Part of **Correlation of Map Units** diagram from USGS SIM 3349, *Geologic map of the Sauvie Island quadrangle, Multnomah and Columbia Counties, Oregon, and Clark County, Washington*, by Russell C. Evarts, Jim O'Connor, and Charles M. Cannon, 2016.

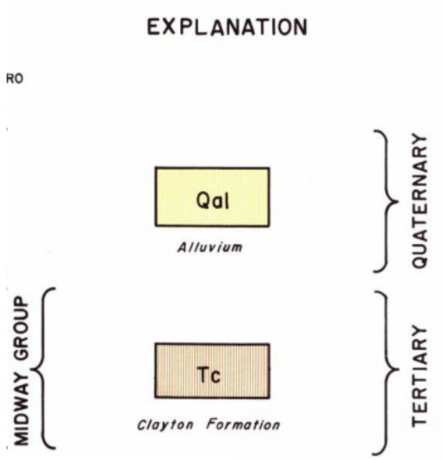
HierarchyKey	***ParagraphStyle***	***MapUnit***	***NAME***
2	Heading2		**BASIN FILL DEPOSITS**
2-1	DMU1	QTc	**Unnamed conglomerate**
2-2	DMU1	Ttfc	**Troutdale Formation, conglomerate member**
2-3	DMU1	Tsr	**Sandy River Mudstone**
3	Heading2		**BEDROCK**
3-1	Heading3		COLUMBIA RIVER BASALT GROUP
3-1-1	DMU1		**Grande Ronde Basalt**
3-1-1-1	DMU2	Tgsb	**Sentinel Bluffs Member**
3-1-1-2	DMU2	Tgww	**Winter Water Member**
3-1-1-3	DMU2	Tgo	**Ortley member of Reidel and Tolan (2013)**
3-1-1-4	DMU2	Tggc	**Grouse Creek member of Reidel and Tolan (2013)**
3-2	Heading3		PALEOGENE SEDIMENTARY ROCKS
3-2-1	DMU1	Tsf	**Scappoose Formation**

NOTES

Map also has younger deposits under heading “SURFICIAL DEPOSITS” (HierarchyKey = 1).

*For purposes of illustration only, the **Name*** field above reproduces typography (font, alignment) of **Description of Map Units** on the published map. This information should be recorded in ParagraphStyle.

The authors chose to treat Columbia River Basalt Group, which is a formal lithostratigraphic unit, as a heading, not a map unit. Grande Ronde Basalt is also a formal lithostratigraphic unit, also is not mapped, and the authors chose to treat it as a map unit. The ParagraphStyle attribute is required to distinguish these choices.



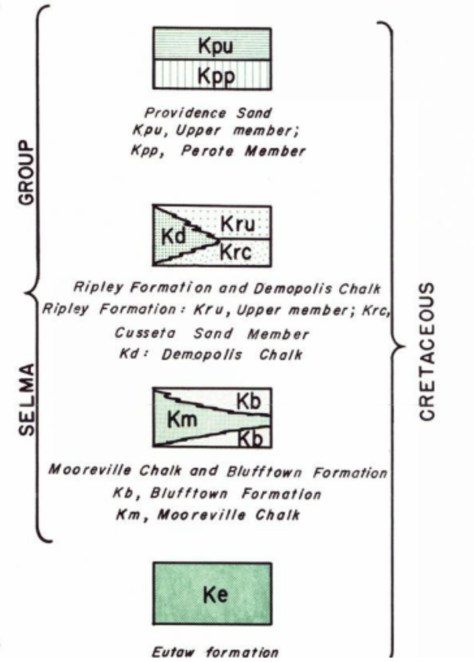
From Geological Survey of Alabama, Special Map 19, *Geologic map of Bullock County, Alabama*, by J.C. Scott, 1961. Map accessed via National Geologic Map Database Mapview

