DIGITAL GEOLOGIC MAP DATA MODEL

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A current version of this report, as well as comments and discussion concerning this report are available at: http://geology.usgs.gov/dm/

About this Document

The following is a working document that constitutes a portion of the recommendations of the Geologic Map Data Model Working Group. The working group was formed as a cooperative effort by the Association of American State Geologists (AASG) and the U.S. Geological Survey (USGS) to promote the development of digital geologic map data standards. This report has not been reviewed or approved by either the AASG or USGS. Updated releases of this report will be placed on a data model discussion site on the Web (http://geology.usgs.gov/dm/) as the report evolves during the informal review process. If you have Web access, please use the discussion Web site for all comments and suggestions. If you do not have Web access, please forward all comments and suggestions to **Bruce Johnson** (address below). To discuss this report or ask detailed questions, contact one of the following: **Bruce Johnson**, U.S. Geological Survey, 954 National Center, Reston, Virginia 20192, USA, telephone: 703-648-6051, fax: 703-648-6383, email: bjohnson@usgs.gov; **Boyan Brodaric**, Geological Survey of Canada, 615 Booth St., room 234B, Ottawa, Ontario K1A 0E9, Canada, telephone: 613/992-3562 fax: 613/995-9273 email: brodaric@gsc.nrcan.gc.ca; or **Gary Raines**, U.S. Geological Survey, c/o Mackay School of Mines MS 176, University of Nevada Reno, Reno, Nevada 89557, USA, telephone: 702-784-5596, fax: 702-784-5079, email: graines@usgs.gov. Please label all comments with the version and date of the manuscript.

Acknowledgments

The effort to create a data model for digital geologic maps has involved many people and a lot of intense discussion. This document attempts to condense that discussion into a manageable form and to present the results, a relational data model for digital geologic maps. Consequently the authors have drawn on their own experiences as well as the contributions of many others. We wish to acknowledge the many people who have contributed, both in direct conversations with the authors and with comments submitted to the discussion Web site mentioned above. We have attempted to organize and compile our understanding of these diverse thoughts to define the grammar and some of the vocabulary of geologic maps in a computer geographic information system context.

Contents

Figures

Tables

Introduction

What is a digital geologic map? A digital geologic map is any geologic map whose geographic details and explanatory data are recorded in a digital format that is readable by computer. What is a geologic map? In the context of this report, a geologic map is a representation of selected geologic objects located in space and time and symbolized and described for some specific purpose. The geologic objects to be represented on the map may be selected either by some set of geologic attributes or by geographic extent; usually both types of criteria are used.

A more formal definition of a geologic map is diagrammed in Figure 1. Each circle represents a class of objects and a portion of the model. Spatial Objects are the digital representations of real-world geologic features that have been observed and mapped. They are typically represented as polygons, lines or points on maps. Descriptive Data represents the archive of characteristics, or attributes, of Spatial Objects. For purposes of data modeling, these characteristics are either singular, relating to a single spatial object such as a structural measurement or an observation, or compound, relating to multiple or compound spatial objects such as a formation or a regional fault. Legends are used to extract the appropriate spatial objects from the archives and to symbolize and describe those objects for a particular map. Legends include information about the extent and scale of the map, the classification scheme to be used, and the symbolization of geologic objects to be presented on the map. Maps are then the intersection of spatial objects, the associated descriptions of the spatial objects, and the selection, classification, and symbolization of the selected objects for the purposes of the map. The intersection of the Legend with the Descriptive Data represents the data selection and classification operation. The intersection of the Legend with the Spatial Objects represents the spatial selection and classification operation. The intersection of Spatial Objects with Descriptive Data represents the singular objects.

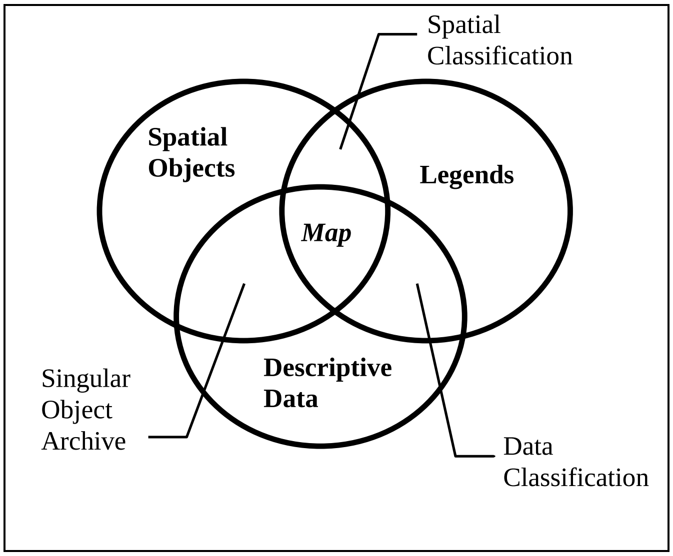


Figure 1: Diagram showing the three classes of objects in the geologic map data model.
Each circle represents a class of objects and a portion of the model.

There are two fundamentally different conceptual uses for digital geologic maps, cartography and analysis. Cartographers are generally concerned with using the digital representation of the geologic map to produce one or more published geologic maps, usually on paper. Analysts are generally concerned with using the digital representation of the geologic map to combine with other data in a computer in order to solve some problem. Although, there are differences of opinion among cartographers about whether digital methods are faster or more efficient for the initial production of geologic maps, nearly all agree that digital maps are much faster and more efficient to update. Furthermore, digital geologic maps are much more likely to be re-used for purposes beyond their original goals. Digital maps can easily be re-drawn at a different scale or projection than the original and features on the maps can be easily added, deleted, or modified. Thus, the original map, that is the digital data, does not become obsolete just because of changing needs or purposes. Both cartographic and analytical aspects are involved in the production and utilization of geologic maps: e.g. both analysts and cartographers must symbolize maps for presentation, though analysts tend to precede presentation with various computations. Therefore the perspective taken in this paper is that cartographic uses can be thought of as a subset of the analytical uses.

Overview

This report is intended for an audience with a wide diversity of GIS, database management, and geologic expertise. Consequently, the individual sections need not be read sequentially and some redundancy is introduced to meet the needs of different readers. Readers may want to focus on the sections relevant to their interests and expertise. This first portion of the report gives an overview of why a geologic map data model is needed for creation, exchange and spatial analysis and how we believe the design should be approached. In subsequent sections, we define a relational database model, which can be implemented on a modern GIS, and discuss issues for implementing and evolving the relational database model.

Purpose

The purpose of a data model for digital geologic maps is to provide a structure for the organization, storage, and use of geologic map data in a computer. The data model defines formally the grammar of geologic maps. This grammar is independent of the vocabulary of geologic maps. To be truly powerful it is necessary to address both the grammar and the vocabulary. The primary objective of the current effort is to develop a digital data model (the formal grammar) for geologic map information. A secondary objective is to develop as much of the vocabulary as possible as examples of the vocabulary that might be used. This vocabulary also helps communicate a better understanding of the model.

The data model is presented as an entity-relational model for relational databases. An object model that is more conceptual in nature and future oriented is also being developed, but is not presented here. Both approaches attempt to be independent of any specific software/hardware configuration. The relational model is the stepping off point for implementing the data model in a GIS such as Arc/Info or Arcview.

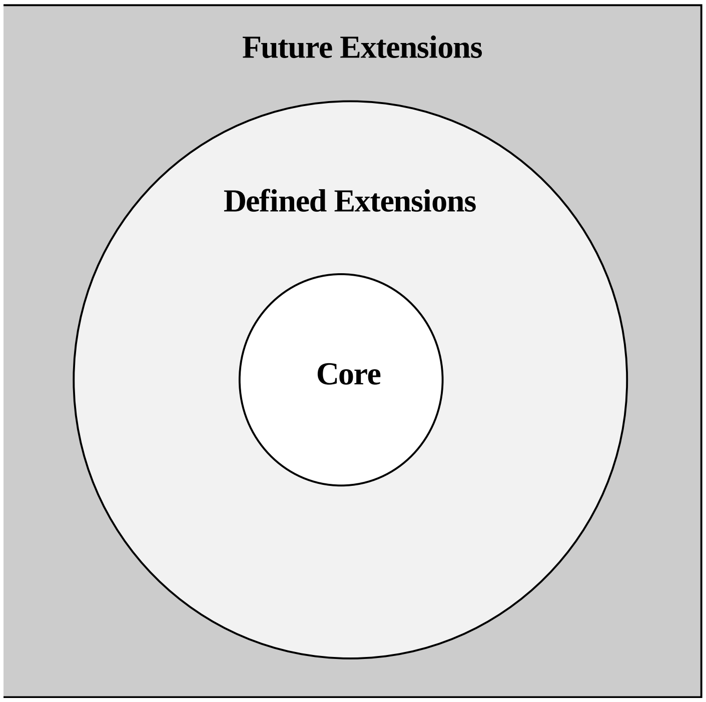
Design Objectives

A number of design criteria have been identified to guide the development of the data model. Those criteria are the following:

- The data model should be easy to implement and place minimal requirements on the person or organization creating a digital geologic map.
- There should be a set of minimal, or core (Figure 2), requirements that are necessary for all geologic maps.
- There are many common types of objects that do not occur on all maps, such as structural symbols, that need to be considered. These are addressed as defined extensions (Figure 2) to the core requirements.
- The data model should be easily extended to include new features, preferably as additional tables that attach additional types of information to the digital model. Examples might include amplification of the legend, engineering properties, etc. The opportunities for future extensions (Figure 2) will evolve with time and definition of new uses.
- Mechanisms are needed within the model to document the source of each individual geologic object. The source should include the full bibliographic reference for the object.
- The data model does not fully define standard vocabulary but provides the capability to incorporate vocabulary standards. The words used in most data fields should be selected from a defined list of terms so that the resulting digital maps can be used efficiently for computer analysis. The words in these lists are by definition broad terms. Specific finer subdivision of terminology can be inserted in open fields or can be added as extensions, as discussed above. The model attempts to add more structure to the communication of information to minimize ambiguity.
- The model should avoid explicit use of code dictionaries for translation of geologic vocabulary. The use of codes where needed, however, can be facilitated through software tools.
- Attributes of geologic objects on geologic maps are commonly interrelated. Thus a fault may separate two polygons and continue internally into a third polygon. Spatial attributes of such features need to be stored

together in order to do structural analyses; for example, selecting individual polygons on the upper plate of a thrust.

- A mechanism for identifying individual geologic occurrences should be included. This mechanism provides for uses such as outcrop mapping, describing the lithology of a specific polygon within a larger map unit, or a specific segment of a fault.



Core

- Unit, Linear Feature and Site attributes
- Map Legend
- Symbolization

Defined Extensions

- Structural measurements, such as strike and dip.
- Individual polygon and line attributes
- Overlay polygons
- Other lines

Future Extensions

- Cross sections
- Engineering properties
- Relation of topographic base for such things as 3-point problems.
- Field data

Figure 2: Diagrammatic representation of the scope of the data model.

The Core is the required minimum that is common to all geologic maps. The Defined Extensions are things that are common to many maps and are used as needed. Future Extensions include things that are complex or unusual, but have to be considered so the model can be extended. These Future Extensions may then become part of the Core or Defined Extensions.

The Relational Model

Geologic Maps

Geologic maps can be extremely complex with many different types of information displayed. Most geologic maps include a background of polygonal areas, which represent geologic units or materials that cover the geologic units such as water, ice, etc. The lines which separate the polygons also have significance where they represent differing types of geological boundaries such as contacts. Overlaying this background, there are usually numerous linear features such as faults, folds, dikes, veins, etc. and several different types of point features such a structural symbols and sample location symbols.

Additional complexity is introduced by the lack of universal standards for the symbolization of geologic maps. Although some general colors are often used for the same general types of rock units, there is no standard in common use for assigning a particular rock unit the same color or pattern on all maps. The same is true to a lesser degree for line patterns and point symbols. Although there are standard patterns for the common types of faults, a pattern that represents a dike on one map may be used to represent an unusual type of fault or a vein on an adjacent map. On two-dimensional geologic maps, geologic features can be geometrically represented as points, lines, or polygons. It is these features, in all of their complexity, that must be included in a digital geologic map data model.

Digital Geologic Map Consistency

Consistency from one map to the next is not a primary concern when users are focused on local problems or when using digital geologic maps only for cartographic purposes. It’s certainly better if adjacent maps use similar styles to depict similar features, but users are adept at compensating for differing map styles across map boundaries. As geologic maps are used for larger, regional studies, consistency of data representation becomes more important. Often it’s much easier to accomplish regional modeling or synthesis programs if the geologic maps are in a digital format. When combining digital geologic maps to create regional data sets, there are three levels of consistency that must be considered.

The first level is the consistency of the original mapping. Were the maps to be combined created for the same purpose? Do they use the same (or at least similar) units? Many kinds of geologic inconsistencies can be ignored. For example, one map may show all Tertiary volcanic rocks as a single unit while the adjacent map splits the Tertiary volcanic rocks into several units. As long as the two maps are in reasonable agreement on what constitutes a Tertiary volcanic rock, the maps can be successfully combined. There would certainly be more detail on one portion of the combined map than on the rest, but if that level of detail would not be important to subsequent users, the combined map would be entirely satisfactory.

If, however, the two adjacent maps had been originally created for different purposes, the combination becomes more difficult and less useful. As an extreme example, suppose one of the two adjacent maps had been created to depict bedrock geology only, and the other had been created specifically to depict surficial deposits. In this case, there might be little, if any overlap in the units depicted and not much point in attempting to combine the maps. Consideration of this first type of geologic consistency becomes important for creating regional digital data archives composed of many individual maps. If maps that were originally created for several different purposes are to be archived, they should be kept in separate archives or in separate data layers within a single archive.

The second level of consistency that is required for successfully combining adjacent maps into regional data layers is consistency of descriptive information. This level assumes geologic consistency is sufficient to make combining the maps a reasonable task. Before the maps can be combined, the descriptive information (attributes) assigned to each feature on each map must be made consistent. If one map includes a polygon attribute for age of rock unit and an adjacent map does not, the maps can be combined, but the results of any attempt to analyze areas by age of rock unit will be misleading. In this case, the rock unit age information should be added where it is missing.

A more usual occurrence, however, is two adjacent maps which both contain age information, but the information is formatted differently. One map may have a single attribute for stratigraphic age for each polygon representing the “best” or central age of the unit. The single attribute for each polygon in the digital map might have a code representing the time-stratigraphic unit during which the unit was deposited. An adjacent map might have two attributes to represent stratigraphic age, a minimum age and a maximum age. Each attribute would still contain a time-stratigraphic unit, but they would represent the extremes of the formation of the unit as opposed to the central age. A third map in the region might also have two attributes for stratigraphic age, but the attributes might contain radiometric ages for the minimum and maximum age of formation of the unit. Although each of these techniques of attributing stratigraphic age might be useful for a single map, it's clear that a great deal of work would be required to combine all of these maps into a regional synthesis with consistent age attributes. The answer to this dilemma, of course, is to create the digital maps with a consistent set of attributes from the beginning. That is one of the goals of creating a consistent data model.

A third level of consistency that is required for successfully combining digital geologic maps is consistency of coding. It's often more convenient and less storage intensive to substitute codes for descriptive attributes. To continue the example of stratigraphic age attributes, time-stratigraphic units could be entered in the database as complete words (Mississippian, Paleozoic, etc.), as shortened abbreviations (M, Pz, etc.), or as numeric codes (1, 10, etc.). If the user of the final regional geologic map wanted to find all areas of Mississippian rocks, it would be easier to search for one of the representations than to have to search for all three. Fortunately, as long as the representation used for each map is internally consistent and all of the maps meet the requirements of the first two levels of consistency, it is usually an easy task to automate the process of converting all attributes to a common representation.

Independent of the consistency required for combining digital maps into regional data sets, another aspect that must be considered is consistency over time. If the digital maps are going to achieve their maximum usefulness, long-term consistency of the underlying data model is important. Careful thought must be given at the beginning of all large-scale attempts to create regional, digital geologic maps to the expected (and unexpected) uses of the maps in the future. Because it is difficult, if not impossible, to foresee how the data will be used in the future, flexibility becomes a primary requirement of all data models. To increase flexibility, all data models should be open-ended so that it is always possible to respond to needs for new types of information to be attached to each feature.

As well as consistency through time, digital map designers should also consider consistency across a spectrum of users. Usually, when the decision is made to acquire digital geology, there is a specific goal that is driving the acquisition. The specific goal may not require a complete set of attributes for each map. It is certainly less expensive initially to collect just the information needed for the immediate goal. However, it is usually more expensive to collect additional data at a later time than to collect the additional data initially. The designer of the data collection scheme should carefully consider other possible uses of the information both within and outside of the collecting organization.

Fundamentals of the Model

The goal of this relational geologic map data model is to build, in the digital world, the equivalent to a geologic map library, or warehouse. From a well-indexed library of paper geologic maps, one could retrieve various maps from a specified geographic area. If the library were well staffed with eager assistants, one could also generate composite regional geologic maps by trimming and pasting existing maps into larger sheets. If the existing maps were originally created at different scales, it would take an extraordinary staff of assistants to perform this task. However, the shift to digital geologic maps alleviates this process, as it allows one to more readily generate composite maps from existing maps created at different scales and projections. It also allows one to create derivative maps at the individual map feature level instead of at the entire map level. For instance, with digital maps, one can select individual units to display, create new units by re-combining original map units, create units based on other features of the existing units such as lithology, etc. Once the existing mapping is stored in the digital library, only the imagination limits further uses of the data.

The core of the relational geologic map data model is an archive of digital geologic objects from which one can create geologic maps (Figure 3). Although the model can be easily extended to include three-dimensional objects, the data model presented here is confined to two-dimensional objects. These objects are two-dimensional representations of three-dimensional geologic objects, which are themselves interpretations of the real world. The digital archive consists of a database representing occurrences of geologic features such as areas of particular rock types, structures, field sites, etc. The archive may include a geographic description of each feature as well as its attribute (descriptive) information and a source reference. The geologic objects in the archive may come from many different sources, including published maps as well as new, unpublished mapping.

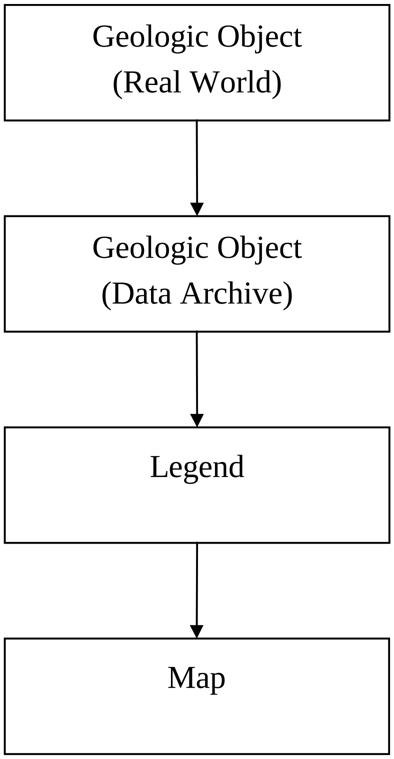


Figure 3. Fundamentals of the relational geologic map data model.

> The core of the data model is an archive of digital geologic objects from which one can create geologic maps. The archive consists of a database of geologic features, including areas of particular rock type, structures, data sites, etc. The archive may include a geographic description of each entity as well as its attribute (descriptive) information and a source reference. The map legend filters the archive for specific geologic objects and symbolizes them for depiction on the map. To create a map from existing data, a new Legend is defined and then applied to the archive.

The digital archive of geologic features is connected to a geologic map legend facility (Figure 3). This legend facility can be viewed as a filter, which selects specific geologic features from the archive and symbolizes them for presentation on a map. Thus, the process of creating a new, or derivative, map from existing data within the archive, becomes a natural process of defining the new map’s legend and then applying it to the archive.

In summary, real world geology is interpreted by the geologist and those interpretations are recorded on maps (or photos) as geographic objects (points, lines, areas, etc.) with descriptive information. The geographic representations of the geologic objects as well as the descriptive information are then stored in the archive. To create a map from the archive, a user formalizes the desired content and symbolization of the map by defining a map legend. The map legend is then applied to the archive to generate the new map or retrieve a previous map.

The previous discussion describes the model as shown on Figure 3 from the point of view of a creator of a new map and from the point of view of a user creating derivative maps from the archive. There are two other cases that should be considered. The first is a user who needs to enter the data from an existing map into the archive. In this case, the user will need to enter the legend information as well as the geologic objects from the existing map into the archive. Storing legend information along with the geologic objects also enables the final use of the map library. A user who wishes to retrieve a previously entered map for some sort of output simply retrieves the previously stored legend information and applies it to the archive to re-create the desired map.

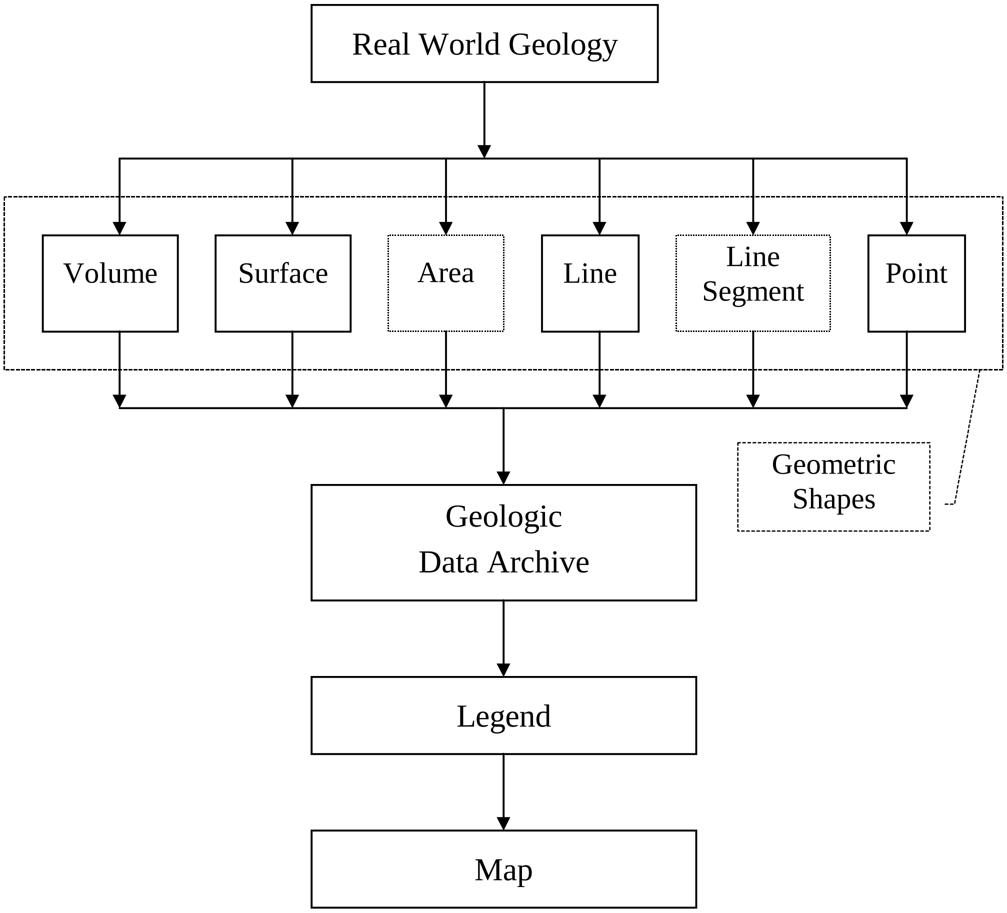


Figure 4. Geometric shapes of geologic objects.

All real-world geologic objects occur in various geometric shapes in space: e.g. points, lines, surfaces, and volumes. Line segments and surface areas are special, bounded cases of lines and surfaces, respectively (dotted box outlines). Any of these geometric shapes can be used to represent geologic objects on maps. For two-dimensional maps, geologic objects are confined to area, line segment, and point representations. A data model must be consistent with the fact that any geologic object may be represented by any of these shapes as a function of the type and scale of the map.

The data model is consistent with the fact that any geologic feature may be represented as one or more geometric shapes (e.g. Figure 4 - volumes, surfaces, areas, lines, etc.) depending on the type and scale of the map. For example, rock units are not confined to a volume (or area, in two-dimensions) geometry. At a small enough map scale, thin rock units may appear as surfaces (represented as lines or line segments in two dimensions) and small, but important, units may be represented as points. Similarly, veins, dikes, fault zones, etc. may change representational geometry with changes in scale.

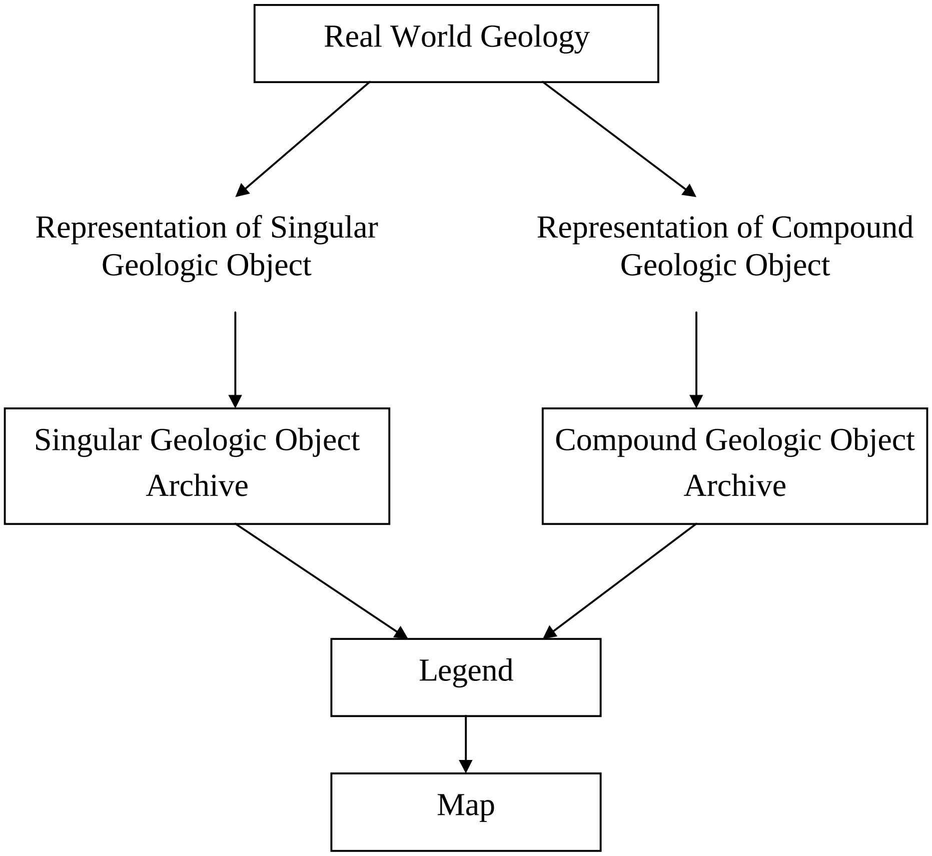


Figure 5. Two categories of geologic objects.

For purposes of data modeling, geologic objects can be divided into two categories, singular objects and compound objects. Singular geologic objects are those which have been directly observed at a single point location, such as bedding orientations, sample descriptions, chemical analyses, measured sections, etc. as well as those which relate to a single map entity (single polygon or line segment). Compound geologic objects typically include information from observations at multiple locations, such as locations of contacts or structures as well as descriptions of stratigraphic units, structural units, metamorphic units, etc. Singular and compound objects are generally treated differently and are therefore stored in different portions of the data archive.

For purposes of data modeling, representations of geologic objects can be divided into two categories, singular objects and compound objects (Figure 5). Singular geologic objects are those which have been directly observed at a single point location, such as bedding orientations, sample descriptions, chemical analyses, measured sections, etc. Singular geologic objects can also be single map entities (a single polygon or line segment) which may also belong to a more general, compound object. Compound geologic objects typically consist of the interpretation, grouping, or classification of many observations at multiple locations. Included are map units made up of many observations of outcrops, faults made by grouping individual fault traces observed in multiple outcrops, as well as extended locations of contacts, structures, rock units, alteration zones, and metamorphic grade zones. Compound objects also include descriptions of stratigraphic units, structural units, metamorphic units, etc.

Individual map features can be both singular objects and parts of compound objects. For example, a single polygon on a map may represent one of many outcrop areas of a rock unit, such as the Babblebrook Granite. Therefore, the polygon is a part of a compound object, which is made up of all of the polygons representing the Babblebrook Granite along with all of the descriptive information about the unit. At the same time, there may be descriptive information that only refers to one of the many polygons that make up the unit, such as the name Clearwater Pluton. Therefore, the polygon that represents the Clearwater Pluton acts as both a singular object and as a portion of a compound object. The same argument can be made for many types of linear and areal objects within the archive. Singular and compound objects are generally treated differently in the process of creating maps from the archive and are therefore stored in different portions of the data archive.

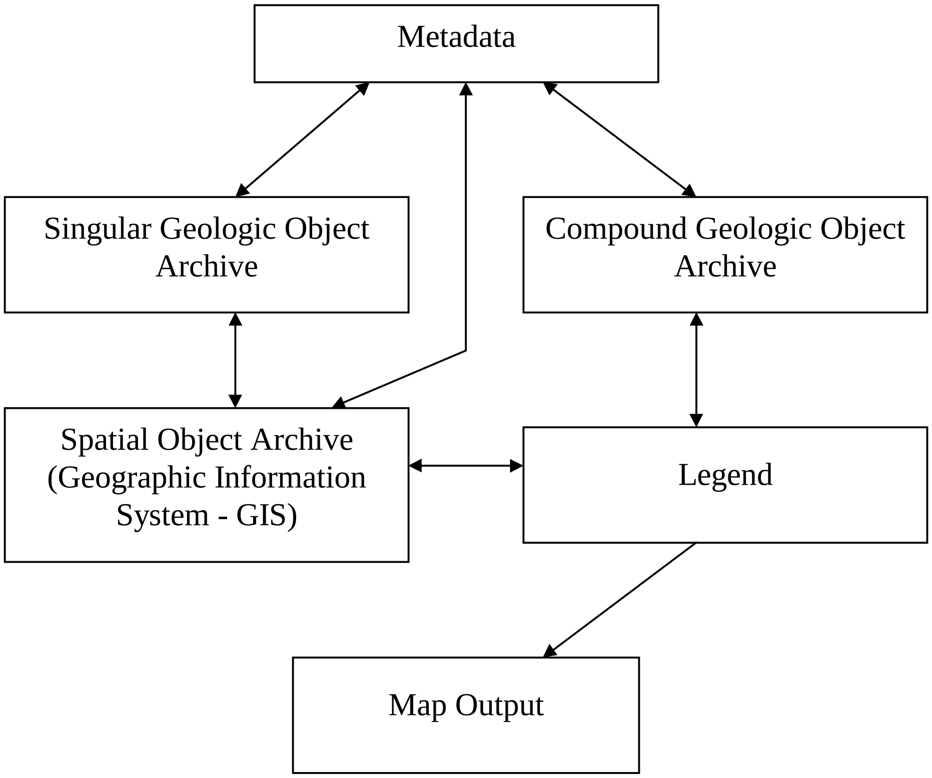


Figure 6. Generalized diagram of the relational geologic map data model.

This diagram differs from the previous diagrams in the addition of Metadata and a Spatial Object Archive (GIS). As before, geologic objects are linked to a geologic map through the Legend. However, the spatial portion of each object (its size, shape, and location) is stored in a Spatial Object Archive. Descriptions of single map objects, which are stored in the Singular Object Archive, are linked to the spatial description directly. Descriptions of compound objects (those that refer to multiple geographic objects), however, are linked to the Spatial Object Archive through the Legend. Thus, in addition to its functions of selecting data objects for a map and symbolizing those objects, the Legend also serves as a classifying agent for connecting multiple spatial objects to a single entry in the Compound Object Archive.

Combining the features of the previous figures yields a generalized diagram of the relational data model (Figure 6). It differs from the previous diagrams in the addition of metadata and a spatial object archive (Geographic Information System, or GIS). Metadata includes an original source for each archive object (whether descriptive or spatial) as well as descriptive information about individual maps. At the general level of this diagram, the box labeled metadata represents all of the metadata for each map in the archive, whether an original publication or a new derivative map. However, in the model presented here, only the information needed for the model is included in the tables. Additional metadata could be added to the model, or the archive could be linked to an external metadata database.

A further addition to the previous diagrams is the delineation of a Spatial Object Archive (GIS). The general notion of a Legend organizing various geologic objects to produce a geologic map still holds. However, the spatial portion of each object (its size, shape, and location) is stored separately from the descriptive portions. In effect the geologic archive has been separated into spatial and non-spatial components. Both singular and compound geologic objects have their attribute (text) descriptions stored in the Singular or Compound Object Archives, respectively, and their spatial description (geometry) stored in the Spatial Object Archive. The two portions of the singular object are directly linked. However, the two portions of compound objects are only linked through the Legend. In addition to its functions of selecting data objects to display on a map and symbolizing those objects, the

Legend also serves as a classifying agent for connecting multiple spatial objects in the Spatial Object Archive to a single description in the Compound Object Archive.

Entity-Relation Diagram Notation

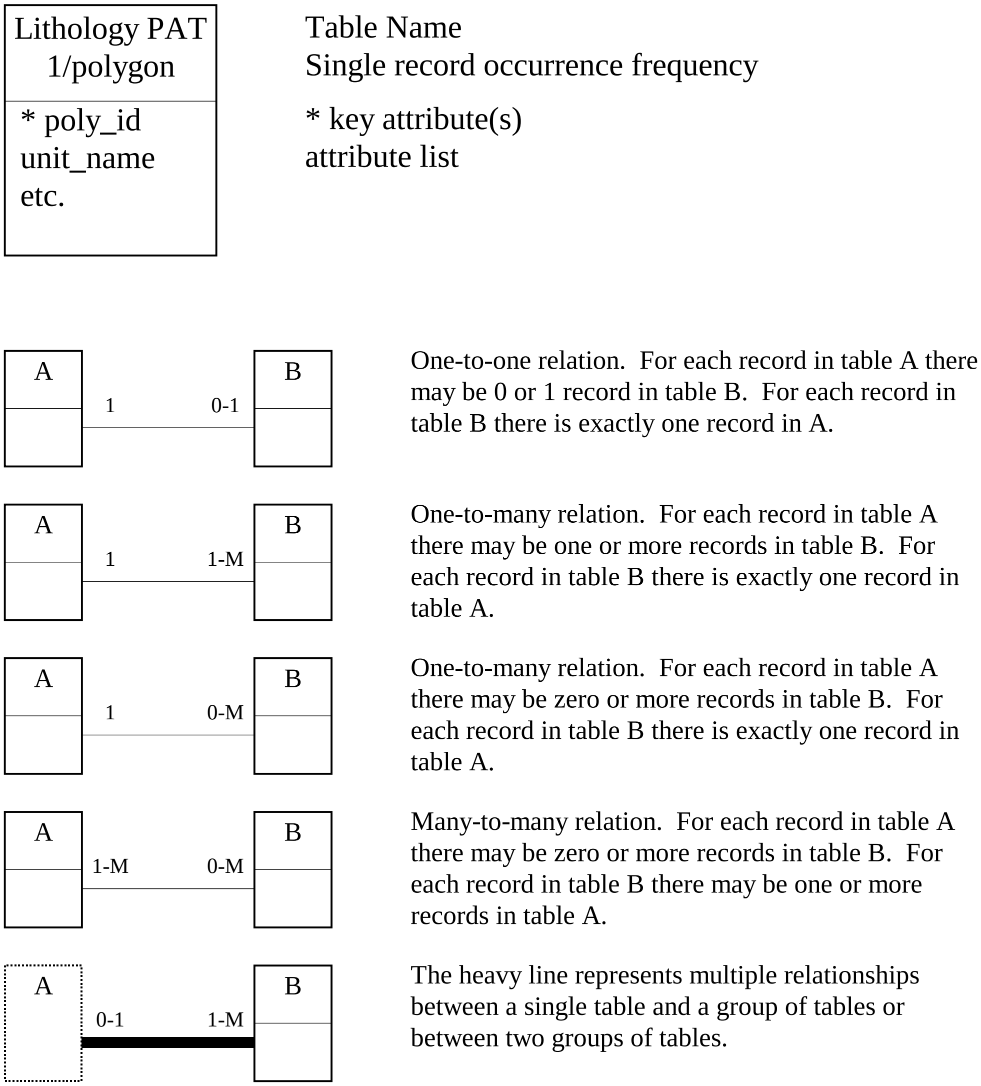


Table Name
Single record occurrence frequency

* key attribute(s)
attribute list

One-to-one relation. For each record in table A there may be 0 or 1 record in table B. For each record in table B there is exactly one record in A.

One-to-many relation. For each record in table A there may be one or more records in table B. For each record in table B there is exactly one record in table A.

One-to-many relation. For each record in table A there may be zero or more records in table B. For each record in table B there is exactly one record in table A.

Many-to-many relation. For each record in table A there may be zero or more records in table B. For each record in table B there may be one or more records in table A.

The heavy line represents multiple relationships between a single table and a group of tables or between two groups of tables.

Figure 7. Diagram of relational notation used for entities (tables) and relations between entities.

General Relational Database Considerations

Because of the need to perform analysis on digital geologic maps and to combine digital geology with other data sets in natural system modeling, it is expected that spatial objects will be generated, displayed, and managed by a GIS, and that the remaining portions of the model, including parts of the Spatial Object Archive and the whole of the Legend and Singular and Compound Archives, will be maintained within a relational database management system (RDBMS). RDBMS store data in one or more tables, where each table contains data headings (columns/fields) and data occurrences (rows/records). Individual tables are linked based on specified columns containing identical values; e.g. two tables may each possess a column for the name of a unit – these tables could then be combined based on common unit name occurrences.

The techniques that are used to design the tables that are linked to the GIS are all variations on the general relational model of database design (cf. Wiederhold, 1983). There are numerous mathematical representations and manipulations that can be pursued to achieve the most efficient database design (normalization processes), but the goal of each of these systems is to reduce redundancy in the database. The normalization process was used throughout the design of the data model to reduce this type of redundancy. In the following sections, the remainder of the data model is described as a series of linked tables. These tables implement the general design outlined in the previous section.

The notational shorthand that is used in all subsequent diagrams is given in Figure 7. In this and the following diagrams, each box represents a table (or entity) in a relational database, the connecting lines represent relations, and the ends of the lines are labeled to show the type of relation. Entities in the model are translated to tables in a relational database implementation and the terms are used interchangeably in this discussion. Each entity is split horizontally with the title of the entity and the occurrence frequency of individual records shown above the split and a list of attributes shown below the split. Key attributes, identified by a leading asterisk, are listed in the lower panel of the entity. Key attributes are those attributes that are necessary to identify an individual record.

The lines connecting entities in the diagrams represent relations between the entities. Figure 7 shows the method used to identify the type of relation between the two entities connected by the line. Relations are characterized by whether an entity's existence is dependent on its related entities, and in what amounts an entity may participate in the relation. Each entity may occur zero, once or many times in the relation. Binary entity relationships may thus have one-to-one, one-to-many, or many-to-many cardinalities. For instance, if entity A is related to entity B in a one-to-many way, then for each occurrence of an instance of A, there may exist many occurrences of B, whereas each occurrence of B can only be related to one instance of A. If B is independent of A, then the relationship could be described as being one-to-zero or many. In general, all of the relations shown in the diagrams are one-to-one or one-to-many. Where a many-to-many relation would be indicated by the nature of the connected entities and their contained data, a correlation table has been inserted between them to convert the many-to-many relation to two one-to-many relations. This type of conversion is required by the nature of relational databases and is one of the differences between the relational model and an object-oriented model. In object oriented database implementations, these correlation tables are not necessary.

The Relational Geologic Map Data Model

In the following sections of this chapter, the relational geologic map data model is described in detail. Due to the complexity of the model, it is presented in logical sections in Figure 8 through Figure 12. A brief overview of the individual sections is followed by a complete description of each table (entity) and relation. The relational model was divided into individual tables to group related attributes, to minimize storage space and duplication of information by normalization of the database, and to capture the relationships between the objects in a geologic map.

Typing Conventions

Within the text of this document, the names of attributes (columns, or fields in tables) are italicized, such as *source_title*. Key attributes that are used to link one table to another are in italicized bold, such as ***source_id***. In addition, the names of model tables are capitalized within the descriptive text.

Within the tables and figures, the following conventions are used:

- Primary key attributes for a table are preceded with an asterisk (*).
- Foreign key attributes are followed by an @ symbol. Foreign keys are attributes in one table, which are also primary keys in a different table.
- Attributes whose values are selected from a pre-existing word list (pick list) are followed by a < symbol.

Metadata, Legend and Related Tables

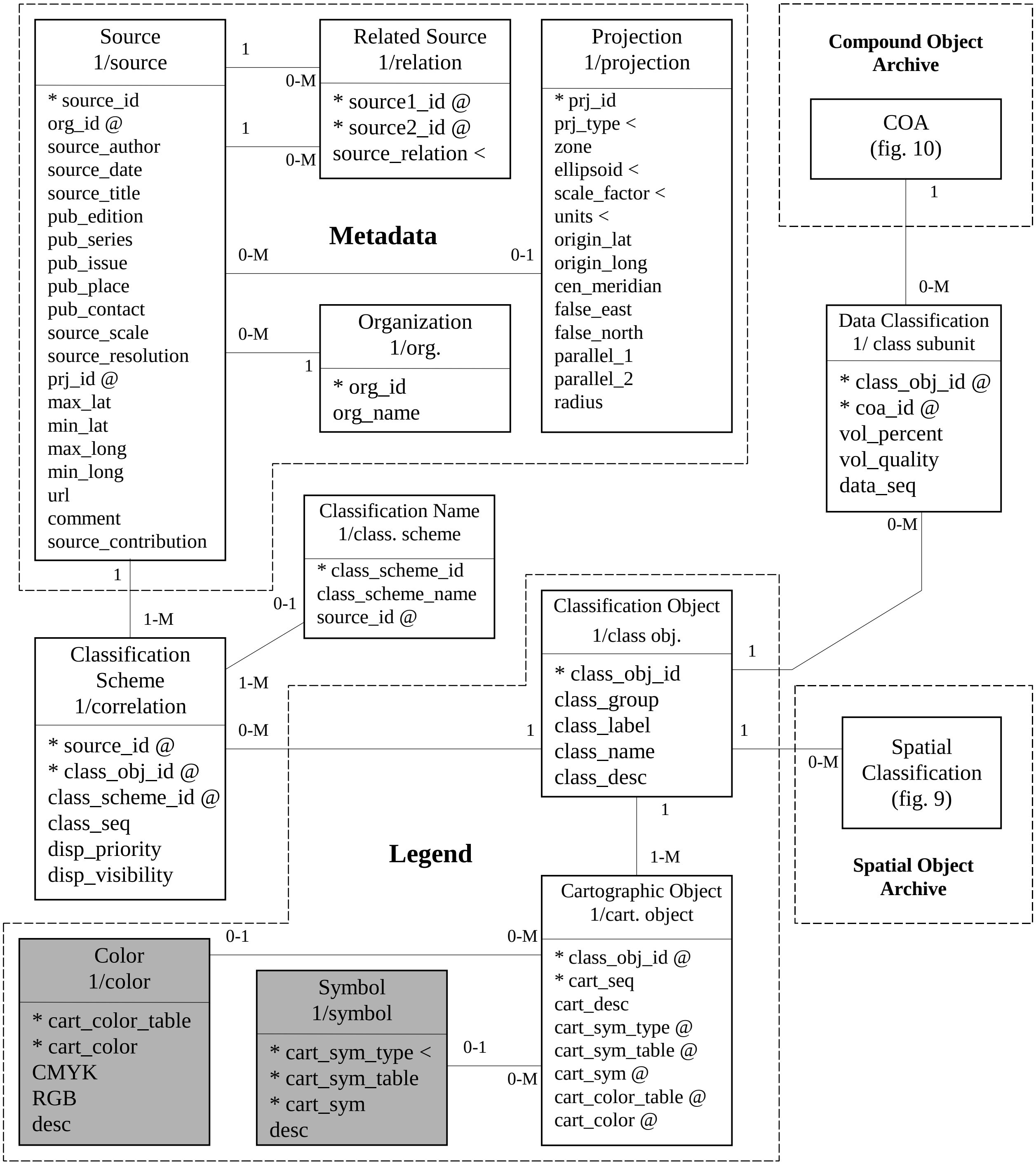


Figure 8. Legend and Metadata portions of the relational model.

The model is in five parts; the Spatial and Singular Archive portions are shown on Figure 9, the Compound Object Archive portion is shown on Figure 10 and Figure 11, and some standard look-up tables are shown on Figure 12. Note that shaded boxes are standard tables that are used with many maps (Figure 8 through Figure 12). Central to this diagram is the classification object. It permits spatial objects to be connected with their descriptive data in the Compound Object Archive, and it permits symbolization to be assigned to each object.