NOTES

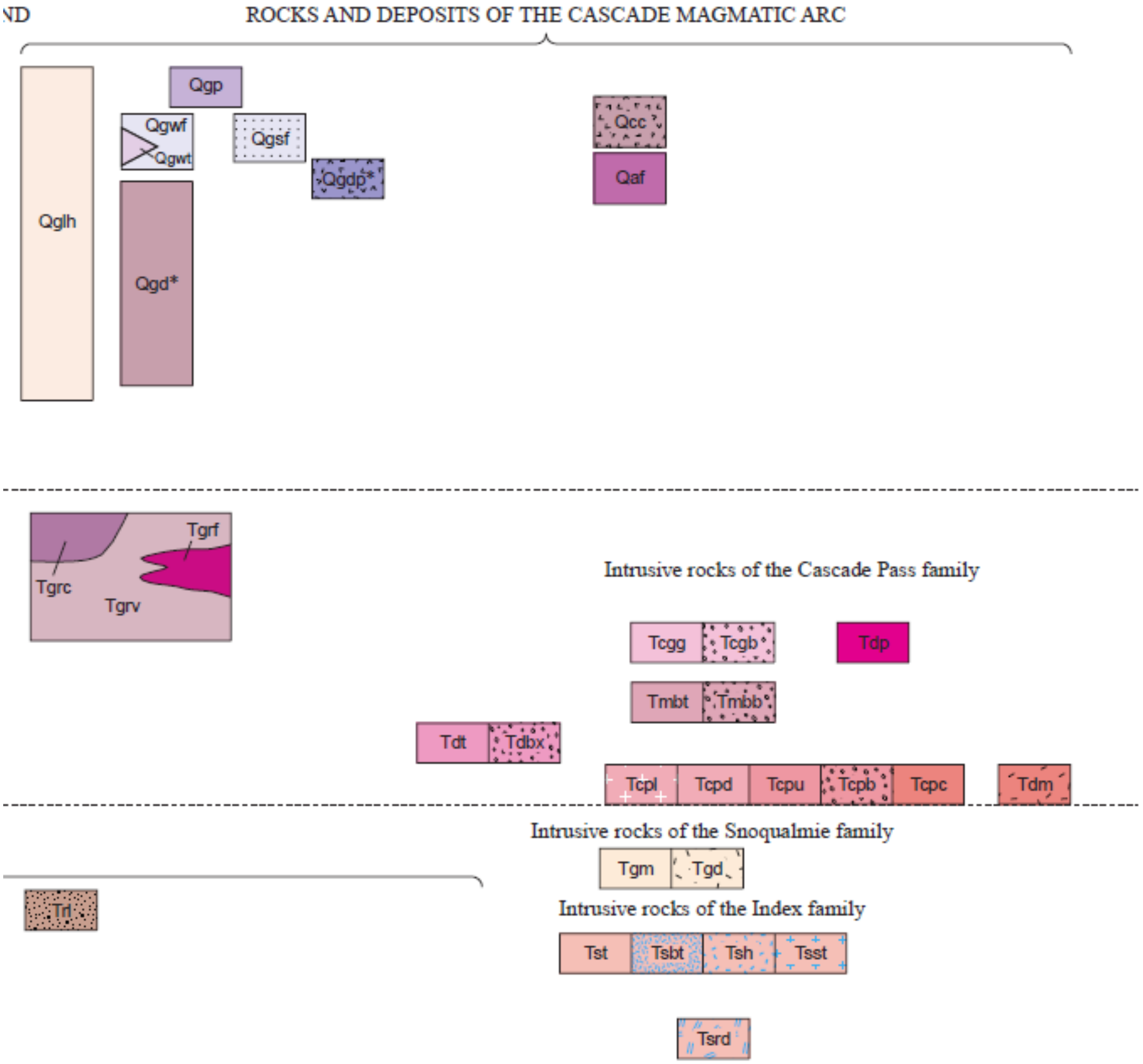
There is no separate Description of Map Units text in this report.

It is unclear whether Midway Group and Selma Group are headings or map units, but this ambiguity does not affect the obvious hierarchy expressed in the EXPLANATION layout or the corresponding HierarchyKey values.

Graphic (read left to right, top to bottom) has Demopolis Chalk preceding Ripley Formation. Order of the associated text suggests the reverse. Values of HierarchyKey below follow the graphic order.