Singular Object Archive, Spatial Object Archive, and Related Tables

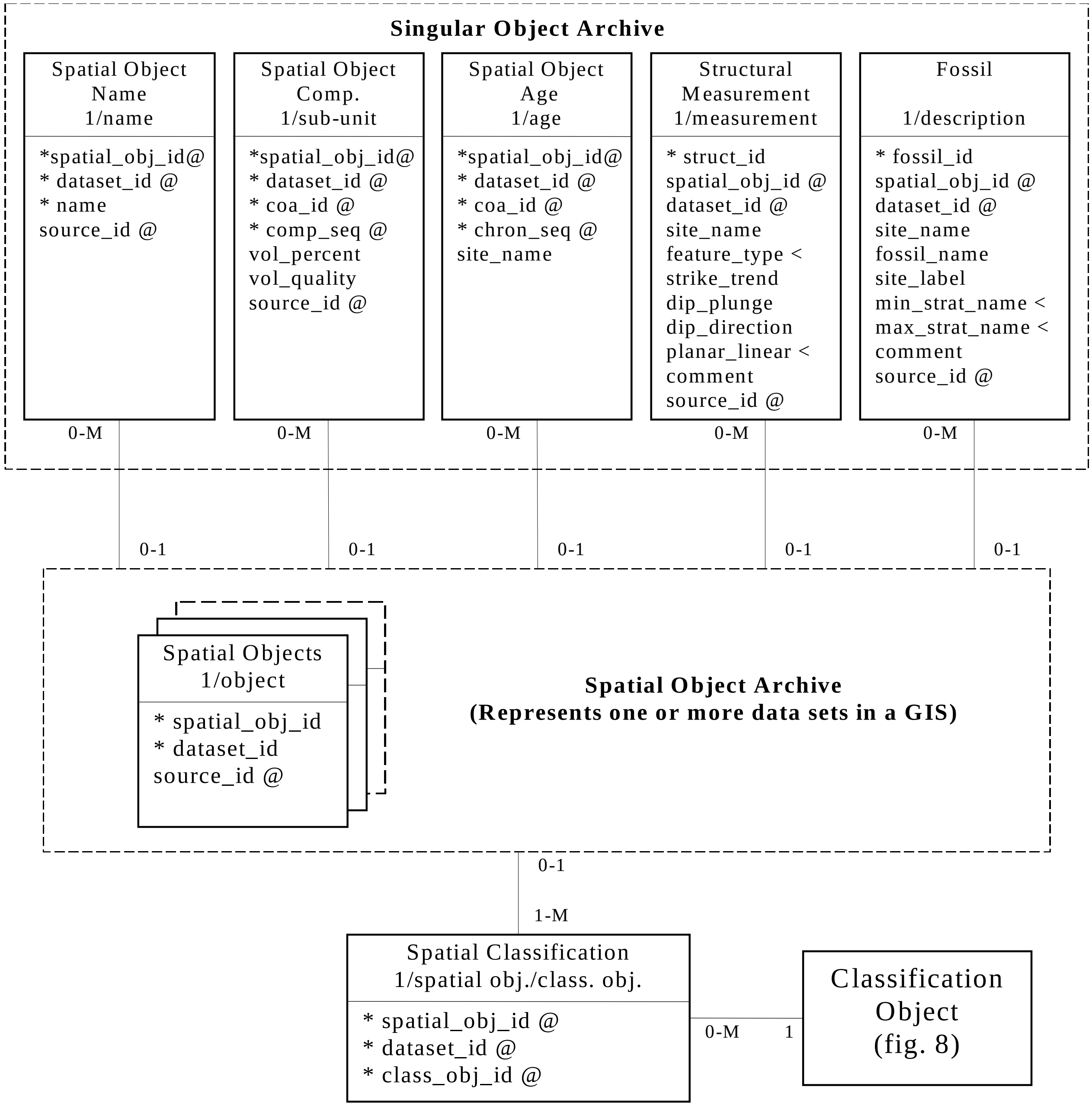


Figure 9. Singular Object Archive and the Spatial Object Archive (GIS) portions of the model.

A relationship can exist between an individual table in the Singular Object Archive and any data set within the GIS. Geologic entities of any type can be represented as any of the GIS geometric types (i.e. areas, lines, or points on 2-D maps) and individual map entities (single point, line segment, or polygon) can be given a specific name and can represent more than one sub-unit. For example, although site details are normally associated with map points, the model allows site details (in the Singular Object Archive) to be associated with any type of map entity. The Singular Object Archive, presented here as individual tables in the relational database, could just as well represent connections to external databases (e.g. a database of field notes). Note that all entities are tied to an original source.

Compound Object Archive and Related Tables

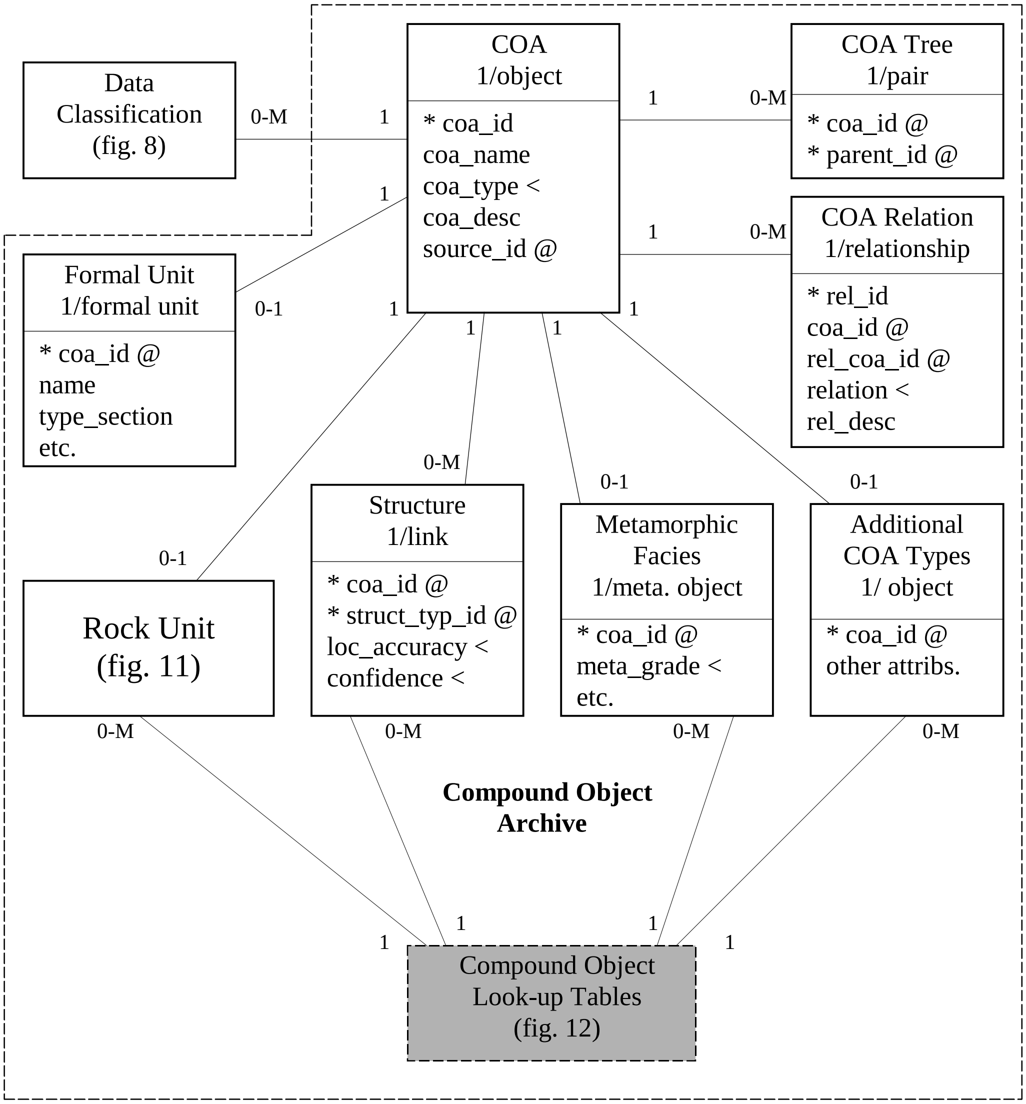


Figure 10. Compound Object Archive portion of the data model.

The Compound Object Archive portion of the relational geologic map data model contains descriptive data. All types of map units are treated uniformly and relationships can be defined between units. Additional types of map units can be easily added. The following figure shows a detailed expansion of the Rock Unit type. Similar details will be needed for additional unit types. Note that all units and their relationships are tied to an original source.

Rock Units and Related Tables

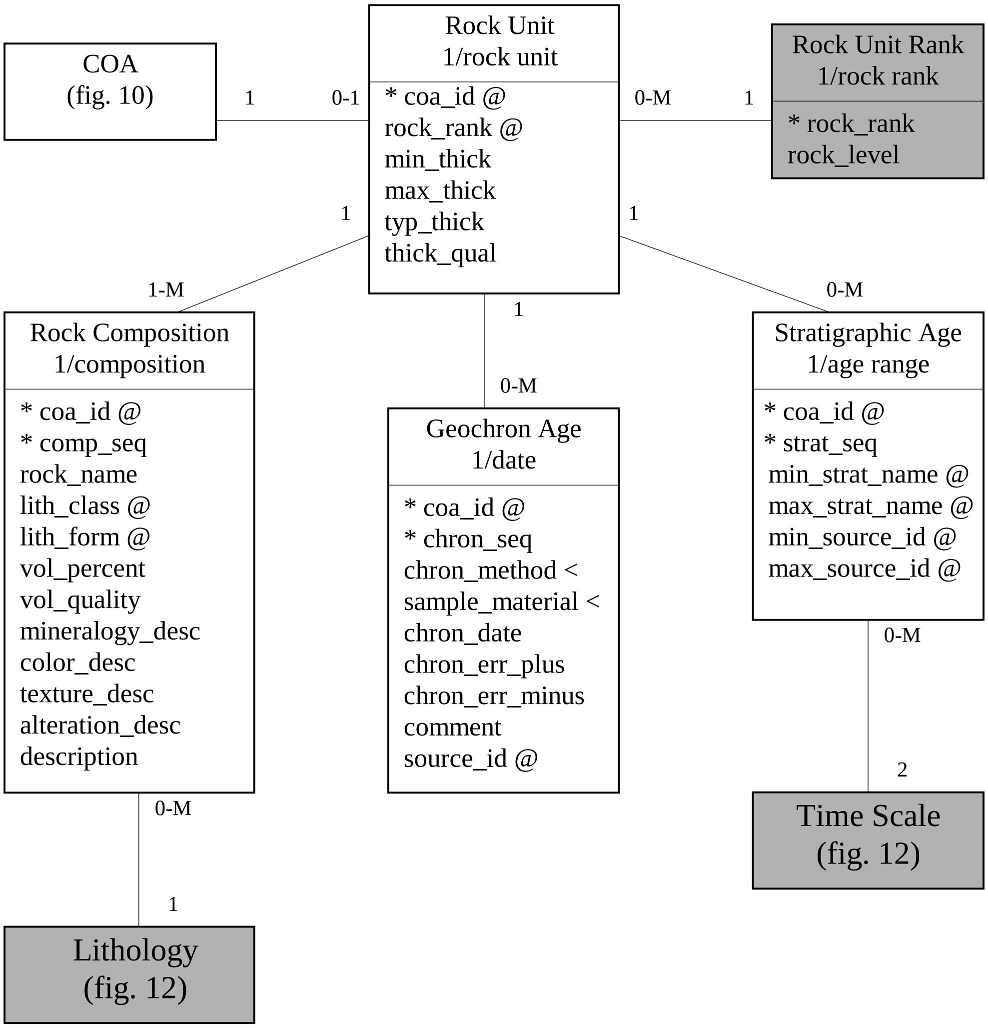


Figure 11. Rock Unit and related tables portion of the Compound Object Archive.

Each rock unit as a whole can have associated any number of stratigraphic age ranges as well as any number of geochronologic ages. These data can come from sources that are different than the source of the unit definition. Each rock unit has a rank (group, formation, member, etc.) and the relative level of unit ranks is maintained in a Unit Rank table. This table allows easy creation of derivative maps at various rank levels. Each rock unit is made up of one or more compositions. Rock compositions correspond to individual rock types, or lithologies, which are included in the defined unit. For example, a clastic rock unit composed of conglomerate, sandstone, and shale would have three rock composition records. Each would describe a single lithology within the unit.

Compound Object Archive Look-up Tables

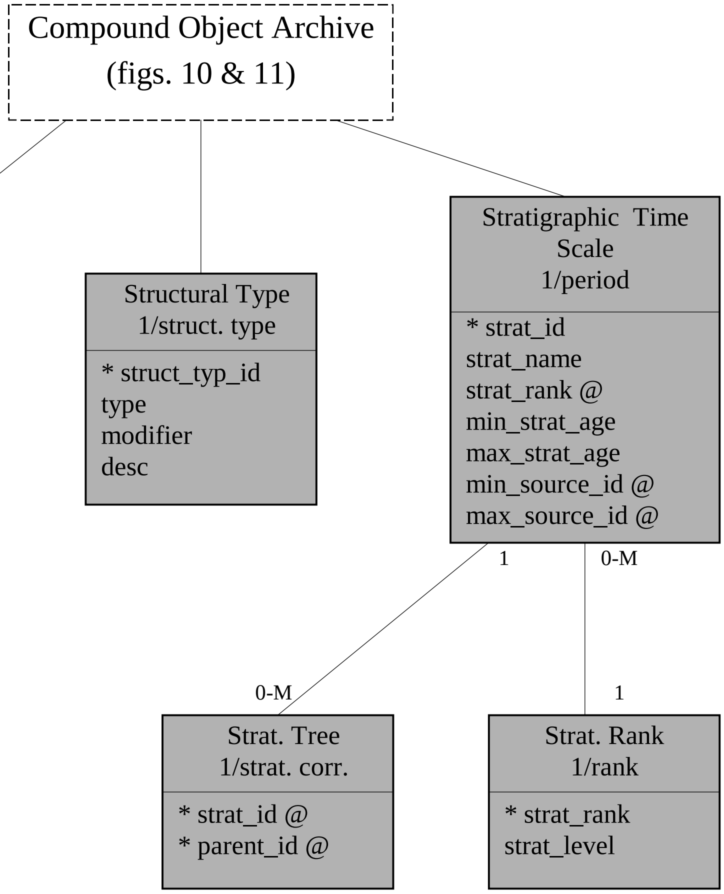


Figure 12. Standard look-up tables which are used with the Compound Object Archive.

Stratigraphic Time Scale and Lithology are hierarchical structured look-up tables. The parent-child relationships are captured in the “Tree” tables and the level within the hierarchy is defined by the “_level” attributes. This structure simplifies the creation of derivative maps such as a simplified geologic map showing geology at the formation level and above or a simplified lithologic map showing only level 1, or level 1 and level 2, lithologic units. Additional look-up tables can be easily added.

Metadata, Legend and Related Tables

The geologic map data model is divided into five interconnected diagrams (Figure 8 through Figure 12) along the same lines as the divisions made in the general overview of the data model as presented in Figure 6. The first diagram (Figure 8) includes the Legend and Metadata portions of the model along with some associated tables.

Metadata

The Metadata portion of the model includes four tables, a Source Table, a Related Source Table, an Organization Table, and a Projection Table. The Source Table contains two slightly different types of records. First, it contains reference information for published and unpublished sources of the information that is contained in the digital library. It is also used to store information pertaining to each derivative map that is created within the archive. As documented here, the Source Table does not include a complete set of NSDI-compliant metadata records. The model assumes full NSDI metadata records are to be stored in a separate database; the Source Table included here can serve as a link to a formal metadata warehouse. There is one record in the Source Table for each individual source of information or derivative map. The Source Table's key attribute, ***source_id***, serves to identify individual records; this same attribute will be found throughout the model wherever it is necessary to identify the source of a map feature or description, or link the feature or description to a derivative map.

The Related Source Table is used to document relationships between various sources of information. Its two-part key, ***source1_id*** and ***source2_id***, is used to identify two records in the Source Table which are related in some fashion. The relationship between the two sources is then defined in the *source_relation* attribute. A record in this table could be used, for example, to link a derivative map to the original map. The *source_relation* attribute might then contain the entry, "modified from", indicating that source #1 had been modified from source #2.

The Organization Table is used to provide a full, formal name for organizations in addition to the shorter, abbreviated identifier that is used in the Source Table. Having only two attributes, it is used as a simple look-up table.

The Projection Table is used to store all of the parameters necessary to fully specify the map projection for each source of information. Although an attempt has been made to provide for all of the normal parameters used to specify map projections, clearly no one projection will have entries in all attributes.

Legend

The second major portion of the model that is diagrammed on Figure 8 is the Legend. The Legend consists of two data tables and a number of standard look-up tables. The functions of the Legend portion of the model are to record the objects to be included on a particular map, to record the descriptions of those objects for the purposes of that map, to specify how the selected objects are to be symbolized for a particular map, and to link the spatial descriptions of objects in the Spatial Object Archive to attribute descriptions in the Compound Object Archive. It's clear from its connections to all other portions of the model that the Legend is the heart of the data model and the Classification Object Table is the heart of the Legend.

The Classification Object Table defines objects that are to appear on a map and also, on the map Legend. The table can be used to define individual objects such as named faults, it can be used to define classes of singular objects which share symbolization such as all normal faults or all foliation symbols, and it can be used to define compound objects such as rock units or alteration zones. Each of these objects is assigned a unique ***class_obj_id*** that forms the key to the table. The table also defines the labeling that is used for each object and the type of each object. The attribute, *class_group,* is used to group similar objects on a map Legend, for example all intrusive rock units or all structural symbols. The attributes, *class_label* and *class_desc,* are used to hold short and long, respectively, descriptive text that will be used on the Legend to define the classification object. For example, when classifying an intrusive rock unit, *class_label* might contain a label such as TKig, while *class_desc* might contain a longer text description of the rock unit.

The Cartographic Object Table is used to symbolize objects that are defined in the Classification Object Table. Each object in the Classification Object Table can be represented by one or more records in the Cartographic Object Table, allowing the symbolization of each feature on the resulting map to be composed of multiple layers. Each of these layers is defined by pointing to a symbol table (contained within the GIS) and a specific symbol within the table and by pointing to a color table and a specific color within the table. There can be multiple standard tables for each type of symbol, if necessary. Thus, point symbols for a single map could be drawn from several Point Symbol Tables. This arrangement allows maximum flexibility of cartographic design. As an example of the flexibility available, consider a polygon, or group of polygons on the map for which the user would like to have a uniform base color overlain by two cross-hatches of different colors. Instead of having to design a special symbol for this combination, the user simply defines three cartographic objects for the classification. The first includes the symbol number and symbol table needed to specify a solid area fill and the color desired for the fill. The other two include the symbol numbers and symbol tables for the appropriate cross-hatching patterns and the desired color numbers and color tables to color the cross-hatching.

Legend Correlation Tables

The Classification Object Table, and therefore the Legend, is connected to the rest of the model through three correlation tables. For example, the Classification Object Table is connected to the Metadata (Source Table) through the Classification Scheme Table. For every record in the Source Table (each with a unique key attribute, ***source_id***) there may be any number of records in the correlation table (each having the same ***source_id***, but a different ***class_obj_id***). But, for each record in the correlation table, there may be only one corresponding record in the Source Table. Similarly, for each record in the Classification Object Table there may be any number of records in the correlation table, but for each record in the correlation table, there may be only one corresponding record in the Classification Object Table. Therefore, the correlation table (Classification Scheme) converts the many-to-many relation between the Source Table and the Classification Object Table into two many-to-one relations between the correlation table and the other two tables. Correlation tables must contain all of the key attributes from each of the tables being correlated, in this case, one key attribute from each table. This technique is used throughout the relational model. An additional use of this correlation table is to define classification schemes so that a single set of features from one or more sources can be reclassified (or re-symbolized) many times to produce different maps.

The Classification Scheme Table includes a classification sequence number and display priority and visibility attributes. The classification sequence number, *class_seq*, is used to sequence the objects in a map Legend according to the user's needs. Display priority, *disp_priority,* allows the user to specify the order in which objects are drawn when the map is created. If a map includes a pattern overlay showing metamorphic grade or, perhaps, alteration, it is important that the output device draw the underlying polygons and lines before drawing the overlay pattern if the underlying geology is to be seen through the pattern. Display priority is used to assure the display occurs in the desired order. The contents of the display visibility attribute, *disp_visibility*, determines whether each object is displayed in the map Legend.

There is a Classification Name Table related to the Classification Scheme Table so classification schemes can be named and tied back to an original source. This allows the user to recall classification schemes by name or by their original source.

The Classification Object Table is also linked to the Compound Object Archive and the Spatial Object Archive through correlation tables. The Data Classification Table links the Classification Object Table to the Compound Object Archive. As a correlation table, it forms the same sort of link between the Legend and the Compound Object Archive as described above; it converts a many-to-many relation to two many-to-one relations. Including a correlation table here provides for the possibility of linking a single classification object (legend object) to multiple objects in the Compound Object Archive. For example, legend objects that refer to more than one rock unit from the archive can be created. Therefore, new maps can be created which combine units from previous maps just by defining new legend objects or re-using existing legend objects. In addition to the required key attributes, the Data Classification Table includes three attributes that increase its utility: *vol_percent*, *vol_quality,* and *data_seq*. The attributes, *vol_percent* and *vol_quality*, are used when a single classification object is composed of multiple objects from the Compound Object Archive. These attributes are used primarily with rock units from the Compound Object Archive. They allow the user to record the estimated proportion, in volume percent, of each rock unit that is part of the legend object and the quality of the proportion estimate. The final attribute, *data_seq*, is also used with legend objects that are composed of multiple objects from the Compound Object Archive. It provides a sequence number, which controls the order of display, within the Legend, of descriptive information from the Compound Object Archive.

The final correlation table that is connected to the Classification Object Table is the Spatial Classification Table (Figure 9) which connects the Legend to the Spatial Object Archive. The Spatial Classification Table has no additional attributes and simply functions as a correlation table to convert the many-to-many relation between the Classification Object Table and the various Spatial Object Archive tables to several many-to-one relations. This many-to-many relation between the spatial object and its classification implies that a spatial object may be classified in more than way: i.e. if its appearance varies on different maps, or if it is classified as more than one type of object such as a fault that is also a contact.

Spatial Object Archive

The Spatial Object Archive (Figure 9) is the storage location for the spatial (geographic and geometric) description of all objects within the map library. All information concerning the shape, size, location, etc. of each map feature is stored in this archive. It is expected the archive will be implemented in a Geographic Information System (GIS). Most GIS provide separate repositories for each geometric type supported. For example, points, lines and polygons and their related properties, are commonly stored in separate archives. In addition, it is often beneficial to divide each geometric type according to some useful thematic scheme; on geological maps one might divide the polygonal features into bedrock geology, surficial geology and metamorphic overlays. There are various names used for these separate layers, or archives; in this document, they are called data sets. Thus GIS maps typically consist of several data sets which are delineated by both theme and geometric type. The geologic map data model depicts the

Spatial Object Archive (in Figure 9) as a series of tables, where each table contains a data set which may be delineated by geometry, theme, or both. The geologic map data model does not impose or demand any particular organization of data sets within the GIS. It only requires that each spatial feature be uniquely identified and provides two key attributes for this purpose, ***spatial_obj_id*** and ***dataset_id***. The attribute, ***spatial_obj_id,*** ensures that a spatial feature is uniquely identified within a data set, while ***dataset_id*** ensures that each data set is uniquely identified: no two data sets may contain the same ***dataset_id***. There is no minimum required list of data sets for a digital geologic map. The number and type of data sets will depend both on the content of the map and on the GIS used to represent spatial features. If the map contains no point data or no linear features, those data layers sets would not be needed. Most maps will have at least one data set for each of point, line, and polygon features although some GIS will contain all of the features in a single data set. Some maps may require additional data layers. For example, if the map includes overlay polygons that cut across the rock unit polygons, a separate polygon data layer may be required. In that case, there would be more than one data set for polygon data. Each record in a data set table corresponds to a single geometric feature in a single data layer of a single map. Thus, these records represent the smallest geometric units from which geologic maps are constructed. Each record corresponds to a single point, polygon, or line segment. Each record contains the two key attributes, ***spatial_obj_id*** and ***dataset_id***, the combination of which must be unique within the map library. In addition, each record, and therefore each map feature, includes the information necessary to link the feature to its original source via *source_id*. As derivative maps are created from multiple original maps, it is always possible to trace the source of each map feature.