Hierarchy-Key	*Paragraph-Style*	*MapUnit*	*NAME*
1	DMU1	Qal	Alluvium
2	Heading2		MIDWAY GROUP
2-1	DMU1	Tc	Clayton Formation
3	Heading2		SELMA GROUP
3-1	DMU1		Providence Sand
3-1-1	DMU2	Kpu	Upper member
3-1-2	DMU2	Kpp	Perote Member
3-2	DMU1		Ripley Formation and Demopolis Chalk
3-2-1	DMU2	Kd	Demopolis Chalk
3-2-2	DMU2		Ripley Formation
3-2-2-1	DMU3	Kru	Upper member
3-2-2-2	DMU3	Krc	Cusseta Sand Member
3-3	DMU1		Mooreville Chalk and Blufftown Formation
3-3-1	DMU2	Km	Mooreville Chalk
3-3-2	DMU2	Kb	Blufftown Formation
4	DMU1	Ke	Eutaw Formation



Part of **Correlation of Map Units** diagram from USGS Map I-2592, *Geologic map of the Sauk River 30- by 60-minute quadrangle, Washington*, by R.W. Tabor, D.B. Booth, J.A. Vance, and A.B. Ford, 2002.

HierarchyKey	***ParagraphStyle***	***MapUnit***	***NAME***
4	Heading2		ROCKS AND DEPOSITS OF THE CASCADE MAGMATIC ARC
4-1	DMU1		Rocks of Glacier Peak volcano and associate volcanic rocks and deposits
4-1-1	DMU2	Qglh	**Laharic deposits**
4-1-2	DMU2	Qgp	**Pumice deposits**
4-1-3	DMU2	Qgwf	**Deposits of the White Chuck fill**
4-1-3-1	DMU3	Qgwt	**Dacitic vitric tuff**
4-1-4	DMU2	Qgsf	**Deposits of the Suiattle fill**
4-1-5	DMU2	Qgd	**Dacite**
4-1-6	DMU2	Qgdp	**Dacite of Disappointment Peak**
4-1-7	DMU2	Qcc	**Cinder cones**
4-1-8	DMU2	Qaf	**Andesite flow**
4-2	DMU1		**Volcanic rocks of Gamma Ridge**
4-2-1	DMU2	Tgrv	**Volcanic rocks**
4-2-2	DMU2	Tgrc	**Conglomerate**
4-2-3	DMU2	Tgrf	**Altered andesite and dacite flows**

HierarchyKey	*ParagraphStyle*	*MapUnit*	*NAME*
4-3	Heading3		Intrusive rocks of the Cascade Pass Family
4-3-1	DMU1		**Cool Glacier stock**
4-3-1-1	DMU2	Tcgg	**Granodiorite**
4-3-1-2	DMU2	Tcgb	**Breccia**
4-3-2	DMU1	Tdp	**Dacite plugs and dikes**
4-3-3	DMU1		**Mount Buckindy pluton**
4-3-3-1	DMU2	Tmbt	**Tonalite and granodiorite**
4-3-3-2	DMU2	Tmbb	**Breccia**
4-3-4	DMU1		**Cascade Pass dike**
4-3-4-1	DMU2	Tdt	**Tonalite**
4-3-4-2	DMU2	Tdbx	**Breccia**
4-3-5	DMU1		**Cloudy Pass batholith and associated rocks**
4-3-5-1	DMU2	Tcpl	**Light-colored granite and granodiorite**
4-3-5-2	DMU2	Tcpd	**Dark-colored granodiorite, tonalite, gabbro, and quartz gabbro**
4-3-5-3	DMU2	Tcpu	**Granodiorite, tonalite, and gabbro, undivided**
4-3-5-4	DMU2	Tcpb	**Intrusive breccia**
4-3-5-5	DMU2	Tcpc	**Clustered light-colored dikes and irregular intrusive bodies**
4-3-6	DMU1	Tdm	**Downey Mountain stock**
4-4	Heading3		Intrusive rocks of the Snoqualmie Family
4-4-1	DMU1		**Grotto batholith**
4-4-1-1	DMU2	Tgm	**Monte Cristo stock**
4-4-1-2	DMU2	Tgd	**Dead Duck pluton**
4-5	Heading3		Intrusive rocks of the Index Family
4-5-1	DMU1		**Squire Creek stock and related intrusive rocks**
4-5-1-1	DMU2	Tst	**Tonalite**
4-5-1-2	DMU2	Tsbt	**Biotite tonalite**
4-5-1-3	DMU2	Tsh	**Hornblende quartz diorite**
4-5-1-4	DMU2	Tsst	**Tonalite of the Shake Creek stock**
4-5-2	DMU1	Tsrd	**Sauk ring dike**

NOTES

"ROCKS AND DEPOSITS OF THE CASCADE MAGMATIC ARC" is preceded by 3 other primary headings: "NON-GLACIAL DEPOSITS", "GLACIAL DEPOSITS", and "EARLY GLACIAL AND NON-GLACIAL DEPOSITS".

Unit Trl (lower left corner of CMU fragment) is not part of ROCKS AND DEPOSITS OF THE CASCADE MAGMATIC ARC

Name field above reproduces typography (font, alignment) of **List of Map Units** on the published map.

APPENDIX D. 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 create one or more Esri annotation feature classes along with instruction on how to use them.

How should I encode structure contours?

You have at least two choices. Structure contours may be encoded in an IsoValueLines feature class, with Type=”top Formation X” (or whatever is contoured), with a corresponding Glossary entry for “top Formation X” that clearly defines the contoured surface. The Glossary entry should also define the units used for the Value field, e.g., meters above NAVD88, and the ValueConfidence field, meters in this case. Alternately, create a new, appropriately named line feature class (e.g., StructureContours) 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) format.

How do I represent dikes?

Again, two choices. (1) Dikes are bodies of rock with finite extent. They may be represented as polygons (in feature class MapUnitPolys) of a MapUnit (e.g., Volcanic dikes) that is defined in DescriptionOfMapUnits and the polygons are surrounded by contacts (encoded in feature class ContactsAndFaults). This representation works with wide dikes and large map scales. As the scale decreases and the dikes narrow, this representation does not work. (2) Dikes are effectively of infinitesimal width and are represented as lines of Type = ‘dike’ (or perhaps Type = ‘Tertiary andesite dike’) that are part of feature class GeologicLines. Or they could be part of a feature class ‘DikesAndSills’.

Small areas of distinct rock type (e.g., intrusive necks, limestone blocks in a continental-slope olistostrome, blueschist knockers in mélange) present the same choice. Either represent them as polygons in MapUnitPolys, bounded by contacts and (or) faults in ContactsAndFaults, or represent them as points (with, e.g., Type = ‘intrusive neck’ or ‘limestone block’) in a RockUnitPoints feature class.

Does this draft 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 previously been published in analog (paper or PDF) form.

What about bedrock contacts under alluvium?

There are several options, all of which are valid in GeMS.

1) Show alluvium with concealed bedrock contacts. MapUnit is “alluvium”, area is colored yellow. There is no feature in the database that directly records the nature of underlying bedrock. The map user does the implicit analysis, extrapolating from the adjoining mapped bedrock, to figure out which bedrock unit underlies alluvium. This is the most commonly implemented option.
2) This is really a bedrock map. Map bedrock polygons. Color the bedrock. Show contact between bedrock units as an unconcealed contact. Use an overlay (yellow dots? yellow diagonal lines?)

to show the extent of overlying alluvium. If "alluvium" is described in table DescriptionOfMapUnit, the overlay reflects a polygon in feature class MapUnitOverlayPolys. If not, the overlay reflects a polygon in feature class OverlayPolys and "alluvium" is defined in table "Glossary"

3) This is not a bedrock map, but bedrock unit Tg is really important because it hosts economic silver mineralization. You want the map user to immediately see where it is present, even where covered by alluvium. Show yellow alluvium and dotted concealed contacts as in possibility 1, but where Tg is present beneath alluvium, show fat diagonal dashed pink lines. You may think of these lines as an "underlay", because they show the map unit that underlies alluvium, but graphically they are an overlay. Thus the fat diagonal dashed pink lines reflect a polygon in feature class MapUnitOverlayPolys.
4) Make a stack-unit map in which polygon Qa/Jm is adjacent to polygon Qa/Jk. You get to figure out how to symbolize polygons and bounding contacts, as the geologic mapping community as a whole doesn't have sufficient experience with such maps to prescribe how you should do this. Prepare to think hard about the DMU table and how it is related to MapUnitPolys.

How do I encode a 3-D geologic map?

ArcGIS, along with most other GIS software, was not designed to handle 3-D (volume) data. A useful approximation to a fully 3-D GIS is provided by a stack-unit map (see R.C. Berg and J.P. Kempton, 1988, Illinois State Geological Survey, Circular 542), in which the Earth's surface is divided into polygons that are characterized by the vertical succession of layers beneath each polygon. Many boundaries between polygons are not map-unit boundaries at the surface, but instead the location of lateral boundaries (pinch-outs, facies changes) below the surface.