Spatial Object Archive Correlation Tables

The diagram of the Spatial Object Archive (Figure 9) has a single line drawn between the Spatial Object Archive and the Spatial Classification Table. However, this line represents several one-to-many relations, one between the Spatial Classification Table and each table within the Spatial Object Archive. Within the Spatial Classification Table, the key attribute, ***dataset_id***, is used to specify the table within the archive to which each classification object is related. The other key attributes, ***spatial_obj_id*** and ***class_obj_id***, are used to specify a particular spatial object within the data set table, and to specify the classification object to which the spatial object is connected, respectively. This correlation table is used in the same manner as the previous examples; it serves to convert a many-to-many relation between classification objects (the Legend) and spatial objects (map features) to several many-to-one relations. Each spatial object can, therefore, be used for multiple maps, which is how the model is used to create derivative maps. And, each classification object can refer to multiple spatial objects, which is how the model is used to connect descriptions of compound objects (e.g. rock units) from the Compound Object Archive to multiple spatial objects (e.g. polygons). It is also the mechanism that is used to classify multiple singular objects to a single legend classification, such as defining a single legend symbol and description for all foliation orientation symbols on a map.

Singular Object Archive

The Singular Object Archive is composed of several tables that are used to store descriptive information related to individual spatial objects. Although only five tables are shown in the Singular Object Archive on Figure 9, the archive could include many more tables. The ones shown here are diagrammatic only. All tables in the archive include the attributes, *spatial_obj_id* and *dataset_id*, which are used to specify the particular spatial object to which each record in the archive table refers. Thus, each record in each table in the archive may only refer to a single spatial object, hence the name, Singular Object Archive. In addition, each record in most of the tables in the archive contains a *source-id* attribute to tie the archive information back to an original source. The Spatial Object Age Table differs slightly from the others in that it refers to a table in the Compound Object Archive that includes source reference attributes.

The Spatial Object Name Table is used to attach names to individual spatial objects. Although many uses could be made of this table, its primary purpose is to attach formal names to objects such as individual plutons that are represented by a single polygon or individual structures that are represented by a single line segment. The single line in Figure 9, which connects the Spatial Object Name Table to the Spatial Object Archive, represents multiple one-to-many relations. For each spatial object, there can be one or more names entered in the Name Table, but each entry in the Name Table can refer to only one spatial object. The relation line signifies a one-to-many relation between the Name Table and *any* of the attribute tables within the Spatial Object Archive.

The Spatial Object Composition Table is used to store information about the composition of individual spatial objects. Although the table could be used to store information about other types of spatial objects, its primary use is to store information about the composition of individual rock unit polygons, and thus this table links individual spatial objects to the Compound Object Archive. The normal procedure for defining a rock unit is to store the definition of the rock unit and its composition in the Compound Object Archive (Figure 10). The rock unit definition is then linked to multiple spatial objects through the Legend and the Spatial Classification Table. In some cases, a compound unit will be defined in the Legend which refers to several rock units in the Compound Object Archive or a rock unit defined in the Compound Object Archive will contain several different compositions. The unit is then linked to multiple polygons through the Spatial Classification Table. For most polygons in the map area, there may be no information as to which of the rock units in the Legend definition (or compositions of a single rock unit) occur within the polygon, or the extent to which they occur within the polygon. However, if there is information about the composition of an individual polygon, the Spatial Object Composition Table permits the user to store information about the composition of an individual polygon in terms of rock units defined in the Compound Object Archive. In addition to the usual attributes shared with all Singular Object Archive Tables, the Composition Table includes attributes for ***coa_id***, ***comp_seq***, *vol_percent*, and *vol_quality, source_org,* and *source_id*. The attributes, ***coa_id***, and ***comp_seq*** are used to identify a specific unit in the Compound Object Archive and the particular portion of the unit (composition), respectively. The unit must be defined in the Compound Object Archive. The attributes, *vol_percent* and *vol_quality,* are used to specify an estimate of the volume percent of the polygon composed by the unit in question and the quality of the estimate. Typically, there would be several records in the Singular Object Composition Table for a given polygon, each referring to a different rock unit or portion of a rock unit in the Compound Object Archive and each specifying the volume percent within the polygon. For this table, the *source_id* attribute refers to the source record for information specific to the composition breakdown specified in the composition record.

The Spatial Object Age Table is used to attach geochronologic ages to individual spatial objects. Although many uses could be made of this table, its primary purpose is to relate geochronologic age information, which is stored in the Compound Object Archive (Geochronologic Age Table, Figure 11), to objects such as individual plutons that are represented by a single polygon or individual structures that are represented by a single line segment. The single line in Figure 9, which connects the Spatial Object Age Table to the Spatial Object Archive, represents multiple one-to-many relations. For each spatial object, there can be one or more records in the Age Table, but each entry in the Age Table can refer to only one spatial object. The relation line signifies a one-to-many relation between the Spatial Object Age Table and *any* of the attribute tables within the Spatial Object Archive. The attributes, ***coa_id*** and ***chron_seq***, are used to identify an individual geochronologic age record in the Geochronologic Age Table.

The Structural Measurement and Fossil Tables are typically used to store information about point locations within the Spatial Object Archive. These tables are representative of the many types of site detail tables which could be included in the archive. For example, there could be additional tables for various types of analytical samples, mineral deposits, etc. In addition, the data need not reside in the local archive; the tables in the archive could serve instead as links to one or more external databases of field data, analytical data, deposit information, etc. In addition to the usual attributes shared with all Singular Object Archive Tables, the Site Detail Tables include attributes for the typical types of information that would be stored for each type of point feature. Additional attributes and additional tables could be added as needed. As with the other tables in the archive, a one-to-many relation is shown between the Spatial Object Archive and these tables. Any spatial object can be tied to any number of site detail records, but each detail record must refer to a single spatial object. For example, a single field location can be tied to any number of structural measurements, but each structural measurement can only refer to a single point location. In the case where spatial objects from multiple maps are stored in the spatial archive, it is possible that a site could be depicted on several maps (e.g. a field station or mineral deposit). In that case, a correlation table must be included between the spatial object and the sites. This will permit a spatial object to be related to many site features (i.e. multiple measurements at a single site), and a single site feature to be related to multiple spatial objects (i.e. one measurement depicted on several maps). This scenario is not currently diagrammed in Figure 9.

Compound Object Archive

The Compound Object Archive is composed of a number of data tables and look-up tables (Figure 10, Figure 11, and Figure 12) which are used to define Compound Geologic Objects. The heart of the archive is the COA Table. The COA Table links the Legend, and thus the rest of the data model, to the various types of compound geologic objects that can be described and defined within the archive. The archive can be used to define many different types of geologic objects, of which only three will be discussed here. The three that are included in this version of the data model have been selected because they represent common types of objects that occur on geologic maps and because each represents a different class of geologic object. The first to be defined, Rock Units, represents the most common use of the archive, to define various types of map units based on rock features (lithology, age, stratigraphic position, mineralogy, etc.) Rock Units will be described in detail because they are the most complex types of geologic object and because they serve as a model for other types of units which could be added to the archive, such as soil units, engineering properties units, etc. Any type of unit that would form a polygonal base for a geologic map would be treated in a fashion similar to Rock Units. Structural Features will also be described in this version of the model because they form the second most common type of geologic object and because they represent a class of geologic objects which are typically, although not entirely, linear. Any other linear geologic object that would be added to the archive would be treated in a manner similar to Structural Features. Finally, Metamorphic Facies Units will be described in the model because they represent a unique class of geologic objects, polygonal objects which overlay a polygonal geologic map base. These units can be thought of as any units that are effectively transparent on a geologic map so that the overlying units modify the underlying Rock Units. Note that these polygons do not represent metamorphic rock units; they represent metamorphism that crosscuts the underlying rock units. Other examples of this class of units would be alteration overlays or glacial extent overlays.

The COA Table (Figure 10) connects the Compound Object Archive to the Legend, and thus, to the rest of the data model, through the Data Classification Correlation Table (described above). The key to the COA Table is the attribute, ***coa_id***, which contains an identification number assigned to the compound object. Because the key attribute to the COA Table must be unique within the Compound Object Archive, the name of the object cannot be used as the key attribute. It is always possible for the same object name to be used on different maps for differing objects. The ***coa_id*** is used to link between the COA Table and the rest of the Compound Object Archive. The COA Table also includes a *source_id* attribute to link each entry in the Compound Object Archive to its original source. The attribute, *coa_name*, contains a short name for the object. The attribute, *coa_desc*, is a text attribute which can be used to describe the object in more detail than what is provided in the *coa_name* attribute. Finally, the attribute, *coa_type*, defines the type of object being described. The *coa_type* attribute is used to determine which of the additional tables in the Compound Object Archive contain the remaining attributes for the object and, therefore, distinguishes rock units from structural or metamorphic facies units, etc.

Connected to the COA Table by a one-to-one relation and sharing the same key attribute, ***coa_id***, the Formal Unit Table is used to store information about formal definitions for the unit being described. For every entry in the COA Table, there can be zero or one entries in the Formal Unit Table. Although it is not required for a record in the COA Table to have a corresponding record in the Formal Unit Table, it may only have one record, if any. If the unit has a formal name and/or a type section definition, this information is stored in the Formal Unit Table in the attributes, *name*, and *type_section*, respectively. This table is not completely defined by the data model. Clearly, additional attributes would be useful such as a reference information for each formal name or type section definition. It is expected that either additional attributes will be defined for this table before as the data model is implemented, or this table will act as a link to an external database of formal geologic object definitions.

Also connected to the COA Table, but by a one-to-many relation, is the COA Relation Table. This table is used to define relations between objects in the COA Table. Virtually any type of geologic relation can be defined between two objects that exist in the COA Table. Examples might include older, younger, equivalent, correlates with, part of, includes, intrudes, etc. The reason for this table is to allow the storage, within the model, of the types of relations between units that are normally shown on a map legend by small graphic figures, particularly those that commonly occur within a correlation chart. Because there is a one-to-many relation between the two tables, multiple relations may be described between the same two objects in the COA Table by creating multiple records in the COA Relation Table. The COA Relation Table contains two attributes, *coa_id* and *rel_coa_id*, which define the objects in the COA Table for which the relation holds. Both attributes refer to the ***coa_id*** attribute in the COA Table and the direction of the relationship is from the object identified in the *coa_id* attribute to the object identified in the *rel_coa_id* attribute. For example, a record in the COA Relation Table with *coa_id* referring to unit A, *rel_coa_id* referring to unit B, and *relation* containing “intrudes” would indicate the relation, unit A intrudes unit B. Because it is possible to have multiple records in the COA Relation Table with the same *coa_id* and *rel_coa_id*, a different attribute is required to form the key attribute for the table. In this table, ***rel_id*** is used for the key and has no additional function in the model. Finally, the table includes an attribute, *rel_desc*, which is used if further description of the relationship is desired.

A COA Tree Table is also linked to the COA Table by a one-to-many relation. Because of the common need to use the stratigraphic hierarchy of rock units for the creation of derivative maps, or to define segmented linear features, these relationships are stored in a special format in the COA Tree Table instead of being stored in the COA Relation Table. This table only contains two attributes, ***coa_id*** and ***parent_id***, which together form the key of the table: i.e. the table lists all hierarchical parents (***parent_id***) of a geologic object (***coa_id***). For example, the group and supergroup units to which a formation belongs would be listed as its parents. If all stratigraphic parent-child relations in a map area are entered in this table, then the table can be used to construct a stratigraphic tree for the area or to create derivative maps of the area based on aggregating stratigraphic units to higher levels. For example, suppose the map area in question contains a mix of units at the group, formation, and member levels. If the parent-child relations are recorded in the table, then it is a relatively simple process to create a derivative map aggregating to the formation or group level from the original units. In the case of a segmented linear feature, the parent would refer to the whole. For example, the San Andreas Fault contains many segments, which may be individually be described, and for which the San Andreas would be a parent in the COA Tree Table

The COA Table contains a general description for compound geologic objects of all types, including rock units, linear features such as contacts, faults, folds and dikes, and overlays such as metamorphic or glacial units. More detailed data pertaining to these different types is stored in other tables specific to the type: the data model describes a Rock Unit Table, a Structure Table and outlines a Metamorphic Facies Table. Additional tables may be added for other compound geologic object types. In general, these other tables possess one-to-one relations with the COA Table so that the major table of a particular object type, such as the Rock Unit Table, has one and only one record for each record in the COA Table of that type. Because the Structure Table is used in a slightly different manner, it has a one-to-many relation, which is described below.

Rock Units

The Rock Unit Table (Figure 11) is the main entry point for descriptive information concerning rock units. For purposes of the model, a rock unit is defined as any mapped unit which may occur on a geologic map, including all types of stratigraphic units, whether layered or not, unconsolidated sediment units, water and ice features where underlying geology is not mapped, etc. The Rock Unit Table includes all information that is consistent for an entire rock unit: the unit’s identification number and it’s rank (attributes ***coa_id*** and *rock_rank*, respectively) and attributes which describe the unit's total thickness, if appropriate. The unit's total thickness can be entered as one or more of the following: minimum thickness (*min_thick),* maximum thickness (*max_thick*), or typical thickness (*typ_thick*). The quality of the thickness estimates can be entered in the attribute, *thick_qual*. All other descriptive information about the rock unit either may relate to just a portion of the rock unit, such as its composition, or may occur more than once, such as an age determination. This additional information is stored in subsidiary tables.

The Rock Unit Rank Table is a simple look-up table that is used to associate a number, rock_level, with each rock unit rank name. This allows the user to insert a word such as “formation” in the ***rock_rank*** attribute but also refer to that rank numerically. Rank levels are hierarchically organized such that the highest rank is assigned the lowest number (e.g. supergroup = 100 and bed = 500).

A rock unit may have any number of geochronologic ages associated with it in the data model. These ages are stored in a separate table, the Geochronologic Age Table, and related to the Rock Unit Table by a one-to-many relation. The key attribute, ***coa_id***, identifies the rock unit with which each age record is associated. Because there can be any number of geochronologic age dates for a single rock unit, the key attribute and the sequence number, ***chron_seq***, are used to assure that each record has a unique key. In addition to the key attributes, the Geochronologic Age Table contains attributes for storing the measured geochronologic age, errors on the age, measurement method, sample media, and a source reference.

The stratigraphic age of the rock unit is stored in the same manner as the geochronologic age, in the Stratigraphic Age Table. A one-to-many relation also links the Stratigraphic Age Table to the Rock Unit Table so that more than one stratigraphic age interval can be associated with each rock unit. In most cases, there will be only one stratigraphic age record for each rock unit, specifying the minimum and maximum age of the unit. There are, however, occasional units on geologic maps that have discontinuous age ranges. These units will require multiple records in the Stratigraphic Age Table. The key attribute, ***coa_id***, identifies the rock unit with which each age record is associated. Because there can be any number of stratigraphic age ranges for a single rock unit, the key attribute and the sequence number, ***strat_seq***, are used to assure that each record has a unique key. The Stratigraphic Age Table contains attributes for minimum and maximum stratigraphic age as well as attributes for source references for the age determinations. A major difference between the two tables is that the Geochronologic Age Table includes numeric values for the ages, while the Stratigraphic Age Table uses the names of stratigraphic intervals from a stratigraphic time scale, which is coded into the data model in the form of three tables, Stratigraphic Time Scale, Stratigraphic Rank, and Stratigraphic Tree (Figure 12).

The Stratigraphic Time Scale Table (Figure 12) is a hierarchical structured look-up table. Parent-child relationships in the stratigraphic time scale are captured in the Stratigraphic Tree Table and the level within the hierarchy is defined in the Stratigraphic Rank Table. This structure solves many of the problems with storing stratigraphic time information and facilitates the production of derivative maps based on rock unit age as well as the creation of derivative rock units based on stratigraphic age. The structure also facilitates the analysis of geologic maps where comparisons of stratigraphic age are required. All three of these tables, Stratigraphic Time Scale, Stratigraphic Rank, and Stratigraphic Tree are standardized look-up tables that are provided with the data model. Any organization using the data model may replace these with their own standardized tables, however, each user or creator of a digital geologic map does not need to create these tables. For maximum use of the archive, the same standard tables should be used for all maps.

The Stratigraphic Time Scale Table contains one record for each stratigraphic period to be represented in the table with the attribute, *strat_name*, containing the name of the time period, such as Mesozoic, Cretaceous, Norian, etc. Each stratigraphic period is then assigned an arbitrary identification number, which is stored in the key attribute, ***strat_id***. The ***strat_id*** is used in the Stratigraphic Tree Table to record parent-child relationships between time periods. Each stratigraphic period is also assigned a rank (epoch, era, etc.) which is stored in the *strat_rank* attribute. The ***strat_rank*** is used in the Stratigraphic Rank Table to assign a numeric rank level to the words that are used for *strat_rank* in the Stratigraphic Time Scale Table. For each period in the table, there is also an attribute for storing minimum and maximum geochronologic ages for the stratigraphic period and the sources of those ages.

Returning to the Rock Unit Table on Figure 11, there is a one-to-many relation between the Rock Unit Table and the Rock Composition Table. The Rock Composition Table is used to store descriptive information about the rock unit. A one-to-many relation is used so that there may be multiple composition records for each rock unit. This is particularly useful for rock units which are composed of a mixture of rock types; each rock type will be described in a separate Rock Composition record with no limit on the number of rock types, or compositions, that may be stored for a single rock unit. The Rock Composition Table uses the ***coa_id*** attribute plus a sequence number, ***comp_seq***, as the key attributes. In addition to providing a unique key, in combination with the ***coa_id***, the sequence number is used to specify the sequence of display of the composition records when a rock unit description is created for a map legend. Rock Composition is another table that is not complete at this stage of design of the data model. It is expected that additional attributes will be added to the table before it is adopted. All information that is unique to a single rock type within a rock unit should be stored in this table or linked to this table. The attributes, *mineralogy_desc*, *color_desc*, *texture_desc*, and *alteration_desc*, represent simple text descriptions of the rock type; additional descriptive attributes could be added. The attributes, *vol_percent* and *vol_quality*, are used to specify an estimate of the volume percent of the rock unit composed of the rock type in question and the quality of that estimate, respectively. These values are important for creating derivative maps based on rock type or lithology. For example, it would be extremely difficult to produce a major lithology derivative map without an estimate of the volume percent of each rock type for each rock unit.

Two additional attributes included in the description of each rock type, *lith_class* and *rock_name*, are used to define the lithology and name of the rock composition, respectively. The *lith_class* attribute is used to select a lithology classification for the rock type from a pre-defined, hierarchical classification of rock types stored in the Lithology Table (Figure 12). The Lithology Table is similar to the Stratigraphic Time Scale Table in that it is a standard classification that is included in the data model. It is somewhat more controversial than the time scale, so that it is more likely that an organization will choose to supply a different classification. To the extent that a single classification can be used by multiple organizations, the ability to analyze geologic map data by rock type, or lithology, will be greatly enhanced. It is hoped that the classification presented here will be improved before final adoption of a data model and that most developers of geologic maps will be able to agree on a classification scheme. The suggested classification is hierarchical with major headings of Unconsolidated, Sedimentary, Volcanic, Plutonic, Metamorphic, and Tectonic. Each of these headings is then further broken down into a second level of individual rock types, such as sandstone, or gneiss, for example (see description of the Lithology Table, below). The second level rock types are further broken down into a third, and occasionally, fourth level of more specific types such as arkose, or calc-silicate gneiss. The user can pick an appropriate rock type from any level of the table to classify a composition. The reason for using a standard table is so that it will be possible to compare rock units based on their rock type. If there is no attempt by the originator of the data to classify the rock type, then subsequent analysts who may not be experts in the geology of the area are forced to classify the rock units, often with less than desirable results. Of course, every geologist who creates a geologic map will want to use rock type terminology that is not contained in the classification. That is the purpose of having a *rock_name* attribute in addition to the *lith_class* attribute. The *rock_name* attribute is a free-entry attribute where the user can enter a preferred rock name. It is this rock name which would be used for creating legends and general descriptions of the rock unit; the lithologic classification is only used for comparing units on the basis of their rock type. The lithologic classification presented here is generally confined to 3 levels; however, the design is flexible enough so that individual organizations, and even individual users, can add classification terms to existing levels or provide as many additional levels as desired. As long as the added terms are defined in terms of their level and their parent from the existing classification, they will allow subsequent users full capability to create derivative maps even if they are not aware of the added terms.

The attribute, *lith_form,* is used to store information about the form, or morphology, of the rock composition. Like the *lith_class* attribute, the *lith_form* attribute is used to select an item from a standard hierarchical list. The list is slightly different according to the type of unit being described. The sets of morphology terms that are appropriate for extrusive rocks are different from those that are appropriate for unconsolidated sediments, for example. The table of rock type forms is not complete at this time, but will be included with a later version of the data model. Examples of morphology terms might include channel, flood plain, levee, and delta for unconsolidated sediments and ash, tuff, volcanic breccia, and flow for extrusive rock compositions.

In addition to the ***lith_class*** attribute, which forms the key, the Lithology Table (Figure 12) also contains attributes for storing an identification number for each record, a level number for each record, and a description of the particular rock type, if needed. The identification number, *lith_id*, forms the link with the Lithology Tree Table, which is used to store parent-child relations between records in the Lithology Table. The tree is used in exactly the same manner as the Stratigraphic Tree Table. There is no Lithology Rank Table because the ranks (or levels in the case of lithology) are stored in the Lithology Table as numeric values. Therefore, there is no need for a look-up table to translate level names to level numbers.

Structural Features

As with all other objects in the Compound Object Archive, structural features are represented in the COA Table (Figure 10) with an object identification number, a name, a description, source information, and a type code which identifies the object as a structural feature. There are two different types of structural features that can be represented in the Compound Object Archive, individual structures, such as named faults, and generic structures, such as all normal faults. Normally, there would be a single record in the COA Table for each generic type of structure, one for all approximately located normal faults, one for all anticlines, one for all queried contacts, etc. For each type of structure, which has an individual symbol or description on the map legend, there would be a generic record in the COA Table. In addition, there would be a record in the COA Table for each individual structure that is uniquely identified on the map, usually by a name. Thus, although the San Andreas Fault might be a dextral, strike-slip fault on a particular map, it would have its own individual record in the COA Table so that the name San Andreas Fault could be associated with the entire structure. For records that are identified in the COA Table as structures, there is a one-to-many relation between the COA Table and the Structure Table.

The Structure Table is used in much the same manner as other correlation tables in the data model. It serves to convert a many-to-many relation between the COA Table and the Structural Type Table (Figure 12) into two one-to-many relations. The many-to-many relation between the two tables, and thus the Structure Table, is required because many structures have multiple aspects. For example, many faults have both strike-slip and dip-slip aspects. To avoid having to create records in the Structural Type Table for all of the possible combinations of structural aspects, the data model allows each structural unit in the COA Table to be related to one or more records in the Structural Type Table. The Structure Table mediates the many-to-many relation and contains the two key attributes from the COA Table and the Structural Type Table, ***coa_id*** and ***struct_typ_id***. In addition, the Structure Table contains the attributes, *loc_accuracy*, which is used to specify the degree of accuracy with which the structure has been mapped, and *confidence*, which is used to record the degree of confidence that the structure exists in the field or has been correctly identified in the field. The first, *loc_accuracy*, might contain words such as approximate or concealed, while the second, *confidence,* might contain terms such as inferred.