To encode a stack-unit map, add field "MapUnitsStack" (type=Text, length ≥ 255 characters) to feature class MapUnitPolys. Values of this field are chains of triplets, in the form $\mathrm{MapUnit}_1$:$\mathrm{Qualifier}_1$:$\mathrm{ScientificConfidence}_1$, $\mathrm{MapUnit}_2$:$\mathrm{Qualifier}_2$:$\mathrm{ScientificConfidence}_2$, …, where each triplet represents a geologic layer, numbered from the surface down, and

MapUnit – has values of MapUnit from DescriptionOfMapUnits

Qualifier – records thickness, continuity, or other attributes. Values of Qualifier are defined in Glossary

ScientificConfidence – records the certainty with which MapUnit and Qualifier are known

$\mathrm{MapUnit}_1$ should be identical to the value of MapUnit in MapUnitPolys. $\mathrm{ScientificConfidence}_1$ should reflect the value of IdentityConfidence; it may not be identical because of uncertainty in $\mathrm{Qualifier}_1$.

The *Notes* field is empty for all records in my ContactsAndFaults feature class. May I delete this field?

Yes, *Notes* fields are optional and may be deleted if desired.

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

A fault map is not a geologic map, so this standard does not fully apply. Most fault maps, however, are analogous to parts of geologic maps and this standard provides useful guidance. Faults could be encoded in GeologicLines and associated tables.

May I give the map database to users in another format?

Certainly. But also make the GeMS format available.

My report has an auxiliary map showing the distribution of sedimentary facies in the Miocene. Where does this map fit in this design?

> The answer varies. Not all information depicted via an analog auxiliary map needs a separate digital map (feature dataset). Distribution of Miocene sedimentary facies could be handled via ExtendedAttributes for polygons of Miocene sedimentary rocks, via overlay polygons (OtherPolys), or via a new polygon feature class. If the map is not complex, then an image of the map may suffice. Use your judgment.

How can I tell if a database is compliant?

> Test compliance to the GeMS schema with the Validate Database script in the GeMS toolkit. This script checks that (1) required tables and feature classes are present, (2) tables and feature classes, both required and any others defined in this standard, have required fields and field characteristics, (3) non-null values are present in all fields where they are required, (4) all tables and feature classes have an *xxx*_ID (user-controlled primary key) field, (5) *xxx*_ID values (primary keys) are unique within the database, (6) all *xxx*SourceID values have corresponding entries in the DataSources table, (7) there are no unreferenced entries in DataSources, (8) all Type, IdentityConfidence, and ExistenceConfidence values have corresponding entries in the Glossary table, (9) there are no unreferenced entries in Glossary, (10) there are no false null values (empty or whitespace strings), (11) values of MapUnit in MapUnitPolys, CMUMapUnitPolys if it is present, any CS*x*MapUnitPolys, and the DescriptionOfMapUnits table correspond to each other, and (12) HierarchyKey values in DescriptionOfMapUnits are well-structured.
>
> The Topology Check script in the GeMS toolkit provides additional checks for automation errors and geologic blunders. This script builds and evaluates an ArcGIS topology with these rules: no overlaps in ContactsAndFaults, no self-overlaps in ContactsAndFaults, no self-intersections in ContactsAndFaults, no gaps in MapUnitPolys, no overlaps in MapUnitPolys, and all MapUnitPoly boundaries are covered by ContactsAndFaults arcs. Topology Check also evaluates node topology, summarizes the map units that bound ContactsAndFaults arcs, checks for duplicate point features, and identifies very small polygons in MapUnitPolys and very short arcs in ContactsAndFaults. Results of Topology Check should be taken with a grain of salt, as some issues flagged by this script may not be errors.

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 design we hope to see the emergence of community tools to solve it. Here are some suggestions: (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 traces—metafaults— analogous to 'routes' in workstation ArcInfo. Draw individual fault arcs as thick lines, thick dashed lines, and thick dots. Smooth (generalize, spline) the metafaults 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. Insofar as possible, avoid cartographic work in 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 the use of GeMS?