The Structure Type Table contains, in addition to the key attribute, ***struct_typ_id***, attributes for the type of structure, a modifier for the type of structure, and a general description of the structure type. The type of structure attribute, *type*, is used to specify whether the structure is a fault, fold, shear zone, etc. The attribute, *modifier*, is used to specify the type of fault or fold, etc. For example, if the structure is a fault, the modifier might be normal, strike-slip, thrust, etc. If it is a fold, the modifier might be anticline, syncline, doubly-plunging syncline, etc. The attribute, *description*, is used for a text description of the structure specified in the record. It might contain a text string such as, "dextral strike-slip fault". The Structural Type Table is another of the standard tables that will be provided with the data model. If it does not contain sufficient records to describe all structures needed, additional records can be added by individual organizations.

Metamorphic Facies Units

Metamorphic facies units are included in the data model to demonstrate the model's capacity to incorporate various types of map units. Any type of polygonal unit that overlies a base polygonal unit can be treated in a similar manner. In the case of the metamorphic facies units, the overlay represents areas of consistent metamorphic grade. On a geologic map, these polygonal areas would normally be shown as a pattern which overlays the background polygons of the rock units. Other examples of the use of this type of unit might be to display areas of alteration or extent of glaciation.

There is a one-to-one relation between the Metamorphic Facies Table and the COA Table. That is, if there is a metamorphic facies object identified in the COA Table, it will have one and only one record in the Metamorphic Facies Table. The Metamorphic Facies Table can be used to specify the grade of the overlay unit as well as other descriptive aspects of the unit. As with several other tables in the Compound Object Archive, the description of the Metamorphic Facies Table is not complete at this time. It is hoped that additional attributes will be defined prior to adoption of the data model. The purpose of including the table at this time is to provide an example of how this type of geologic object could be modeled and to provide a source of data for testing the model.

Descriptions of Individual Tables

This section of the report defines the attributes that are included in each of the data model tables. Each attribute is named, defined, and assigned a format. The formats used are primarily character, integer, and float. Character format attributes are used to store text of any kind. Integer formats are used to store numeric values, primarily unique, integer identification numbers used to associate tables with each other. Float formats are used to store real numbers. Lengths of attribute fields are not specified as these may vary between implementations. For attributes which make use of restricted word or term lists, tables of the applicable words or terms are included. These tables are, in general, neither complete nor final. Comments and improvements are encouraged. Please contact the authors.

Metadata and Related Tables

The Metadata portion of the model includes 4 tables, Source, Related Source, Organization, and Projection. The information in these tables may be used to link to a database of formal metadata. These tables are intended to supply reference information for all geologic objects in the archive. In an archive of more than one map, the ***source_id*** attribute is carried throughout the archive so that any object within the archive can always be traced back to its original source. In addition, there are two related tables that are defined here, the Classification Scheme and Classification Name tables.

Source Table

The Source Table (Table 1) contains reference information for all maps that are original sources for geologic objects in the map archive. The key attribute, ***source_id***, is carried throughout the archive wherever a geologic object is identified so that each object can be traced back to its original source. The minimum information which is required in the source table to fully track each geologic object includes: a code representing the source organization and that organization's identification code for the publication, a full bibliographic reference to the original geologic map, the scale of the original map, and some indication of the precision of the analog-to-digital processing. For ease of searching the database and for compatibility with formal metadata requirements, the bibliographic reference information should be divided into several attributes, as shown in Table 1. If formal metadata is available, this table could also be used as a link to the metadata database.

Table 1: Definition of the attributes in the Source Table.

Attribute	Definition	Format
*** source_id**	Unique identification number of an information source	integer
org_id @	Unique organization identifier for an information source	character
source_author	List of information source authors	character
source_date	Year of information source publication or creation	date
source_title	Title of information source	character
pub_edition	Publication edition of a published information source	character
pub_series	Publication series name of a published information source	character
pub_issue	Issue identification of a published information source	character
pub_place	Place of publication	character
pub_contact	Contact for information about the source	character
source_scale	Scale of source map (denominator of scale fraction)	integer
source_resolution	Resolution of digital source map, in meters	integer
prj_id @	An identification code linking to the projection definition in the projection table	character
max_lat	Northern limit of map in decimal degrees	float
min_lat	Southern limit of map in decimal degrees	float
max_long	Eastern limit of map in decimal degrees	float
min_long	Western limit of map in decimal degrees	float
url	World Wide Web address for the organization that published the source	character
comment	Additional information about the source	character
source_contribution	The contribution made by this source to an object referencing this source; e.g. if the source is documenting a change to a geologic object on a map, then this field would record the nature of the modification	character

Related Source Table

The Related Source Table is used to document relationships between various sources of information. Its two-part key, ***source1_id*** and ***source2_id***, is used to identify two records in the Source Table which are related in some fashion. The relationship between the two sources is then defined in the *source_relation* attribute. A record in this table could be used, for example, to link a derivative map to the original map. The *source_relation* attribute might then contain the entry, "modified from", indicating that source #1 had been modified from source #2.

Table 2: Definition of the attributes in the Related Source Table.

Attribute	Definition	Format
*** source1_id @**	Unique identification number of an information source	integer
*** source2_id @**	Unique identification number of a second information source	integer
source_relation <	Specifies the type of relationship source1 has with source2	character

The following table (Table 3) contains examples of terms that might be entered into the *source_relation* attribute. This list is not intended to be comprehensive, but to serve as an example only.

Table 3: Terms that could be used for the *source_relation* attibute in the Related Source Table.

source_relation	**Definition**
digitized from	Indicates source1 is a digital version of source2
modified from	Indicates source1 has been modified from source2. The *source_contribution* attribute in source1 might include details of the type of modification

Projection Table

The Projection Table (Table 4) is used to store all of the parameters necessary to fully specify the map projection for each source of information. Although an attempt has been made to provide for all of the normal parameters used to specify map projections, clearly no one projection will have entries in all attributes. Multiple records in the Source Table can refer to the same record in the Projection Table if the details of the projection are the same.

Table 4: Definition of the attributes in the Projection Table.

Attribute	**Definition**	**Format**
*** prj_id**	A unique identification code assigned to a projection record	character
prj_type <	Type of projection; e.g. UTM, TM, Mercator, etc.	character
zone	The grid zone specification for a UTM projection	integer
ellipsoid <	The name of the ellipsoid used	character
scale_factor <	The scale factor for the projection	float
units <	The units; e.g. feet, survey feet, meters, etc.	character
origin_lat	The latitude of the origin of the projection in decimal degrees	float
origin_long	The longitude of the origin of the projection in decimal degrees	float
cen_meridian	The longitude of the central meridian of the projection in decimal degrees	float
false_east	The offset in the x direction in projection units.	float
false_north	The offset in the y direction in projection units.	float
parallel_1	The first standard parallel for a Lambert projection in decimal degrees	float
parallel_2	The second standard parallel for a Lambert projection in decimal degrees	float
radius	The radius associated with some polar-type projections, in kilometers	float

Organization Table

The Organization Table (Table 5) is used to provide a full, formal name for organizations (such as U.S. Geological Survey) in addition to the shorter, abbreviated identifier (USGS) that is used in the Source Table. Having only two attributes, it is used as a simple look-up table.

Table 5: Definition of the attributes in the Organization Table.

Attribute	**Definition**	**Format**
*** org_id**	Unique organization identifier	character
org_name	Full organization name	character

Classification Scheme Table

The Classification Scheme Table (Table 6) provides the correlation between the Source Table and the Legend’s Classification Object Table. It allows the user to define a classification scheme (a set of classification objects) and save it for further use, making it easier to create multiple maps using the same classification scheme. In addition, the Classification Scheme Table includes a classification sequence number and a display priority and visibility attributes.

Table 6: Definition of the attributes in the Classification Scheme Table.

Attribute	Definition	Format
*** source_id @**	Unique identification number of an information source	integer
class_obj_id @	A unique identifier for each category of objects described and symbolized in the map legend. It is the link to the Classification Object Table	integer
class_scheme_id @	Identification number, unique to a classification scheme, used to link a classification scheme with its name and source	integer
class_seq	A number defining the sequential position of the object in the legend, within its classification group (see Classification Object Table)	integer
disp_priority	A priority number which allows the user to specify the order in which objects are drawn when the map is displayed. Objects with larger numbers are drawn on top of , and may hide, objects with smaller numbers	integer
disp_visibility	A toggle, which indicates whether the object is displayed in the legend or remains hidden from view when the legend is displayed	character

Classification Name Table

The Classification Name Table (Table 7) is used for naming classification schemes and tying them back to an original source. This table also allows the user to recall classification schemes by name or by their original source.

Table 7: Definition of the attributes in the Classification Name Table.

Attribute	Definition	Format
*** class_scheme_id**	Identification number; unique to a classification scheme; used to link all objects in a classification scheme with a name and source	integer
class_scheme_name	Descriptive name for the classification scheme	character
source_id @	Unique identification number of an information source	integer

Legend and Related Tables

The Legend portion of the data model is used to select the objects to be included on a particular map, to record the descriptions of those objects for the purposes of that map, to specify how the selected objects are to be symbolized for a particular map, and to link the spatial descriptions of objects in the Spatial Object Archive to attribute descriptions in the Compound Object Archive.

Classification Object Table

The Classification Object Table (Table 8) is used to define the objects that are to appear on a map and therefore, on the map legend. This table also defines the sequence of objects on the map legend and the labeling that is used for each object. The Classification Object Table can be used to define individual objects such as named faults or other features, it can be used to define classes of singular objects which all use the same symbolization, such as all normal faults or all foliation symbols, and it can be used to define compound objects such as rock units or alteration zones. The table also defines the legend labeling that is used for each object and the object's type. The attribute *class_group* is used to group similar objects on a map legend, for example all intrusive rock units or all structural symbols.

Table 8: Definition of the attributes in the Classification Object Table.

Attribute	Definition	Format
*** class_obj_id**	A unique identifier for each object or category of objects described and symbolized in a map legend	integer
class_group	Used to group similar objects within the map legend. On paper maps these terms are the headings for various sections of the legend	character
class_label	The character symbol for the item on the legend. For a rock unit, this would be the unit label, such as TKgr	character
class_name	The name assigned to this legend item. For a rock unit, this might be the unit name, such as Pike's Peak Granite, or alluvium. For a structural unit, it might be a formal name, such as San Andreas Fault, or an informal name, such as normal fault.	character
class_desc	An English language description of the legend object or group of objects. For objects or groups of objects which are not defined in the Compound Object Archive, this is the descriptive text which would appear on a map legend	character

The following table (Table 9) contains examples of terms that might be entered into the *class_group* attribute. This list is not intended to be comprehensive, but to serve as an example only.

Table 9: Terms that could be used for the *class_group* attibute in the Classification Object Table.

class_group
Sedimentary
Intrusive
Extrusive
Volcanic
Metamorphic
Structural Symbols
Proterozoic Rocks
Upper Plate Rocks

Cartographic Object Table

The Cartographic Object Table (Table 10) symbolizes map objects that are defined in the Classification Object Table. Each object in the Classification Object Table can be represented by one or more records in the Cartographic Object Table, allowing the symbolization of each feature on the resulting map to be composed of multiple layers. Each of these layers is defined by pointing to a symbol table and a specific symbol within the table and by pointing to a color table and a specific color within the table. The type of symbol to be used is determined by the attribute, *cart_sym_type*. The attribute, *cart_sym_table*, specifies the symbol table to be used and the attribute, *cart_sym*, specifies the symbol to be used from the table. There can be multiple standard tables for each type of symbol, if necessary. Thus, point symbols for a single map could be drawn from several Point Symbol Tables. Each record in this table also includes a brief description of the symbol, the name of a color table where a color definition can be found, and the color number to be used within that table. If the definition of a symbol within a symbol table includes a color definition, then the *cart_color_table* and *cart_color* attributes can be left blank to use the defined color or they can be specified to override the defined color with a different color.

Table 10: Definition of the attributes in the Cartographic Object Table.

Attribute	Definition	Format
*** class_obj_id @**	A unique identifier for each object or category of objects described and symbolized in a map legend	integer
*** cart_seq**	A number representing the drawing sequence of the individual patterns which make up a symbol; a value of 1 is the bottom pattern, 2 is the next up, etc.	integer
cart_desc	Description of the pattern	character
cart_sym_type @	Specifies the type of symbol as: area, line, or point	character
cart_sym_table @	Name of a symbol table	character
cart_sym @	The symbol number from the table specified in *cart_sym_table*	integer
cart_color_table @	Name of a color table	character
cart_color @	The color number from the table specified in *cart_color_table*	integer

Symbol Table

The Symbol Table (Table 11) represents the various symbol tables that are used within each individual GIS. The attribute, ***cart_sym_type***, specifies the type of symbol, and the attribute, ***cart_sym_table***, allows for the use of multiple symbol tables within a single map.

Table 11: Definition of the attributes in the Symbol Table.

Attribute	Definition	Format
*** cart_sym_type <**	Specifies the type of symbol as: area, line, or point	character
*** cart_sym_table**	Name of a symbol table	character
*** cart_sym**	The number of a specific symbol pattern within a symbol table	integer
desc	Description of the symbol pattern and suggested uses	character

Color Table

The Color Table (Table 12) is a compilation of definitions of symbol colors. There is one display color defined by each record in the table. Multiple Color Tables can be used within a single map.

Table 12: Definition of the attributes in the Color Table.

Attribute	Definition	Format
*** cart_color_table**	Name of a color table	character
*** cart_color**	The unique number for a specific color within a color table	integer
CMYK	Definition of color in cyan-magenta-yellow-black coordinates	character
RGB	Definition of color in red-green-blue coordinates	character
desc	Description of the color and suggested uses	character

Data Classification Table

The Data Classification Table (Table 13) is a correlation table that joins the Classification Object Table to the Compound Object Archive (COA Table). Because there is a many-to-many relationship between the Classification Object Table and the COA Table, an intermediate table is required to correlate the entries in one table to the entries in the other. For example, a single entry in the Classification Object Table (map legend), such as a rock unit, may refer to more than one unit in the COA Table. This would be the case where a single rock unit on the current map is defined as including several units from the archive. Similarly, a single unit record in the COA Table may be included in more than one Classification Object. For example, a single fault may be represented on more than one map. In addition to its correlation function, which is handled by the two key attributes, ***class_obj_id*** and ***coa_id***, this table has two additional functions: sequencing multiple units within a Classification Object and indicating the relative abundance of multiple units. If a map legend item (Classification Object) includes more than one object from the COA Table, the sequence in which those units appear in the legend description may be defined using the *data_seq* attribute. In addition, the relative volume importance of those units may be defined by the *vol_percent* and *vol_quality* attributes. The *vol_percent* attribute is used to specify the volume percent of the combined legend item that is represented by each individual unit making up the item and the *vol_quality* attribute is used to specify the quality of the volume estimate. The *vol_percent* and *vol_quality* attributes are discussed more fully in the COA Tables from which they are derived.

Table 13: Definition of the attributes in the Data Classification Table.

Attribute	Definition	Format
*** class_obj_id @**	A unique identifier for each object or category of objects described and symbolized in the map legend	integer
*** coa_id @**	Unit identifier which is the key attribute of the COA Table	integer
vol_percent	Estimated volume percent an individual unit in the Compound Object Archive comprises of the entire Classification Object	integer
vol_quality	Quality of the volume percent estimate (entered as: ± nn %)	integer
data_seq	Specifies the order in which individual units in the Compound Object Archive should appear in a composite map legend item (a classification object that includes more than one COA unit)	integer

Spatial Object Archive and Related Tables

The Spatial Object Archive is the storage location for the spatial description of all objects within the map library. All information concerning the shape, size, location, etc. of each map feature (spatial object) is stored in this archive. The archive is intended to be implemented in a Geographic Information System (GIS). Individual tables in the archive are linked through the GIS to the spatial descriptions of the individual features. A spatial object is any geometric object (e.g. polygon, line, or point, etc.) that is defined, and stored in the GIS. The spatial objects are stored in individual data sets within the GIS. Depending on the implementation in the GIS, a digital map will require one or more data sets for complete storage of all map objects. Each map object in a single data set is assigned a unique ***spatial_obj_id*** attribute. The combination of the ***spatial_obj_id*** and the data set identifier, which is stored in the ***dataset_id*** attribute, are sufficient to uniquely identify any individual map object within the archive.

Spatial Objects Table: An Example of a GIS Data Set

One or more GIS data sets are used to store the geographic coordinates and topologic definitions that make up the spatial description of map objects. The spatial data stored in the GIS is linked to the rest of the data model through attribute tables (Table 14 is an example). There must be one attribute table for each data set in the digital map library. The combination of ***spatial_obj_id*** and ***dataset_id*** provide a unique identifier for each spatial object in the data set, while the *source_id* attribute provides a link back to the original source for every spatial object.

Table 14: Definition of the attributes in the Spatial Objects Table.

Attribute	Definition	Format
*** spatial_obj_id**	A unique identifier for each object in an individual data set, or layer	integer
*** dataset_id**	Unique identification number for each data set or layer in a GIS	integer
source_id @	Unique identification number of an information source	integer

Spatial Classification Table

The Spatial Classification Table (Table 15) is a correlation table that joins the GIS tables of the Spatial Object Archive to the Classification Object Table of the map Legend. Because there is a many-to-many relationship between the GIS tables and the Classification Object Table, an intermediate table is required to correlate the entries in one table to the entries in the other. A single entry in the Classification Object Table, such as a rock unit, will normally refer to many features (polygons, lines, and/or points) in the GIS Tables. Similarly, a single feature in a GIS Table may be included in more than one Classification Object within a single map or within multiple maps. For example, a single fault segment (one line or arc in the GIS) may have more than one sense of motion and therefore, be represented on the map legend (Classification Object) by more than one symbol. Therefore, the Spatial Classification Table is needed as a means of correlating the many-to-many relationship.

Table 15: Definition of the attributes in the Spatial Classification Table.

Attribute	Definition	Format
*** spatial_obj_id @**	A unique identifier for each object in an individual data set, or layer	integer
*** dataset_id @**	Unique identification number for each data set or layer in a GIS	integer
*** class_obj_id @**	A unique identifier for each object or category of objects described and symbolized in a map legend	integer

Singular Object Archive Tables

The Singular Object Archive is composed of several tables that are used to store descriptive information related to individual spatial objects. Although only five tables are described below, the archive could include many more tables. Those described here are intended as examples only. All tables in the archive include the attributes, *spatial_obj_id* and *dataset_id*, which are used to specify the particular spatial object to which each record in the archive table refers. Each record in each table in the archive may only refer to a single spatial object, hence the name, Singular Object Archive. In addition, each record in most of the tables in the archive contains the *source_id* attribute to tie the archive information back to an original source. The Spatial Object Age Table differs slightly from the others in that it refers to a table in the Compound Object Archive that includes source reference attributes.

Spatial Object Name Table

The Spatial Object Name Table (Table 16) is used to apply names (or any other text) to a single map object. For example, there may be a number of polygons on a map that are classified as a particular intrusive unit. That classification and labeling of those polygons would be done through the Spatial Classification and Classification Object Tables. If, however, there is a single polygon on the map which represents a named pluton within the intrusive unit, that polygon name would be entered into the Spatial Object Name Table so that the name could be applied to a single feature instead of to an entire class of features.

Table 16: Definition of the attributes in the Spatial Object Name Table.

Attribute	Definition	Format
*** spatial_obj_id @**	A unique identifier for each object in an individual data set, or layer	integer
*** dataset_id @**	Unique identification number for each data set or layer in a GIS	integer
*** name**	Name to be attached to an individual point, line, or polygon. For example the name of a pluton or a fault	character
source_id @	Unique identification number of an information source	integer

Spatial Object Composition Table

The Spatial Object Composition Table (Table 17) is used to define the composition breakdown of individual map objects, where it is known. For example, a rock unit legend object may be defined to include several units from the Compound Object Archive. At most locations in a map area, the mix of these units within the individual polygons may not be known. However, there may be a single polygon within the map where the mix is known (perhaps only a single unit of the mix is present in this area). Then, the Spatial Object Composition Table can be used to define the composition of that single map object. If the polygon is composed of several units, the relative abundance of each unit can be defined by the *vol_percent* and *vol_quality* attributes. The *vol_percent* attribute is used to specify the volume percent of the spatial object that is represented by each individual unit making up the object and the *vol_quality* attribute is used to specify the quality of the volume estimate. Similarly, the Spatial Composition Table can be used to specify the mix of rock unit compositions (see Rock Composition Table, below) that compose a single polygon on the map. If the rock unit represented by an individual polygon is composed of several rock types within the definition stored in the Compound Object Archive, the specific composition of a polygon can be specified with this table by entering the same ***coa_id*** in each record, but entering a different ***comp_seq*** for each composition which exists within the polygon. The *vol_percent* and *vol_quality* attributes are used as described above. If the ***comp_seq*** attribute is zero, the assumption is that the entire rock unit is intended.

Table 17: Definition of the attributes in the Spatial Object Composition Table.

Attribute	Definition	Format
*** spatial_obj_id @**	A unique identifier for each object in an individual data set, or layer	integer
*** dataset_id @**	Unique identification number for each data set or layer in a GIS	integer
*** coa_id @**	Unit identifier which is the key attribute of the COA Table	integer
*** comp_seq @**	Identification number of a single composition description within a rock unit (see Rock Composition Table) or zero to indicate entire unit	integer
vol_percent	Estimated volume percent that the individual unit or composition in the Compound Object Archive comprises of the single spatial object	integer
vol_quality	Quality of the volume percent estimate (entered as: ± nn %)	integer
source_id @	Unique identification number of an information source	integer

Spatial Object Age Table

The Spatial Object Age Table (Table 18) is used to attach geochronologic ages to individual spatial objects. Although many uses could be made of this table, its primary purpose is to relate geochronologic age information which is stored in the Compound Object Archive (Geochronologic Age Table, Figure 11) to objects such as individual plutons which are represented by a single polygon or individual structures which are represented by a single line segment. The attributes, ***coa_id*** and ***chron_seq***, are used to identify an individual record in the Geochronologic Age Table (Table 36).

Table 18: Definition of the attributes in the Spatial Object Age Table.

Attribute	Definition	Format
*** spatial_obj_id @**	A unique identifier for each object in an individual data set, or layer	integer
*** dataset_id @**	Unique identification number for each data set or layer in a GIS	integer
*** coa_id @**	Unit identifier which is the key attribute of the COA Table	integer
*** chron_seq @**	Record identifier for a specific age determination within the Geochron Age Table for the unit identified by the *coa_id.*	integer
site_name	Name or field number associated with the sample site.	character

Structural Measurement Table

The Structural Measurement Table (Table 19) represents an example of a table for storing information generally depicted on a map as point objects. There are many types of data that can be associated with point locations, of which structural information is, perhaps, the most common. The minimum information that should be stored with each structural measurement location is the information that would be required to re-create the symbol that appears at that location on a published map. For single structural symbols, the minimum information includes an indication of what type of structure is represented on the map (strike & dip, foliation, overturned bed, joint attitude, etc.), a rotation angle (to indicate strike or bearing direction), and an additional dip (or plunge) angle. From this information, the appropriate symbol can be selected for plotting, it can be rotated to align with the strike direction if appropriate, and a dip angle can be posted next to the symbol. These items are stored in the example in the following attributes: *feature_type, strike_trend,* and *dip_plunge,* respectively. For maximum utility across organizations, the meaning of the values in *strike_trend* should be standardized. A common standard, for example, is for all values to represent the strike or bearing angle as a true azimuth between 0 and 359°. If a planar feature is being described, the strike angle is measured such that the feature dips to the right as one looks along the strike azimuth. In addition, the attribute, *site_name* is included for cases where there is an outcrop name (or number) which should be associated with the information. Because the link with the Spatial Object Archive is a one-to-many relation, multiple Structural Measurement records can be associated with each point location.

Many organizations are in the process of automating their field methods so that field geologists are able to capture information in a digital format in the field. This information is then transferred to a master field database. In this case, instead of storing the specifics of each location in the data model, a Field Detail Table takes the place of the Structural Measurement Table shown here. The Field Detail Table then acts as a correlation table which links a master field database to the geologic map data model.

Table 19: Definition of the attributes in the Structural Measurement Table.

Attribute	Definition	Format
*** struct_id**	A unique identifier for a record in the Structural Measurement Table	integer
spatial_obj_id @	A unique identifier for each object in an individual data set, or layer	integer
dataset_id @	Unique identification number for each data set or layer in a GIS	integer
site_name	Name or field number associated with the sample site.	character
feature_type <	The type of structural measurement (bedding, fold axis, foliation, etc.)	character
strike_trend	The azimuth direction of the strike or trend of the structural measurement, in degrees (for planar features use the right-hand rule for strike direction; for linear features, the trend is down the plunge direction)	integer
dip_plunge	The dip or plunge angle of the structural measurement, in degrees	integer
dip_direction	The azimuth direction of the dip of a planar feature projected to the horizontal, in degrees. This direction is equal to the strike direction plus 90 degrees	integer
planar_linear <	A toggle, which indicates whether the measurement is for a planar or a linear feature	character
comment	A text description of the structural measurement.	character
source_id @	Unique identification number of an information source	integer

Fossil Table

The Fossil Table (Table 20) is another example of the type of table that could be built into the archive to store non-structural information collected from a single site. For each point feature in the GIS there may be one or more entries in this table representing the information gathered at a single field location, in this case information about a fossil locality. Each entry may have a *site_name* (field location number or other text), a *site_label* if the text to label the map is different than the name, minimum and maximum stratigraphic ages, etc. The symbol that is used for an entire class of locations, such as all fossil localities, is defined in the map Legend (Classification Object Table). However, if the defined symbol requires additional text, the additional text for each location is stored in this table. In the simplest case, this table may be a real table in the database that contains the appropriate information for each map. Alternatively, this table may be a correlation table that links the map archive to an external database of fossil information. Similar tables could be built for many additional types of topical data. In fact, the entire Singular Object Archive could be an external database with only the linking correlation tables stored with the rest of the geologic map data.

Table 20: Definition of the attributes in the Fossil Table

Attribute	Definition	Format
*** fossil_id**	A unique identifier for a single record in the Fossil Table	integer
spatial_obj_id @	A unique identifier for each object in an individual data set, or layer	integer
dataset_id @	Unique identification number for each data set or layer in a GIS	integer
site_name	Name or field number associated with the sample site.	character
fossil_name	Name of the identified fossil	character
site_label	A label to associate with the map symbol, if it is different than the site_name	character
min_strat_name <	The minimum time-stratigraphic age selected from the Stratigraphic Time Scale Table.	character
max_strat_name <	The maximum time-stratigraphic age selected from the Stratigraphic Time Scale Table.	character
comment	A text description of the fossil	character
source_id @	Unique identification number of an information source	integer

Compound Object Archive and Related Tables

The Compound Object Archive is composed of a number of data tables and look-up tables that are used to define Compound Geologic Objects. The heart of the archive is the COA Table, which links the Legend, and thus the rest of the data model, to the various types of compound geologic objects that can be described and defined within the archive. The Compound Object Archive stores the definitions of all objects that are related to multiple spatial entities (points, lines, or polygons). The archive can be used to define many different types of geologic objects, of which only three will be described here. These three have been selected because each represents a common and different class of geologic object. The first to be defined, Rock Units, represents the most common use of the archive, which is to define various types of map units based on rock features (lithology, age, stratigraphic position, mineralogy, etc.) Any type of unit, which forms a polygonal base for a geologic map, would be treated in a fashion similar to Rock Units. Structural Features will also be described because they form the second most common type of geologic object and because they represent a class of generally linear geologic objects. Any other linear geologic object would be treated in a manner similar to Structural Features. Finally, Metamorphic facies units will be described because they represent a unique class of geologic objects—polygonal objects that overlay a polygonal geologic map base. These units are an example of any unit type that overlies the base rock units and are thus, in a sense, transparent to this base. Note that these polygons do not represent metamorphic rock units; they represent metamorphism that crosscuts the underlying rock units. Other examples of this class of units would be alteration overlays or glacial extent overlays. The diagrams of the Compound Object Archive show a table for Additional COA Types (Figure 10), which is included to indicate additional types of objects, such as geomorphologic or soil objects. These additional types of objects are distinct from additional attributes, such as engineering properties of rock units, which would attach to the Rock Unit Table.

Compound Object Archive (COA) Table

The COA Table (Table 21) is the central table used to describe Compound Objects. The primary use of the COA Table is to specify which type of unit is being described and, therefore, which additional tables should be consulted for the remainder of the description of the unit. The *coa_type* attribute specifies which type of object is being defined and the ***coa_id*** attribute is used as a unique identifier for each unit within the archive. There is also an attribute, *coa_name* for the name of the unit and provision for a text description of the object (*coa_desc* attribute) which would normally contain the text that would be used in the map legend to describe this unit. Finally, the COA Table contains an attribute for linking each object in the archive back to its original source.

Table 21: Definition of the attributes in the COA Table.

Attribute	Definition	Format
*** coa_id**	Unique identification number of a unit in the Compound Object Archive	integer
coa_name	The name of the unit in the Compound Object Archive	character
coa_type <	Type of Compound Object (Rock Unit, Structure, etc.)	character
coa_desc	A text description of the Compound Object	character
source_id @	Unique identification number of an information source	integer

The following table (Table 22) contains a list of words that can currently be used in the *coa_type* field. This list can be expanded as additional data types are incorporated in the Compound Object Archive.

Table 22: Word list for the *coa_type* attribute in the COA Table.

coa_type	Definition
Structure	Structural features, such as contacts, faults, and folds
Rock Unit	Rock units of all types
Metamorphic Facies	Metamorphic facies units, which overprint or cross-cut rock units

Formal Unit Table

The Formal Unit Table (Table 23) is used to store information about the formal definition of a unit. Its most common use will be for formal definitions of rock units, but it could be used for any type of unit within the archive. It may include formal names, references to type sections or areas, etc. The formal unit data may be included within this table in the map archive, or this table may be used as a correlation table to link to a national database of formal stratigraphic units. Therefore, this table could represent an independent database that is linked with the ***coa_id*** attribute.

Table 23: Definition of the attributes in the Formal Unit Table.

Attribute	Definition	Format
*** coa_id @**	Unique identification number of a unit in the Compound Object Archive	integer
name	Formal name of the compound object	character
type_section	Location of a defining type section or area	character
etc.	Additional attributes may be defined	

COA Relation Table

The COA Relation Table (Table 24) is used to store information about the relationships between objects that occur in the COA Table. Some examples of relationships as they are displayed on geologic maps are shown in Figure 13. Relationships are primarily temporal and structural. The *coa_id* attribute refers to a unit defined in the COA Table. The *rel_coa_id* attribute refers to a second unit defined in the COA Table. The direction of the relation is from the unit represented by the *coa_id* to the unit represented by the *rel_coa_id*. Therefore, the relation, “overlies”, means that the *coa_id* unit overlies the *rel_coa_id* unit. The purpose of defining relationships in this table is to allow automated analysis of the various kinds of relationships between defined units. The relationship can take many forms. It can be an age relationship such that one object is known to be older than, younger than, or contemporaneous with another. This kind of information is often known even if the actual ages of the two objects are not known sufficiently to be able to determine their age relationship from other data. For example, two rock units may only be known to be Cretaceous and therefore appear to be the same age if one only considers the age attributes. But, if one is known to overlay the other, that age relationship can be recorded in this table. The relationship may be of one object containing another as a group may contain a formation (see also the COA Tree Table). The relationship may be one of correlation or equivalence where an object from one area is known to correlate with or be equivalent to an object in another area. Relationships need not be confined to lithostratigraphic units; structural and other types of objects may also have age, correlation, and other relationships. Sometime these relationships are described in words in a report; but they are often described with diagrams such as shown in Figure 13. Relationships, which can be defined between two objects, are stored in this table using keywords in the *relation* attribute and, if desired, a text description of the relationship in the *rel_desc* attribute. An initial list of relationship keywords (Table 25) is included with the data model, but the list is intended to be expanded by mutual consent as new uses for the table are discovered.

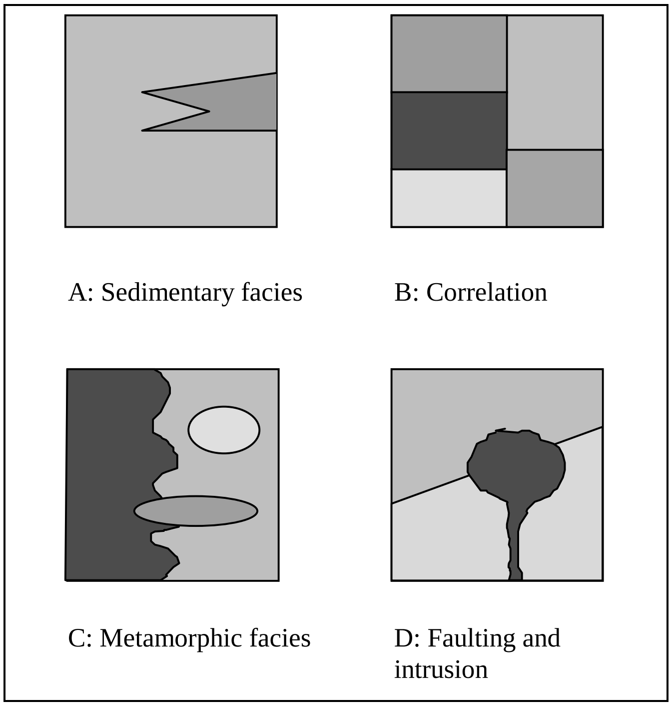

A: Sedimentary facies
B: Correlation
C: Metamorphic facies
D: Faulting and intrusion

Figure 13. Diagrams used on geologic maps to describe relationships between map objects.

Table 24: Definition of the attributes in the COA Relation Table.

Attribute	**Definition**	**Format**
*** rel_id**	Unique identification number for a record in this table	integer
coa_id @	Unique identification number of a unit in the Compound Object Archive	integer
rel_coa_id @	Unique identification number of a second unit in the COA Table to which the first object is related in some fashion	integer
relation <	A broad category of temporal and structural relationships between units. This information may allow for refinement of age, structural, or spatial relationships	character
rel_desc	Text description of the relationship	character

The following table (Table 25) contains an initial word list for the *relation* attribute of the COA Relation Table. This list is not complete. In developing this list, it seems most appropriate that the list include verbs or prepositions. Thus ‘correlates’ is suggested instead of ‘facies’. This usage allows for rough construction of sentences, which may be useful in the automation of descriptions of objects. Note that other aspects of the relationships between specific occurrences of objects is also stored in the COA Tree Table, the Structural Type Table, and in various rock unit tables.

Table 25: Example word list for the *relation* attribute in the COA Relation Table.

Relation	Definition
contains	A relationship in which coa_id contains rel_coa_id
contemporaneous	Formed or existing at the same time (Jackson, 1997).
correlates	To show correspondence in character and stratigraphic position between such geologic phenomena as formations or fossil faunas of two or more separate areas (Jackson, 1997).
equivalent	Corresponding in geologic age or stratigraphic position; esp. said of strata or formations that are contemporaneous in time of formation or deposition or that contain the same fossil forms (Jackson, 1997)
intrudes	An intrusive rock relationship in which coa_id intrudes rel_coa_id
overlies	A lithostratigraphic relationship in which coa_id is stratigraphically younger than rel_coa_id
above	A structural relationship in which coa_id is above rel_coa_id because of a structural process, such as faulting

COA Tree Table

The COA Tree Table (Table 26) is used to store information about parent-child relationships between units that occur in the COA Table. The ***coa_id*** attribute refers to an object in the COA Table. The ***parent_id*** attribute refers to the ***coa_id*** of a second object in the COA Table, which is a parent of the first object. The purpose of defining the relationships in this table is to allow automated simplification of geologic maps. For example, formations in a map area may be defined as parts of a group and the group may be further defined as a part of a supergroup. Then, in this table there would be two records for the formation, one showing the group as a parent and the other showing the supergroup as a parent. There would also be a record for the group showing the supergroup as its parent. With this data in the archive, simplifying the map to the group or supergroup level becomes a simple table look-up operation. Another purpose of this table is to permit queries into the archive that would return data belonging to any unit or linear feature, including references to its subdivisions. Thus, a search for a specific group could also return its composing formations, members, beds, etc. A search for a specific linear feature such as the San Andreas Fault could return it and all its separately described segments. Although this table is required for certain COA queries, in some implementations it could be computed from the COA Relations Table by adding the relation, “child of”, to the allowed *relation* word list.

Table 26: Definition of the attributes in the COA Tree Table.

Attribute	Definition	Format
*** coa_id @**	Unique identification number of a unit in the Compound Object Archive	integer
*** parent_id @**	Unique identification number of a second unit in the COA Table which is the parent of the unit identified in coa_id	integer

Rock Units and Related Tables

These tables store information about the composition, rank, and age of rock units. For purposes of the model, a rock unit is defined as any mapped unit which may occur on a geologic map, including all types of rock units, whether layered or not, unconsolidated sediment units, water and ice features where underlying geology is not mapped, etc.

Rock Unit Table

The Rock Unit Table (Table 27) is central to organization of the description of rock map units. The table is used to assign a rank to each unit and as a correlation table between the COA Table and descriptive records in the Age and Composition Tables. The *rock_rank* attribute contains a keyword that defines the rank or lithostratigraphic level of each defined unit. The keyword list will contain words such as, supergroup, group, formation, member, bed, etc. There are also four attributes in this table for specifying the total thickness of the rock unit

Table 27: Definition of the attributes in the Rock Unit Table.

Attribute	**Definition**	**Format**
*** coa_id @**	Unique identification number of a unit in the Compound Object Archive	integer
rock_rank @	A keyword defining the lithostratigraphic level or rank of the defined unit	character
min_thick	Minimum thickness of the rock unit, in meters	integer
max_thick	Maximum thickness of the rock unit, in meters	integer
typ_thick	Typical, or average thickness of the rock unit, in meters	integer
thick_qual	Quality of the typical thickness estimate as a percent of the typical thickness (entered as: ± nn %)	integer

The following table (Table 28) is an initial word list for the *rock_rank* attribute of the Rock Unit Table. This list is incomplete and intended as an example to amplify the definition and intended usage.

Table 28: Example word list for the *rock_rank* attribute in the Rock Unit Table.

rock_rank	**Definition (Jackson, 1997)**
supergroup	A formal assemblage of related or superposed groups, or of groups of formations
group	The formal lithostratigraphic unit next in rank above formation. The term is applied most commonly to a sequence of two or more contiguous or associated formations with significant and diagnostic lithologic features in common
formation	A body of rock identified by lithic characteristics and stratigraphic position; it is prevailingly but not necessarily tabular, and is mappable at the Earth's surface or traceable in the subsurface
member	A formal lithostratigraphic unit next in rank below a formation, comprising some specially developed part of a formation
bed	A layer of sediments or sedimentary rocks bounded above and below by more-or-less well defined bedding surfaces. A bed (or beds) is the smallest formal lithostratigraphic unit of sedimentary rocks
tongue	A projecting part of a lithostratigraphic unit extending beyond its main body
informal formation	An informal equivalent of formation
informal member	An informal equivalent of member
suite	An association of apparently comagmatic igneous rock bodies of similar or related lithologies and close association in time, space, and origin

Rock Unit Rank Table

The Rock Unit Rank Table (Table 29) is used as a look-up table to correlate the rank, given in the Rock Unit Table as a word, with a numeric level number. Each rank term will be assigned a number in this table to improve the ease of searching, sorting and simplifying the database based on lithostratigraphic rank.

Table 29: Definition of the attributes in the Rock Unit Rank Table.

Attribute	**Definition**	**Format**
*** rock_rank**	A keyword defining the lithostratigraphic level or rank of the defined unit	character
rock_level	A number indicating the relative rank.	integer

The following table (Table 30) contains an initial list of values for the attributes, ***rock_rank*** and *rock_level*, in the Rock Unit Rank Table.

Table 30: Examples of the ***rock_rank*** and *rock_level* values for the Rock Unit Rank Table.

rock_rank	rock_level
top	0
supergroup	100
group	200
formation	300
suite	300
member	400
bed	500
tongue	500
sub-bed	600

Rock Composition Table

The Rock Composition Table (Table 31) is used to define a single composition within a rock unit. Each rock unit may be composed of one or more compositions, or lithologies. Each composition is represented in this table by a single record. The attributes, *mineralogy_desc*, *color_desc*, *texture_desc*, and *alteration_desc* are text fields used to describe the details of the composition represented by the record. The attributes *rock_name* and *lith_class* are used to describe the major lithology of this composition. *Rock_name* is a free text field in which the author of the original map can use whatever terminology most accurately represents the major lithology of this composition. The *lith_class* attribute is used to store a lithologic classification term, selected from a hierarchical classification of rock types (see the Lithology Table, below), which best represents the lithology of the composition. Two attributes are used because of the large variety of lithologic terms that are currently in use in the geologic literature. The *lith_class* attribute is used with a restricted list of terms to make searching and sorting the database on lithology a possibility. The inclusion of this attribute will also make it possible to automate the process of making derivative maps based on lithology. The *rock_name* attribute is included so authors will not be confined to the keyword list when choosing the most accurate lithologic term or terms to describe the composition. The attribute *vol_percent* contains information that is normally shown diagrammatically on maps by means of cross sections or columnar section diagrams. The *vol_percent* attribute, containing an estimate of the volume percent of the entire rock unit represented by the current composition, is used to explicitly order the compositions within a rock unit to answer questions concerning the dominate, or major compositions vs. minor compositions. The *vol_quality* attribute is included to indicate how well the *vol_percent* is known. The intent is to formalize the capture of critical information, such as the dominant lithology, that has often been poorly handled on paper maps. Finally, the *description* attribute is a long text field where the author can store a complete description of the individual composition. This is the information that would be displayed on a map legend in the description of rock units.

Table 31: Definition of the attributes in the Rock Composition Table.

Attribute	**Definition**	**Format**
*** coa_id @**	Unique identification number of a unit in the Compound Object Archive	integer
*** comp_seq**	Unique identification number of a composition within a rock unit. Also indicates the sequence number for displaying descriptive information about this composition within a rock unit description. Compositions are normally sequenced from most abundant to least abundant	integer
rock_name	A free-text attribute for storing the map author's preferred complete name for the rock composition	character
lith_class @	A lithologic classification term selected from those available in the Lithology Table (see below)	character
lith_form @	A form or morphology classification term selected from those available in a Form Table (not yet created)	character
vol_percent	An estimate of the volume percent of the composition within the rock unit	integer
vol_quality	Quality of the volume percent estimate (entered as: ± nn %)	integer
mineralogy_desc	A mineral modifier associated with the rock name, or description of the mineralogy of the composition	character
color_desc	A description of the color or colors of the composition	character
texture_desc	A description of the texture of the composition	character
alteration_desc	A description of any alteration associated with the composition	character
description	A text description of this composition. Intended to be read by people, this is where a long, detailed map legend description would be stored.	character

Lithology Table

The Lithology Table (Table 32) is used as a look-up table for lithologic terms used in the Rock Composition Table. In order to analyze maps based on the composition of rock units, the list of terms used for rock composition need to be finite and defined. The Lithology Table defines a hierarchy of lithologic terms in a standard list. This hierarchy is useful for generalization of terms and explicitly defines the system of naming of lithologic units. The term, lithology, is used here in its broadest sense; we include terms for unconsolidated sedimentary units, etc. as well as terms for lithified rock units.

There are many systems for hierarchical classifications of lithology. The selection and use of a single defined system will greatly facilitate the use of digital geologic maps. Although we present a classification system in this document, it is intended only as a mechanism to describe how a classification system is used with the data model and as a starting point for the development of a standard classification. It is hoped that consensus can be reached among organizations which use digital geologic maps so that the same classification can be used for most maps. However, if that is not the case, then individual organizations are free to develop their own classification schemes. Please refer to the previous discussion in Rock Units for more on the implementation of a standard list of lithological terms.

Table 32: Definition of the attributes in the Lithology Table.

Attribute	**Definition**	**Format**
*** lith_class**	A predefined hierarchical list of lithologic terms used for classifying rock compositions.	character
lith_id	A unique identifier for the lithologic term which is used in the Lithology Tree table to store parent-child relations	integer
lith_level	A numeric value for the level in the hierarchy of lithologic terms.	integer
lith_desc	An English language definition of the lithologic term.	character

The following table (Table 33) presents a sample lithologic classification as it would appear in the Lithology Table. The *lith_id* attribute is a unique integer that is only used in this table and in the Lithology Tree Table. It does not need to be a sequential number, although keeping it sequential can help when printing out the table as this number can then be used to sort the records. The *lith_level* attribute shows the level in the hierarchy for each classification. As described previously, this classification is limited to 3, or occasionally 4, levels; however, the design is flexible enough so that individual organizations, and even individual users, can add classification terms to provide as many additional levels as desired. As long as the added terms are defined in terms of their level and their parent from the existing classification, they will allow subsequent users full capability to create derivative maps even if they are not aware of the added terms.