When fully adopted by the National Cooperative Geologic Mapping Program, conformance will be required on delivery of products funded by the Program. If adopted by the USGS as a whole, the Science Publishing Network may check for conformance as part of the publication process. If the design is widely adopted, users will demand conformance so that tools developed to manipulate these databases work properly.

APPENDIX E. CHANGES FROM NCGMP09v1.1 TO THIS DRAFT MANUSCRIPT OF GEMS

Substantive changes to the schema are highlighted in yellow.
Other changes are modifications to this draft manuscript.

Name change from NCGMP09 to GeMS

Change in authorship statement

Provision of a Table of Contents at beginning of manuscript

Throughout draft manuscript, numerous minor changes in formatting that should be invisible to most readers

Throughout draft manuscript, minor revisions for clarity

Change of most instances of "geodatabase" to "database"

Reduction in the use of 1st-person voice

Section **INTRODUCTION**

> Significant revisions for clarity
>
> Changed intent—from "proposes a schema" to "describes a schema"
>
> Changed "two decades" to "three decades"
>
> Added evolution of the schema post v1.1
>
> Former section **Contents** deleted
>
> Former section **Review, comment and revision** deleted
>
> Acknowledgments section moved to end of **INTRODUCTION**

Section **DESIGN CONSIDERATIONS**

> Significant revisions for clarity
>
> Section **Content of a tradition geologic map**: Bolding of elements of the map that are prescribed within GeMS
>
> Within **Extensions to traditional geologic map content**, headings **Glossary** and **GeoMaterial** renamed, and headings reordered
>
> Significant rewriting of the *Location confidence (spatial accuracy)* section of **Extensions to traditional geologic map content / Feature-level metadata.** Goal is to better explain intent of LocationConfidenceMeters attribute and better illustrate its use. Addition of example picklist for LocationConfidenceMeters values
>
> Addition of an example picklist for IdentityConfidence values to *Existence confidence, identity confidence, and scientific confidence* section of **Extensions to traditional geologic map content / Feature-level metadata**
>
> Addition of section *Working with multiple feature attributes* to **Extensions to traditional geologic map content / Feature-level metadata**

- Significant revision of section *GeoMaterial* (formerly *GeneralLithology*) in **Extensions to traditional geologic map content**
- In section **Naming database elements**, changed CamelCase to the more accurate PascalCase. Bullets re-ordered to separate cognitive and coding concerns

Section **THE DATABASE DESIGN**

- Paragraphs 2-4 moved to new section **Field hygiene**
- Addition of section **Field hygiene** under **General Considerations**. This section
  - States that required fields should not be deleted
  - Clarifies that this standard does not, in general prescribe field lengths
  - Describes use of explicit null values
  - Prohibits repurposing of required fields
  - Notes that *Notes* fields are optional and may be omitted
  - Includes paragraphs previously directly under heading **THE GEODATABASE DESIGN**
  - Includes table fragments illustrating use of primary (_ID) and foreign (ID) keys
- Section **Transparent Identifiers** revised for clarity
- Former section **Open file formats**
  - Section renamed to **File formats**
  - Specify use of .gdb only (not .mdb)
  - Discussion of text, table, and image formats substantially revised for clarity

Section **REQUIRED, AS-NEEDED, AND OPTIONAL CONTENTS OF A DIGITAL GEOLOGIC MAP PUBLICATION**

- Removed mentions of mapXYZ-mdb.zip, base.mdb, in line with suggestions to deprecate .mdb format
- Renamed base.gdb to mapXYZ-base.gdb

Section **THE DATABASE DESIGN**

- Initial paragraph, insertion of note that additional optional elements are permitted
- All tables: _ID field descriptions moved to ends of field lists. Note that field order is NOT prescribed by the standard. However, a consistent field order (as exemplified in this standard) makes use of the schema easier. Workflow considerations in ArcGIS make it desirable to have the Type (or MapUnit, or similar) field first
- All tables: RuleID and Override fields removed. Inclusion of these fields in the description of the schema is perceived by the USGS-AASG-DMT community as an impediment to understanding of the schema by those who do not use Esri's Cartographic Representations. Those who use Cartographic Representations will add these optional fields
- All tables: Statements that the Notes field is optional
- All tables: Change from "Nulls OK" to "Null values permitted"