Table 33: Sample hierarchical classification for the *lith_class* attribute in the Lithology Table.

lith_class	**lith_id**	**lith_level**	**lith_desc (Jackson, 1997, unless otherwise noted)**
Top	0	0	
Unconsolidated deposit	1	1	A sediment that is loosely arranged or unstratified, or whose particles are not cemented together, occurring either at the surface or at depth.
Alluvium	2	2	A general term for clay, silt, sand, gravel or similar unconsolidated detrital material, deposited during comparatively recent geologic time by a stream or other body of running water, as a sorted or semisorted sediment…
Flood plain	3	3	The surface or strip of relatively smooth land adjacent to a river channel, constructed by the present river in its existing regimen and covered with water when the river overflows its banks.
Levee	4	3	A long broad low ridge or embankment of sand and coarse silt, built by a stream on its flood plain and along both banks of its channel, esp. in time of flood when water overflowing the normal banks is forced to deposit the coarsest part of its load.
Delta	5	3	The low, nearly flat, alluvial tract of land at or near the mouth of a river, commonly forming a triangular or fan-shaped plain of considerable area…
Alluvial fan	6	3	A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream (esp. in a semiarid region) at the place where it issues from a narrow mountain valley upon a plain or broad valley…
Alluvial terrace	7	3	A stream terrace composed of unconsolidated alluvium (including gravel), produced by renewed downcutting of the flood plain or valley floor…
Eolian	8	2	Sediments such as loess or sand deposited by the action of the wind. (working definition)
Dune sand	9	3	A type of blown sand that has been piled up by the wind into a sand dune, usually consisting of rounded mineral grains, commonly quartz, having diameters ranging from 0.1 to 1 mm.
Sand sheet	10	3	A large irregularly shaped plain of eolian sand, lacking the discernible slip faces that are common on dunes.
Loess	11	3	A widespread, homogeneous, commonly nonstratified, porous, friable, slightly coherent, usually highly calcareous, fine-grained blanket deposit, consisting predominantly of silt with

			subordinate grain sizes ranging from clay to fine sand.
Lake deposit (non-glacial)	12	2	A sedimentary deposit laid down conformably on the floor of a lake, usually consisting of coarse material near the shore and sometimes passing rapidly into clay and limestone in deeper water…
Playa	13	3	…a dry, vegetation-free, flat area at the lowest part of an undrained desert basin, underlain by stratified clay, silt, or sand, and commonly by soluble salts.
Lake terrace	14	3	A narrow shelf, partly cut and partly built, produced along a lake shore…and later exposed when the water level falls.
Marine	15	2	Deposits constructed by the action of waves and currents of the sea. (working definition)
Beach sand	16	3	A loose aggregate of unlithified mineral or rock particles of sand size forming a beach (the relatively thick and temporary accumulation of loose water-borne material that is in active transit along, or deposited on, the shore zone between the limits of low water and high water). (working definition)
Marine terrace	17	3	…a wave-cut platform that has been exposed by uplift along a seacoast or by the lowering of sea level, and from 3 m to more than 40 m above mean sea level; an elevated marine-cut bench.
Mud flat	18	3	A relatively level area of fine silt along a shore (as in a sheltered estuary) or around an island, alternately covered and uncovered by the tide, or covered by shallow water…
Mass wasting	19	2	Deposits formed by the dislodgement and downslope transport of soil and rock material under the direct application of gravitational body stresses.
Colluvium	20	3	A general term applied to any loose, heterogeneous, and incoherent mass of soil material and/or rock fragments deposited by rainwash, sheetwash, or slow, continuous downslope creep, usually collecting at the base of gentle slopes or hillsides.
Mudflow	21	3	Deposits formed by a process characterized by a flowing mass of predominantly fine-grained earth material possessing a high degree of fluidity during movement.
Lahar	22	4	A mudflow composed chiefly of volcaniclastic materials on the flank of a volcano.
Debris flow	23	3	A moving mass of rock fragments, soil, and mud, more than half of the particles being larger than sand size.
Landslide	24	3	A general term covering a wide variety of mass-movement landforms and processes involving the downslope transport, under gravitational influence, of soil and rock material, en mass.
Talus	25	3	An outward sloping and accumulated heap or mass of rock fragments of any size or shape (usually coarse and angular) derived from and lying at the base of a cliff or very steep, rocky slope, and formed chiefly by gravitational falling, rolling, or sliding.
Tectonic mélange	26	3	A mélange produced by tectonic processes.

Glacial drift	27	2	A general term applied to all rock material (clay, silt, sand, gravel, boulders) transported by a glacier and deposited directly by or from the ice, or by running water emanating from a glacier.
Glacial till	28	3	Dominantly unsorted and unstratified drift, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by meltwater…
Stratified glacial sediment	29	3	Stratified glacial drift deposited by, or reworked by running water, or deposited in standing water. (working definition)
Outwash	30	4	Stratified detritus (chiefly sand and gravel) removed or “washed out” from a glacier by meltwater streams and deposited in front of or behind the end moraine or the margin of an active glacier.
Glaciolacustrine	31	4	Deposits and landforms composed of suspended material brought by meltwater streams flowing into lakes bordering the glacier, such as deltas, kame deltas, and varved sediments.
Glacial-marine	32	4	Deposits of glacially eroded, terrestrially derived sediment in the marine environment.
Peat	33	2	An unconsolidated deposit of semicarbonized plant remains in a water saturated environment, such as a bog or fen, and of persistently high moisture content (at least 75%).
Residuum	34	2	An accumulation or rock debris formed by weathering and remaining essentially in place after all but the least soluble constituents have been removed…
Sedimentary rock	35	1	A rock resulting from the consolidation of loose sediment that has accumulated in layers…
Mudstone	36	2	A general term that includes clay, silt, claystone, siltstone, shale, and argillite, and that should be used only when the amounts of clay and silt are not known or specified or cannot be precisely identified…
Claystone	37	3	An indurated rock with more than 67% clay-sized minerals.
Shale	38	3	A laminated, indurated rock with more than 67% clay-sized minerals.
Siltstone	39	3	An indurated silt having the texture and composition of shale but lacking its fine lamination or fissility; a massive mudstone in which the silt predominates over clay.
Sandstone	40	2	A medium-grained clastic sedimentary rock composed of abundant rounded or angular fragments of sand size with or without a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material…
Arenite	41	3	A “clean” sandstone that is well-sorted, contains little or no matrix material, and has a relatively simple mineralogic composition; specifically a pure or nearly pure, chemically cemented sandstone containing less than 10% argillaceous matrix.
Orthoquartzite	42	4	A clastic sedimentary rock that is made up almost exclusively of quartz sand (with or without chert), that is relatively free of or lacks a fine-grained matrix; a quartzite of sedimentary origin, or a “pure quartz sandstone”.

Arkose	43	3	A feldspar-rich sandstone, commonly coarse-grained and pink or reddish, that is typically composed of angular to subangular grains that may be either poorly or moderately well sorted… Quartz is usually the dominant mineral, with feldspars constituting at least 25%.
Wacke	44	3	A “dirty” sandstone that consists of a mixed variety of unsorted or poorly sorted mineral and rock fragments and of an abundant matrix of clay and fine silt; specifically an impure sandstone containing more than 10% argillaceous matrix.
Conglomerate	45	2	A coarse-grained clastic sedimentary rock, composed of rounded to subangular fragments larger than 2 mm in diameter typically containing fine-grained particles in the interstices, and commonly cemented by calcium carbonate, iron oxide, silica, or hardened clay…
Sedimentary breccia	46	2	A breccia (coarse-grained clastic rock composed of angular broken rock fragments held together by a mineral cement or a fine-grained matrix) formed by sedimentary processes. (working definition)
Sedimentary mélange	47	2	A body of rock mappable at a scale of 1:24000 or smaller, characterized by a lack of internal continuity of contacts or strata and by the inclusion of fragments and blocks of all sizes, both exotic and native, embedded in a fragmental matrix of finer-grained material.
Carbonate	48	2	A sedimentary rock composed of more than 50% by weight carbonate minerals.
Limestone	49	3	A sedimentary rock consisting chiefly (more than 50% by weight or by areal percentages under the microscope) of calcium carbonate, primarily in the form of the mineral calcite…
Dolomite	50	3	A carbonate sedimentary rock of which more than 50% by weight or by areal percentages under the microscope consists of the mineral dolomite.
Evaporite	51	2	A nonclastic sedimentary rock composed primarily of minerals produced from a saline solution as a result of extensive or total evaporation of the solvent.
Chert	52	2	A hard, extremely dense or compact, dull to semivitreous, microcrystalline or cryptocrystalline sedimentary rock, consisting dominantly of interlocking crystals of quartz less than 30 µm in diameter…
Coal	53	2	A readily combustible rock containing more than 50% by weight and more than 70% by volume carbonaceous material, formed by compaction and induration of variously altered plant remains…
Extrusive rock	54	1	Igneous rock that has been erupted onto the surface of the earth.
Glassy	55	2	Extrusive rock with a texture which is similar to that of glass or quartz and developed as a result of rapid cooling of the lava without distinct crystallization.
Obsidian	56	3	A black or dark-colored volcanic glass, usually of rhyolite composition, characterized by conchoidal fracture.

Vitrophyre	57	3	Any porphyritic igneous rock having a glassy groundmass.
Pumice	58	3	A light-colored vesicular glassy rock commonly having the composition of rhyolite.
Pyroclastic	59	2	…clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent.
Ash	60	3	A fine pyroclastic material (under 2.0 mm in diameter). The term usually refers to the unconsolidated material…
Tuff	61	3	Consolidated or cemented volcanic ash.
Ignimbrite	62	3	The deposit of a pyroclastic flow.
Volcanic breccia	63	2	A volcaniclastic rock composed mostly of angular volcanic fragments greater than 2 mm in size.
Felsic flow	64	2	A solidified body of igneous rock having abundant light-colored minerals in its mode, that has been erupted onto the surface of the earth. (working definition)
Rhyolite	65	3	A volcanic rock defined in the QAPF diagram as having Q/(Q+A+P) between 20 and 60% and P/(P+A) between 10 and 65%…
Dacite	66	3	A volcanic rock defined in the QAPF diagram as having Q/(Q+A+P) between 20 and 60% and P/(P+A) > 65%…
Trachyte	67	3	A volcanic rock defined in the QAPF diagram as having Q/(Q+A+P) between 0 and 20% or F/(F+A+P) between 0 and 10%, and P/(P+A) between 10 and 35%. (working definition)
Latite	68	3	A volcanic rock defined in the QAPF diagram as having Q/(Q+A+P) between 0 and 20% or F/(F+A+P) between 0 and 10%, and P/(P+A) between 35 and 65%. (working definition)
Intermediate flow	69	2	A solidified body of igneous rock having approximately equal light- and dark-colored minerals in its mode, that has been erupted onto the surface of the earth. (working definition)
Andesite	70	3	A volcanic rock defined modally by Q/(Q+A+P) between 0 and 20% or F/(F+A+P) between 0 and 10%, P/(A+P) > 65%, and M < 35.
Basaltic andesite	71	3	A volcanic rock defined in the TAS diagram as rock falling in the area bounded by points with the SiO_2 and total alkali coordinates: 52, 0; 52, 5; 57, 0; 57, 5.9.
Mafic flow	72	2	A solidified body of igneous rock having abundant dark-colored minerals in its mode, that has been erupted onto the surface of the earth. (working definition)
Basalt	73	3	A volcanic rock defined modally by Q/(Q+A+P) between 0 and 20% or F/(F+A+P) between 0 and 10%, P/(A+P) > 65 %, and M > 35.
Intrusive rock	74	1	An igneous rock mass formed by the process of emplacement of magma in pre-existing rock.
Aplite	75	2	A light-colored hypabyssal igneous rock characterized by a fine-grained allotriomorphic-granular (i.e. aplitic) texture.
Pegmatite	76	2	An exceptionally coarse-grained igneous rock, with interlocking crystals, usually found as irregular dikes, lenses,

			or veins, esp. at the margins of batholiths.
Granitoid	77	2	A general term for all phaneritic igneous rocks dominated by quartz and feldspars.
Granite	78	3	A plutonic rock with Q between 20 and 60% and P/(A+P) between 10 and 65%.
Granodiorite	79	3	A plutonic rock with Q between 20 and 60% and P/(A+P) between 65 and 90%.
Tonalite	80	3	A plutonic rock with Q between 20 and 60% and P/(A+P) greater than 90%.
Quartz syenite	81	3	A plutonic rock with Q between 5 and 20% and P/(A+P) between 10 and 35%.
Quartz monzonite	82	3	A plutonic rock with Q between 5 and 20% and P/(A+P) between 35 and 65%.
Quartz diorite	83	3	A plutonic rock with Q between 5 and 20%, P/(A+P) greater than 90%, and plagioclase more sodic than An_{50}.
Alkalic intrusive rock	84	2	An igneous rock that contains more sodium and/or potassium than is required to form feldspar with the available silica.
Syenite	85	3	A plutonic rock with Q between 0 and 5% and P/(A+P) between 10 and 35%.
Monzonite	86	3	A plutonic rock with Q between 0 and 5% and P/(A+P) between 35 and 65%.
Mafic intrusive rock	87	2	A plutonic rock composed chiefly of one or more ferromagnesian, dark-colored, minerals in its mode.
Diorite	88	3	A plutonic rock with Q between 0 and 5%, P/(A+P) greater than 90% and plagioclase more sodic than An_{50}.
Gabbro	89	3	A plutonic rock with Q between 0 and 5%, P/(A+P) greater than 90% and plagioclase more calcic than An_{50}.
Norite	90	4	A plutonic rock satisfying the definition of gabbro, in which pl/(pl+px+ol) is between 10 and 90% and opx/(opx+cpx) is greater than 95%.
Troctolite	91	4	A plutonic rock satisfying the definition of gabbro, in which pl/(pl+px+ol) is between 10 and 90% and px/(pl+px+ol) is less than 5%.
Lamprophyre	92	3	A group of porphyritic igneous rocks in which mafic minerals form the phenocrysts; feldspars, if present, are restricted to the groundmass.
Ultramafic intrusive rock	93	2	A general name for plutonic rock with color index M greater than or equal to 90…
Peridotite	94	3	A plutonic rock with M equal to or greater than 90 and ol/(ol+opx+cpx) greater than 40%.
Pyroxenite	95	3	A plutonic rock with M equal to or greater than 90 and ol/(ol+opx+cpx) less than 40%.
Hornblendite	96	3	A plutonic rock with M equal to or greater than 90 and hbl/(hbl+px+ol) greater than 90%.

Carbonatite	97	2	An igneous rock composed of at least 50% carbonate minerals.
Anorthosite	98	2	A plutonic rock with Q between 0 and 5, P/(A+P) greater than 90, and M less then 10. A group of monomineralogic plutonic igneous rocks composed almost entirely of plagioclase feldspar…
Metamorphic rock	99	1	A rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the earth’s crust.
Hornfels	100	2	A fine-grained rock composed of a mosaic of equidimensional grains without preferred orientation and typically formed by contact metamorphism.
Slate	101	2	A compact, fine-grained metamorphic rock that possesses slaty cleavage and hence can be split into slabs and thin plates.
Metasedimentary	102	2	A sedimentary rock that shows evidence of having been subjected to metamorphism.
Argillite	103	3	A compact rock derived either from mudstone or shale, that has undergone a somewhat higher degree of induration than mudstone or shale but is less clearly laminated than shale and without its fissility, and that lacks the cleavage distinctive of slate.
Quartzite	104	3	A granoblastic metamorphic rock consisting mainly of quartz and formed by recrystallization of sandstone or chert by either regional or thermal metamorphism.
Marble	105	3	A metamorphic rock consisting predominantly of fine- to coarse-grained recrystallized calcite and/or dolomite, usually with a granoblastic, saccharoidal texture.
Metavolcanic	106	2	A volcanic rock that shows evidence of having been subjected to metamorphism.
Greenstone	107	3	A field term applied to any compact dark-green altered or metamorphosed basic igneous rock (e.g. spilite, basalt, gabbro, diabase) that owes its color to the presence of chlorite, actinolite, or epidote.
Keratophyre	108	4	…all salic extrusive and hypabyssal rocks characterized by the presence of albite or albite-oligoclase and chlorite, epidote, and calcite, generally of secondary order.
Spilite	109	4	An altered basalt, characteristically amygdaloidal or vesicular, in which the feldspar has been albitized and is typically accompanied by chlorite, calcite, epidote, chalcedony, prehnite, or other low-temperature hydrous crystallization products characteristic of a greenstone.
Phyllite	110	2	A metamorphosed rock, intermediate in grade between slate and mica schist. Minute crystals of graphite, sericite, or chlorite impart a silky sheen to the surfaces of cleavage (or schistosity).
Schist	111	2	A strongly foliated crystalline rock, formed by dynamic metamorphism, that can be readily split into thin flakes or slabs due to the well developed parallelism of more than 50% of the minerals present, particularly those of the lamellar or

			elongate prismatic habit, e.g. mica and hornblende.
Mica schist	112	3	A schist whose essential constituents are mica and quartz, and whose schistosity is mainly due to the parallel arrangement of mica flakes.
Quartz-feldspar schist	113	3	A schist whose essential constituents are quartz and feldspar and with lesser amounts of mica and/or hornblende. (working definition)
Calc-silicate schist	114	3	A metamorphosed argillaceous limestone or calcareous mudstone, containing calcium-bearing silicates such as diopside and wollastonite, with a schistose structure produced by parallelism of platy minerals. (working definition)
Amphibole schist	115	3	A schist whose essential constituent is amphibole with lesser amounts of feldspar, quartz, and/or mica. (working definition)
Semischist	116	2	Schistose rock formed by granulation of coarser grains and incipient development of schistosity (Williams, Turner, and Gilbert, 1954).
Gneiss	117	2	A foliated rock formed by regional metamorphism, in which bands or lenticles of granular minerals alternate with bands or lenticles in which minerals having flaky or elongate prismatic habits predominate. Generally less than 50% of the minerals show preferred parallel orientation.
Felsic gneiss	118	3	Gneissic rock dominated by light-colored minerals, commonly quartz and feldspar. (working definition)
Granitic gneiss	119	4	Gneissic rock with a general granitoid composition. (working definition)
Mafic gneiss	120	3	Gneissic rock dominated by dark-colored minerals, commonly biotite and hornblende. (working definition)
Augen gneiss	121	3	Gneissic rock containing augen (large lenticular mineral grains or mineral aggregates having the shape of an eye in cross section).
Flaser gneiss	122	3	A dynamically metamorphosed rock in which lenses or layers of original or relatively unaltered granular materials are surrounded by a matrix of highly sheared and crushed material, giving the appearance of a crude flow structure. (working definition)
Migmatite	123	3	A composite rock composed of igneous or igneous-appearing and/or metamorphic materials, which are generally distinguishable megascopically.
Amphibolite	124	2	A crystalloblastic rock consisting mainly of amphibole and plagioclase with little or no quartz.
Granulite	125	2	A metamorphic rock consisting of even-sized, interlocking mineral grains less than 10% of which have any obvious preferred orientation.
Eclogite	126	2	A granular rock composed essentially of garnet (almandine-pyrope) and sodic pyroxene (omphacite).
Greisen	127	2	A pneumatolytically altered granitic rock composed largely of quartz, mica, and topaz.

Skarn (tactite)	128	2	A rock of complex mineralogic composition, formed by contact metamorphism and metasomatism of carbonate rocks. It is typically coarse-grained and rich in garnet, iron-rich pyroxene, epidote, wollastonite, and scapolite.
Serpentinite	129	2	A rock consisting almost wholly of serpentine-group minerals, derived from the hydration of ferromagnesian silicate minerals such as olivine and pyroxene.
Tectonic breccia	130	2	A breccia formed as a result of crustal movements, usually developed from brittle rocks.
Cataclasite	131	3	A fine-grained, cohesive cataclastic rock, normally lacking a penetrative foliation or microfabric, formed during fault movement.
Phyllonite	132	3	A rock that macroscopically resembles phyllite but that is formed by mechanical degradation (mylonitization) of initially coarser rocks…
Mylonite	133	3	A fine-grained, foliated rock, commonly possessing a distinct lineation, found in narrow, planar zones of localized ductile deformation.

Lithology Tree Table

The Lithology Tree Table (Table 34) is used to store information about parent-child relations between lithologies that occur in the Lithology Table. The ***lith_id*** attribute refers to a lithology in the Lithology Table. The ***parent_id*** attribute refers to the ***lith_id*** of a second lithology in the Lithology Table, which is a parent of the first. The purpose of defining the relationships in this table is to allow automated simplification of geologic maps based on composition. As shown in the classification above, arenite is defined as a type of sandstone and sandstone is further defined as a type of sedimentary rock. Then, in this table there would be two records for arenite, one showing sandstone as a parent and the other showing sedimentary as a parent. There would also be a record for sandstone showing sedimentary as its parent. With this data in the archive, simplifying the map to any lithologic level becomes a simple table look-up operation. Another purpose of this table is to permit queries into the archive that could return data belonging to any lithological family, including references to its subdivisions. Thus, a search for sedimentary data could also return items described as mudstone, siltstone, sandstone, arenite, etc.

Table 34: Definition of the attributes in the Lithology Tree Table.

Attribute	**Definition**	**Format**
*** lith_id**	A unique identifier for a lithologic term from the Lithology Table	integer
*** parent_id**	A unique identifier for a second lithologic term from the Lithology Table which is the parent of the first term	integer

The following table (Table 35) shows some sample data as it would appear in the Lithology Tree Table (based on the example above).

Table 35: Example of the data in the Lithology Tree Table.

lith_id	**parent_id**
41	40
41	35
40	35

Geochronologic Age Table

The Geochronologic Age Table (Table 36) is used for storing geochronologic age data for rock units. There may be one or more records in this table for each rock unit. The data in each record in this table represents a minimum date and a maximum date with appropriate error values, analytical method, and sample media. In the simplest case, this table may be a real table in the database, which contains the appropriate geochronologic information for each rock unit. Alternatively, this table may be a correlation table that links the map archive to an external database of geochronologic ages..

Table 36: Definition of the attributes in the Geochronologic Age Table.

Attribute	**Definition**	**Format**
*** coa_id @**	Unique identification number of a unit in the Compound Object Archive	integer
*** chron_seq**	Record identifier for a specific age determination for the unit identified by the *coa_id.*	integer
chron_method <	Analytical method used to obtain the age	character
sample_material <	A description of the material sampled	character
chron_date	Geochronologic age, in millions of years	float
chron_err_plus	The positive error for the geochronologic age, in millions of years	float
chron_err_minus	The negative error for the geochronologic age, in millions of years	float
comment	Additional comments concerning this age determination	character
source_id @	Unique identification number of an information source	integer

Stratigraphic Age Table

The Stratigraphic Age Table (Table 37) is used for storing information about the time-stratigraphic age of the unit. The minimum and maximum stratigraphic ages (*min_strat_name* and *max_strat_name*) contain the name of the smallest time-stratigraphic interval that is appropriate for the top and bottom (or end and beginning), respectively, of the rock unit. If the rock unit is contained within a single time-stratigraphic unit and no further information is known, then *min_strat_name* and *max_strat_name* will be equal. If the unit covers multiple, discrete time intervals, there will be multiple records for the unit in the Stratigraphic Age Table. Entries for the *min_strat_name* and *max_strat_name* attributes are selected from the geologic time scale, which is encoded in the Time Scale Table (see below).

Table 37: Definition of the attributes in the Stratigraphic Age Table.

Attribute	**Definition**	**Format**
*** coa_id @**	Unique identification number of a unit in the Compound Object Archive	integer
*** strat_seq**	Record identifier for a specific time interval for the unit identified by the *coa_id.*	integer
min_strat_name @	The minimum time-stratigraphic age selected from the Stratigraphic Time Scale Table	character
max_strat_name @	The maximum time-stratigraphic age selected from the Stratigraphic Time Scale Table	character
min_source_id @	Unique identification number of an information source for the minimum age reference	integer
max_source_id @	Unique identification number of an information source for the maximum age reference	integer

Stratigraphic Time Scale Table

The Stratigraphic Time Scale Table (Table 38) is used as a look-up table for time-stratigraphic intervals which are used to define the maximum and minimum stratigraphic age of units defined in the Rock Unit Table. In order to analyze maps based on the age of rock units, the list of words used for stratigraphic age needs to be finite and defined. The Stratigraphic Time Scale Table defines a hierarchy of stratigraphic age terms in a standard word list. Time-stratigraphic intervals of all ranks are defined here with one record for each interval. The attribute, ***strat_id***, is a unique integer which is only used in this table and in the Stratigraphic Tree Table. It does not need to be a sequential number, although keeping it sequential can help when printing out the table as this number can then be used to sort the records.