DataSourcePolys (polygon feature class) moved from **Required Elements** to **As Needed Elements**. Minor revisions to introductory paragraph

Many tables: in field outlines, reordering of fields for consistency and clarity. *Note that GeMS does not prescribe field order*

DescriptionOfMapUnits (non-spatial table):

Deletion of Table 1 and references thereto. This material is now covered by Appendix C

Within field outline, revisions of paragraphs *Name* and *Description* describing how headings and headnotes are entered in DMU table

Within field outline, paragraph *Name*, clarification that formal names should verified in GEOLEX

Within field outline, addition of sentence to paragraph *Name* stating that text in this field should be unformatted

Statement that DMU heading text should be placed in Name field and accompanying headnote text, if present, should be in the Description field. This is a change from version 1.1.

Within field outline, Description of HierarchyKey rewritten for clarity

Fields GeneralLithology and GeneralLithologyConfidence replaced with GeoMaterial and GeoMaterialConfidence. Discussion of these fields moved down to be consistent with Field List

Added subheadings ‘Note on contents of Description field’ and ‘Implementation’

Extensive new material, mostly quoted from Suggestion to Authors (Hansen, 1991) and R.E. Wells (written communication), describing a traditional USGS map-unit description

Deletion of paragraph suggesting development of more-structured version of DMU descriptions

Addition of short paragraph that refers reader to Appendix C which illustrates construction of HierarchyKey values.

Revision of paragraph describing use of ParagraphStyle

DataSources (non-spatial table)

Addition of optional URL field.

Deletion of sentence at end that refers to ChangeLog.

GeoMaterialDict (non-spatial table) New section that describes new table

Glosssary (non-spatial table)

Qualifier and Property deleted from list of fields for which all values used must be defined in Glossary. These fields are within table Extended Attributes, which is removed from this version.

GeoMaterial and GeoMaterialConfidence deleted from list of fields, as these are defined in table GeoMaterialsDict and this documentation (Appendix A)

Sentence “Lithology terms used in GeneralLithology must not be redefined from the NGMDB standard” deleted from descriptive paragraph following table outline. The field name has changed and the need to not redefine these terms is addressed in the discussion of new table GeoMaterialDict.

As-needed elements: Guidelines for naming and designing additional feature classes

CamelCase changed to the more accurate term PascalCase

Deletion of last sentence requesting comments on naming of feature classes

As-needed elements:

Structure of point data: Point feature classes in general

Addition of short paragraph explaining utility of MapUnit field

Changed “Sample-oriented point feature classes shall have the fields:” to “…may have the fields”

Some examples of as-needed feature classes

Orientation Points

Addition of fields StationID and MapUnit, for consistency with generic point class outlined earlier. Renaming of DataSourceID to LocationSourceID. Addition of field OrientationSourceID

Deletion of last sentence in explanatory paragraph that referred to ExtendedAttributes table

Stations (point feature class)

Addition of short paragraph explaining utility of ObservedMapUnit field

In field outline, MapUnit field, changed “Null values not permitted” to “Null values permitted, but will only be present for Stations points outside extent of MapUnitPolys”

In field outline, addition of “Default value is 0 (display at all scales)” to text describing *PlotAtScale* field

In field outline, addition of “and affiliation (optional)” to text describing *Observer* field

GeochronPoints

Renaming of DataSourceID to LocationSourceID. Addition of field AnalysisSourceID

IsoValueLines

Addition of field LocationConfidenceMeters

OtherPolys (polygon feature class)

Section renamed to Overlay Polygons

Addition of as-needed feature class MapUnitOverlayPolys.

Feature class OtherPolys renamed to OverlayPolys.

Explanatory text revised significantly

DataSourcePolys (point feature class)

Deletion of topology rule “Polygon boundaries may in part be coincident” as unnecessary

Section **SYMBOLIZATION**

Last paragraph moved to be 2nd paragraph.

Substantial revisions for clarity, including new paragraph breaks

New 4th paragraph: new URL for Esri’s Geologic Mapping Template.