Table 38: Definition of the attributes in the Stratigraphic Time Scale Table.

Attribute	Definition	Format
*** strat_id**	A unique identifier for the strat_name	integer
strat_name	The time-stratigraphic name for the time interval	character
strat_rank @	A keyword representing the rank of the time-stratigraphic term. Must be defined in the Stratigraphic Rank table	character
min_strat_age	Minimum numerical age, in millions of years	float
max_start_age	Maximum numerical age, in millions of years	float
min_source_id @	Unique identification number of an information source for the minimum age reference	integer
max_source_id @	Unique identification number of an information source for the maximum age reference	integer

The following table (Table 39) presents a sample stratigraphic classification as it would appear in the Stratigraphic Time Scale Table. The table is incomplete as shown here, but includes examples of the various ranks of stratigraphic time. The ***strat_id*** attribute is a unique integer that is only used in this table and in the Stratigraphic Tree Table. It does not need to be a sequential number, although keeping it sequential can help when printing out the table as this number can then be used to sort the records. The *strat_rank* attribute indicates the level in the hierarchy for each term. As described, the classification has 8 individual levels; however, the design is flexible enough so that individual organizations, and even individual users, can add rank terms to provide as many additional levels as desired. As long as the added terms are defined in terms of their level and their parent from the existing terms, they will allow subsequent users full capability to create derivative maps even if they are not aware of the added terms. This table is taken from the Geologic Time Scale of the Decade of North American Geology (Bally and Palmer, 1989)

Table 39: Sample entries in the Stratigraphic Age Table.

strat_id	strat_name	min_age	max_age	strat_rank
0	Top			top
1	Phanerozoic	0	570	eon
2	Cenozoic	0	66.4	era
3	Quaternary	0	1.6	period
4	Holocene	0	0.01	epoch
5	Pleistocene	0.01	1.6	epoch
6	Calabrain	0.01	1.6	age
7	Tertiary	1.6	66.4	period
8	Neogene	1.6	23.7	subperiod
9	Pliocene	1.6	5.3	epoch

10	Late Pliocene	1.6	3.4	subepoch
11	Piacenzian	1.6	3.4	age
12	Early Pliocene	3.4	5.3	subepoch
13	Zanclean	3.4	5.3	age
14	Miocene	5.3	23.7	epoch
15	Late Miocene	5.3	11.2	subepoch
16	Messinian	5.3	6.5	age
17	Tortonian	6.5	11.2	age
18	Middle Miocene	11.2	16.6	subepoch
19	Serravallian	11.2	15.1	age
20	Langhian	15.1	16.6	age
21	Early Miocene	16.6	23.7	subepoch
22	Burdigalian	16.6	21.8	age
23	Aquitanian	21.8	23.7	age
24	Paleogene	23.7	66.4	epoch
25	Oligocene	23.7	36.6	epoch
26	Late Oligocene	23.7	30.0	subepoch
27	Chattian	23.7	30.0	age
28	Early Oligocene	30.0	36.6	subepoch
29	Rupelian	30.0	36.6	age
30	Eocene	36.6	57.8	epoch
31	Late Eocene	36.6	40.0	subepoch
32	Priabonian	36.6	40.0	age
33	Middle Eocene	40.0	52.0	subepoch
34	Bartonian	40.0	43.6	age
35	Lutetian	43.6	52.0	age
36	Early Eocene	52.0	57.8	subepoch
37	Ypresian	52.0	57.8	subepoch
38	Paleocene	57.8	66.4	epoch
39	Late Paleocene	57.8	63.6	subepoch
40	Selandian	57.8	63.6	age
41	Thanetian	57.8	60.6	subage

42	unnamed	60.6	63.6	subage
43	Early Paleocene	63.6	66.4	subepoch
44	Danian	63.6	66.4	age
45	Mesozoic	66.4	245	era
46	Cretaceous	66.4	144	period
47	Late Cretaceous	66.4	97.5	epoch
48	Maastrichtian	66.4	74.5	age
49	Campanian	74.5	84.0	age
50	Santonian	84.0	87.5	age
51	Coniacian	87.5	88.5	age
52	Turonian	88.5	91	age
53	Cenomanian	91	97.5	age
54	Early Cretaceous	97.5	144	epoch
55	Albian	97.5	113	age
56	Aptian	113	119	age
57	Neocomian	119	144	subepoch
58	Barremian	119	124	age
59	Hauterivian	124	131	age
60	Valanginian	131	138	age
61	Berriasian	138	144	age
62	Jurassic	144	208	period
63	Late Jurassic	144	163	epoch
64	Tithonian	144	152	age
65	Kimmeridgian	152	156	age
66	Oxfordian	156	163	age
67	Middle Jurassic	163	187	epoch
68	Callovian	163	169	age
69	Bathonian	169	176	age
70	Bajocian	176	183	age
71	Aalenian	183	187	age
72	Early Jurassic	187	208	epoch
73	Toarcian	187	193	age

74	Pliensbachian	193	198	age
75	Sinemurian	198	204	age
76	Hettangian	204	208	age
77	Triassic	208	245	period
78	Late Triassic	208	230	epoch
79	Norian	208	225	age
80	Carnain	225	230	age
81	Paleozoic	245	570	era
82	Permian	245	286	period
83	Late Permian	245	258	epoch
84	Carboniferous	286	360	period
85	Pennsylvanian	286	320	period
86	Mississippian	320	360	period
87	Devonian	360	408	period
88	Silurian	408	438	period
89	Ordovician	438	505	period
90	Cambrian	505	570	period
91	Late Cambrian	505	523	epoch
92	Trempealeauan	505		age
93	Franconian			age
94	Dresbachian			age
95	Middle Cambrian	523	540	epoch
96	Early Cambrian	540	570	epoch
97	Precambrain	570	3800	era
98	Proterozic	570	2500	eon
99	Late Proterozoic	570	900	era
100	Middle Proterozoic	900	1600	era
101	Archean	2500	3800	eon
102	Late Archean	2500	3000	era
103	Middle Archean	3000	3400	era
104	Early Archean	3400	3800	era

Stratigraphic Tree Table

The Stratigraphic Tree Table (Table 40) is used to store information about parent-child relationships between time-stratigraphic intervals that occur in the Stratigraphic Time Scale Table. The ***strat_id*** attribute refers to a time-stratigraphic interval in the Stratigraphic Time Scale Table. The ***parent_id*** attribute refers to the ***strat_id*** of a second interval in the Stratigraphic Time Scale Table, which is a parent of the first. The purpose of defining the relationships in this table is to allow automated simplification of geologic maps based on time-stratigraphic units. For example, periods in stratigraphic time are defined as parts of an era and the era is further defined as a part of an eon. Then, in this table there would be two records for the period, Triassic, one showing the era (Mesozoic) as a parent and the other showing the eon (Phanerozoic) as a parent. There would also be a record for the era (Mesozoic) showing the eon (Phanerozoic) as its parent. With this data in the archive, simplifying the map to any time-stratigraphic level becomes a simple table look-up operation. Another purpose of this table is to permit queries into the archive that could return data belonging to any time interval, including references to its subdivisions. Thus, a search for Precambrian data could also return items described as Proterozoic, Early Proterozoic, Archean, Middle Archean, etc.

Table 40: Definition of the attributes in the Stratigraphic Tree Table.

Attribute	**Definition**	**Format**
*** strat_id @**	A unique identifier for a time-stratigraphic interval from the Stratigraphic Time Scale table	integer
*** parent_id @**	A unique identifier for a second time-stratigraphic interval from the Stratigraphic Time Scale table which is a parent of the first interval	integer

The following table (Table 41) shows some sample data as it would appear in the Stratigraphic Tree Table (based on the example above).

Table 41: Example of the data in the Stratigraphic Tree Table.

strat_id	**parent_id**
77	45
77	1
45	1

Stratigraphic Rank Table

The Stratigraphic Rank Table (Table 42) is a look-up table, which provides a numeric value for the time-stratigraphic rank key words used in the Stratigraphic Time Scale Table. Each rank term will be assigned a number in this table to improve the ease of searching, sorting and simplifying the database based on time-stratigraphic rank.

Table 42: Definition of the attributes in the Stratigraphic Rank Table.

Attribute	**Definition**	**Format**
*** strat_rank**	A keyword representing the rank of the time-stratigraphic term.	character
strat_level	A numeric value for the level in the hierarchy of time-stratigraphic terms.	integer

The following table (Table 43) is a sample key word list with level values for time-stratigraphic ranks. This standard table is used for sorting the ranks in queries and in producing derivative maps based on stratigraphic age.

Table 43: Values for *strat_level* in the Stratigraphic Rank table.

strat_rank	strat_level
top	0
eon	100
era	200
period	300
subperiod	350
epoch	400
subepoch	450
age	500
subage	550

Structure Table

The Structure Table (Table 44) links the COA Table to the Structural Type Table. Because there is a many-to-many relationship between the COA Table and the Structural Type Table, an intermediate table is required which correlates the entries in one table to the entries in the other. A single structural feature defined in the COA Table, such as a formally named fault, may refer to several records in the Structural Type Table. For example, a single fault segment may have more than one sense of motion and therefore refer to more than one record in the Structural Type Table. Similarly, there can be many structural units that represent a particular fault type, such as a normal fault. Therefore, the Structure Table is needed as a means of correlating the many-to-many relationship. Each record in the Structure Table contains the key attributes of the corresponding records in the COA Table and the Structural Type Table as well as the attributes, *loc_accuracy*, which is used to record the positional accuracy of each feature, and *confidence*, which is used to record the confidence in the existence or identification of the feature. It is expected that a limited set of pre-defined terms, such as definite, approximate, concealed, gradational, etc. will be used within the *loc_accuracy* attribute, while a set of predefined terms such as inferred and queried will be used with the *confidence* attribute.

Table 44: Definition of the attributes in the Structure Table.

Attribute	Definition	Format
*** coa_id @**	Unique identification number of a unit in the Compound Object Archive	integer
*** struct_typ_id @**	Unique identification number of a record in the Structural Type table	integer
loc_accuracy <	Locational or positional accuracy of the structure	character
confidence <	A measure of confidence that the geologic feature exists in the field or has been identified correctly in the field (Matti and others, 1997)	character

Structural Type Table

The Structural Type Table (Table 45) contains the attributes of various types of structural features. It is linked to the Structure Table in the Compound Object Archive. Each record in the table defines a single type of structural element. A structural unit in the Compound Object Archive, whether formal or informal, may be composed of more than one structural element. Each structural element defined in this table can be used for many structural features. Therefore, there is a many-to-many relation between the Structural Type Table and the structural features defined in the Compound Object Archive; the Structure Table is used to convert the many-to-many relation to two one-to-many relations.

Although the Structural Type Table is a pre-defined, standard, look-up table which is supplied with the data model, individual organizations are free to replace it with a different table or add records to extend the table. In order to analyze maps with a computer, the list of terms used for selected attributes needs to be finite and defined. Structuring the terms as suggested here leads to a relatively short list of standard terms. The combination of these terms and the many-to-many relation between structural types and structural features provides a wide range of possible structural descriptions with a relatively limited vocabulary.

Table 45: Definition of the attributes in the Structural Type Table.

Attribute	Definition	Format
*** struct_typ_id**	Unique identifier for each combination of type and modifier	integer
type	A major category of types of geologic structures	character
modifier	A modifier to the major structure type specifying the specific type of structure	character
desc	A short description defining the structure type	character

The following table (Table 46) presents a sample Structural Type Table. This list of terms is not intended to be complete, but it is hoped that a more complete table will be developed before the data model is released for general use.

Table 46: A sample of proposed values for the attributes in the Structural Type Table.
Definitions for the terms are taken from Jackson (1997). The list is incomplete.

struct_typ_id	type	modifier	desc
1	contact	unknown	A contact of unknown type
2	contact	conformable	A conformable contact
3	contact	unconformable	An unconformable contact
4	contact	facies	A facies boundary between two map units
5	contact	intrusive	
6	contact	scratch	
7	fault	unknown	
8	fault	normal	
9	fault	detachment	
10	fault	reverse	
11	fault	thrust	
12	fault	low-angle thrust	
13	fault	strike-slip	
14	fault	strike-slip dextral	
15	fault	strike-slip sinistral	
16	fold	anticline	
17	fold	anticline, plunging	
18	fold	anticline, plunging in	
19	fold	anticline, plunging out	
20	fold	anticline, overturned	
21	fold	syncline	
22	fold	syncline, plunging	

23	fold	syncline, plunging in	
24	fold	syncline, plunging out	
25	fold	syncline, overturned	
26	fold	monocline	

Metamorphic Facies Table

The Metamorphic Facies Table (Table 47), used to store information about metamorphic facies units, is included as an example of other types of unit description tables which could be added to the data model. Note the difference between rock units that happen to be metamorphic in character (described in the Rock Unit Table) and metamorphic overlays. This table is used to describe units of a metamorphic character, which overlie or are superimposed on (in the map sense, not in the geologic sense) pre-existing rock units. These units are different in that they are represented on a map as polygonal shapes that are superimposed on and crosscut the underlying rock unit polygons. Examples would include metamorphic gradient zones, metamorphic aureoles, etc. Similar additional types of units could be defined for alteration zones or zones of glacial extent, among others. This example is not intended to be a complete list of all of the attributes that would be needed to completely describe metamorphic overlays; additional attributes and, possibly, additional standard look-up tables would be required to complete the description.

Table 47: Definition of the attributes in the Metamorphic Facies Table.

Attribute	**Definition**	**Format**
*** coa_id @**	Unique identification number of a unit in the Compound Object Archive	integer
meta_grade <	The metamorphic grade of the metamorphic facies, which should be selected from a defined list of terms	character
etc.	As yet undefined additional attributes needed for this table	

Hierarchical Coding Schemes

There is a tendency, when designing digital geologic data models, to develop extensive coding schemes for some attributes. There are advantages and disadvantages to most coding schemes. The usual advantage is to save storage space. In the extreme, the designer could assign numeric values to all attributes and force the user to either remember an entire array of numeric codes or use charts to look up the codes every time a query was made of the database. Although this approach minimizes the storage space required for the database, it places an unreasonable burden on the user. The goal of all digital geologic maps, after all, is to make the user's job easier and more efficient.

The other extreme of not coding any attributes also has its disadvantages. Many attributes are difficult to manipulate if left as descriptive text. As an example of the difficulties that can be encountered, consider encoding rock units so that their stratigraphic sequence can be analyzed. The goal is to be able to search the database for all rock units which are older than a given unit (or younger than, or the same age as, or some more complex combination). Furthermore, the search is to be based on a coding attached to the unit name, not on an attribute that represents the unit's stratigraphic age. The reason for not using the unit's age is because in many areas ages are only poorly known and an entire sequence of rock units may be assigned the same, broad age. However, the stratigraphic sequence of units may be known so that relative ages are more useful than absolute ages.

The first attempt may be to simply assign a number to each rock unit based on its position in the stratigraphic column. As long as the project is confined to a single map with no rock units that crosscut time horizons, this approach works well. Relative age can be determined simply by comparing a sequence of numbers; if the numbers run from oldest to youngest, then unit 5 is always older than unit 6. There are some obvious problems with this approach. First, there is no allowance made for units with poorly constrained relative ages. What number would be assigned to an intrusive unit if the intrusive age is unknown within the resolution of the rest of the rock units? There are also problems caused by attempting to expand the system to adjacent maps. Every time a new unit is added to the total stratigraphic column, a complete renumbering is required. A similar problem occurs whenever the map is updated. If new units are created or the relative ages of units are changed, a complete renumbering is required. Another problem may occur within a single map or when adjacent maps are joined. That is the problem of a single unit on one portion of the map being equivalent in age to several units on another portion of the map. If a single unit, A, is equivalent to units 5, 6, and 7, what number is assigned to A? This coding scheme is only workable for local problems where there is no intent to expand to adjacent areas.

Usually, these coding attempts lead to the development of some sort of hierarchical coding scheme. One such coding scheme goes something like this: assign large numbers to the major divisions, assign intermediate numbers to smaller divisions, and assign smaller intermediate numbers to even small divisions. For example, let 1000 represent the Cenozoic, 2000 represent Mesozoic, 3000 represent Paleozoic, and 4000 represent Precambrian. Within the Mesozoic, 2100 might represent Cretaceous, 2200 Jurassic, and 2300 Triassic. Within the Triassic, 2310 might represent upper Triassic, 2320 middle Triassic, and 2330 lower Triassic. For those who use such things, 2311 might represent Rhaetian, 2312 Norian, etc.

This scheme solves some of the problems with the preceding attempt. In particular, if a rock unit represents the entire Triassic on one portion of the map, it would be assigned a code of 2300. If the Triassic on another portion of the map was divided into upper, middle, and lower portions, they would be assigned codes of 2310, 2320, and 2330. Re-coding would not be required. If existing units were later subdivided, or new units were added by combining adjacent maps, no re-coding would be required. The problem of poorly constrained ages has not been completely solved. The system will work well for rock units which are only known to be Mesozoic, for example, but what code can be assigned to a rock unit that is known to be either Permian or Triassic? What about a rock unit that is known to span the Permian-Triassic boundary? Another problem occurs if the area includes several rock units of upper Triassic age. It may not be possible to fit any of the units into the individual stages of the upper Triassic, but the relative ages of the rock units may be known. How would these units be coded? If they are coded 2311, 2312, and 2313, the implication is that the stage is known for each unit; if they are all coded as 2310, the information about their relative ages is lost. Finally, what code would be assigned to several units for which their relative age is known, but which are all within the Norian? There is not a fine enough subdivision to accommodate these units in the current scheme. Although this scheme is more useful than the previous example, it still falls short of being universally applicable.

The scheme of the previous example can be improved by providing two codes for each rock unit, representing a maximum age and a minimum age. This will solve the problems of the Permo-Triassic rock units and their relatives. In addition, fractional codes could be used to code multiple units which all fall within the smallest subdivision. For example, three Norian units could be coded 2312.1, 2312.2, and 2312.3. A similar trick could then be used to code the three units that are known to be upper Triassic with stage unknown as 2310.1, 2310.2, and 2310.3. This scheme comes close to meeting the original objectives at the cost of some complication. It still does not solve all of the problems of joining adjacent maps. Unit 2310.1 on one map may not be a time equivalent to unit 2310.1 on an adjacent map. The solution proposed in the current relational data model is to use upper and lower age attributes for each unit as described here, and to also include knowledge of the geologic time scale in the model so that actual time scale names can be used instead of numeric codes. In addition, a separate table is used to show relationships between units. The user can then specify the exact relationship between any two units in the archive, whether on the same map sheet or not.

The lesson to be learned from these hierarchical coding examples is that it is easy to code oneself into a corner. The best coding schemes are always open-ended. No matter how many slots are set aside for future growth, if the number is fixed it will eventually be found to be insufficient. Coding schemes offer the potential for greatly enhancing the utility of digital data, but they must be devised with care and concern for future expansion and flexibility.

Word Lists

Perhaps the most controversial aspect of the data model is the standardized vocabulary included in the word lists and, in particular, the Lithology Table of the standard lookup tables. These tables are included to indicate how they might be used, especially to deal with the hierarchical terminology that is commonly used by geologists. The use of such tables will greatly facilitate data entry, communication of what the words mean, and analysis of the maps by computer. In order to minimize the perception that word lists restrict science, descriptive attributes are included to allow for English-language descriptions. These descriptions are intended for people, not computers. The word lists are critical to meeting one of the design goals for wider use of geologic maps and combining of geologic maps from diverse sources, i.e. increase the use of geologic maps.

It is important that the lists provided here be seen only as examples. Once a word list is agreed upon by the geologic community, it will be necessary to establish a process to evolve the list. The word lists should not be thought of as set in concrete. These lists should evolve as scientific thought evolves and as deficiencies are identified. Such an evolutionary process is required if the model is to reflect evolving geologic thinking.

If a single national set of tables cannot be defined and agreed to by most users, then individual organizations could use their own lists. These lists would then need to be explicitly identified in the data model so the user would know which list to use. This will make it more difficult to combine maps from various sources; but possibly translation tables could be developed to define equivalencies between various lists.

Suggestions for the Future

Tools

The complex relationships between objects that define a geologic map, and the concepts of normalized data structures, which contribute to minimizing the size of data sets and to increase the speed of access, lead to a data model with a large number of tables with complex linkages. The complexity of such data structures is best dealt with through user interface tools, which make the complexity of the data model transparent to the user. The critical tools needed are computerized data entry forms, legend preparation forms, standardized query packages, output definition tools, and data transfer protocols. Some of the required functions of these tools can be achieved by linking to a map visualization tool such as ArcView. Prototype tools are being developed to investigate the data model and as the beginning phase of implementation of the data model. These developments will be announced on the Web site, **http:// geology.usgs.gov/dm/**, for testing, as they become available.

Data Exchange

Because of the separation of the spatial objects and their attributes, the diversity of spatial objects, and the multi-map concepts in the design of the data model, the exchange of digital data files is not simple. Exchange will require the transfer of several different types of files including GIS coverages, attribute tables, and files associated with map symbolization and the map legend. This diversity of files and the complexity of the relations and connections of these files will require careful consideration in the implementation of export procedures.

Suggested Future Extensions and Additions.

In review of the data model, various types of extensions and additional attributes have been suggested. A few of these might be considered as part of the core attributes or objects in a geologic map. Others are clearly suggestions that should be future extensions of the data model. These additional attributes and suggested future extensions are included here for two purposes: 1) to document the suggestions and 2) to further explain the data model by suggesting where these extensions might be attached to the model.

Table 48: Additional attributes. These are additional attributes describing existing objects.

Attribute	Suggested Table
Environment of deposition	Additional attribute in the Composition Table.
Engineering properties of rock units.	New table attached to the Rock Units Table.
Aquifer properties of rock units.	New table attached to the Rock Units Table
Geochemical properties of rock units	New table attached to the Rock Units Table

Future Development

The design of this data model recognizes specifically that geologic maps are very complex documents. This complexity can be seen by looking at the diversity of geologic maps. To deal with this complexity in a timely fashion, this model has only addressed what is common to most geologic maps, that is the core elements. This core is designed to be expanded. There is also the question of development of the vocabulary for many attributes (i.e. word lists). To deal with all of these issues, the data model should be implemented as part of an evolutionary process. If our objective is to come to consensus on the format of digital geologic maps in order to facilitate exchange and use of geologic maps, then it will be necessary to have a formal mechanism to evolve the data model. This will include approving extensions and refinements to the model, sharing the cost of tool development for use of the model with different GIS, and refinement of approved word lists. This refinement of word lists might also include, for example, addition of new terms to the list or development of standard translators between various ways of classifying rocks. Thus, some sort of standing, formal organization or mechanism is needed to deal with this evolution. A North American Geologic Map Data Model Steering Committee has been created to deal with these and other issues arising from the development of a standard data model. To learn more about this group, or to participate, contact one of the authors, or view the web site: **http:// geology.usgs.gov/dm/.**

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