New 5th paragraph: changed “we also require provision of an ArcReader document” to “we suggest provision of an ArcReader document”. This makes this paragraph consistent with digital publication contents enumerated in **REQUIRED, AS-NEEDED, AND OPTIONAL CONTENTS OF A DIGITAL GEOLOGIC MAP PUBLICATION**

Section **SHAPEFILE VERSIONS OF THE DATABASE**

Minor revisions for clarity

Some shapefile field names changed for clarity: IdeCon to IdeConf, MUnPol_ID to MUPs_ID, Des to Descr, ParSty to ParaSty, ConFau_ID to CAFs_ID, ExiCon to ExiConf. New field names GeoMat and GeoMatConf

Section **APPENDIX A. TERMS FOR GEOMATERIAL AND GEOMATERIALCONFIDENCE**

Section renamed from **LITHOLOGY AND CONFIDENCE TERMS FOR GENERALLITHOLOGY**

Minor changes for clarity in first two paragraphs

Revision of 3rd paragraph to remove reference to future evolution of term list

Deletion of initial indefinite article from many term descriptions

Term “**Debris flows, landslides, and other localized mass-movement sediment**”: Elimination of penultimate sentence. Addition of “downslope” to ultimate sentence

Addition of terms **Limestone** and **Dolomite** under **Carbonate rock**.

Addition of term **Chert** under **Sedimentary rock**

Addition of term **Volcanic mass flow** under **Extrusive igneous material**

For all metamorphic rocks, change of “shearing stress” to “deformation”

Addition of term **Lower-grade metamorphic rock, of unspecified origin** under **Regional metamorphic rock, of unspecified origin**

Change of term **Medium and higher-grade metamorphic rock, of unspecified origin** to **Higher-grade metamorphic rock, of unspecified origin**. Minor revision of penultimate sentence for clarity

Term **Deformation-related metamorphic rock:** First sentence modified to emphasize primary role of deformation. Added “and cataclasite” to last sentence

Addition of term **Meta-carbonate rock** under **Metasedimentary rock**.

Deletion of term **Marble**.

Addition of term **Meta-ultramafic rock**, under term **Metaigneous rock**

Addition of term **Meta-mafic rock**, under term **Metaigneous rock**

Addition of term **Meta-felsic and -intermediate rock**, under term **Metaigneous rock**

Addition of term **Meta-volcaniclastic rock**, under term **Metaigneous rock**

Section **Appendix B. OPTIONAL ELEMENTS**

Section **Correlation of Map Units (feature dataset)**: 2nd paragraph deleted

MiscellaneousMapInformation (non-spatial table): New section that describes new table.

Former sections **ExtendedAttributes** and **GeologicEvents** deleted. To our knowledge no one in the USGS-AASG community has implemented these tables in a published database. Note that this deletion does not preclude implementation of either table

New section **Deprecated non-spatial tables** added. Refers interested map authors and publishers to v1.1 documentation for descriptions of ExtendedAttributes and GeologicEvents

Former section **Appendix C. BUILDING A COMPLIANT DATABASE**:

Deleted. We expect this material, in revised form, to appear in a less-formal document that describes techniques for working with the GeMS schema

Section **Appendix C. PARSING THE DESCRIPTION OF MAPUNITS AND HIERARCHYKEY**

New section illustrating the translation of traditional text DESCRIPTION OF MAP UNITS into the DescriptionOfMapUnits table, and describing HierarchyKey, giving rules for its construction, and illustrating these rules using Explanations or Correlation of Map Units diagrams from four published maps.

Section **Appendix D. FREQUENTLY ASKED QUESTIONS**

Question "How do I represent dikes?" First paragraph, penultimate sentence, "OtherLines" changed to "GeologicLines." "OtherLines" was an error in v1.1

New question "What about bedrock contacts under alluvium?"

Question "The *Notes* field is empty for all records in my ContactsAndFaults feature class. May I delete this field?" Answer changed to indicate that *Notes* fields are optional and may be deleted

Question "What about my fault map? It doesn't show geologic units." Answer changed to suggest encoding of faults in GeologicLines rather than ContactsAndFaults

Question "My report has an auxiliary map showing the distribution of sedimentary facies in the Miocene. Where does this map fit in this design?" Second sentence, changed "feature class" to "feature dataset" (an error in version 1.1)

Question "How can I tell if a database is compliant?" Substantially expanded

Question "How do I use one of these databases to make a publication-quality map image?" Minor revisions for clarity

Section **Appendix E. CHANGES FROM NCGMP09V1.1 TO GEMS**

New section