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DIGITAL GEOLOGIC MAP DATA MODEL

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By

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Additional Chapters on the Object Model, Background, and Tools are in preparation (May 19, 1998)

WARNING!

The following is a working document that constitutes 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 support the needs of the National Geologic Map Database Project. This report has not been reviewed or approved by either the AASG or USGS. Updated releases of this report will be placed on the Web (<http://ncgmp.usgs.gov/ngmdbproject/>) as the report evolves as part of an informal review process. Please forward all comments and suggestions to Gary Raines (address below). To discuss this report or ask detailed questions, contact one of the following: **Bruce R. 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.

This data model does not address the format or content of the metadata. Metadata files, of course, eventually need to be associated with the files described here.

Acknowledgment

The effort to create a data model for digital geologic maps has involved many people and a lot of intense discussion. This paper attempts to condense that discussion into a manageable form and to present the results, a data model. Consequently the authors have drawn on their own experiences and have functioned in a fashion similar to compilers of geologic maps. We wish to acknowledge that many people have contributed. 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. If this report generates nothing more than discussion of what is a digital geologic map, then we will have succeeded.

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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 1-1. 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 the tools that 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.

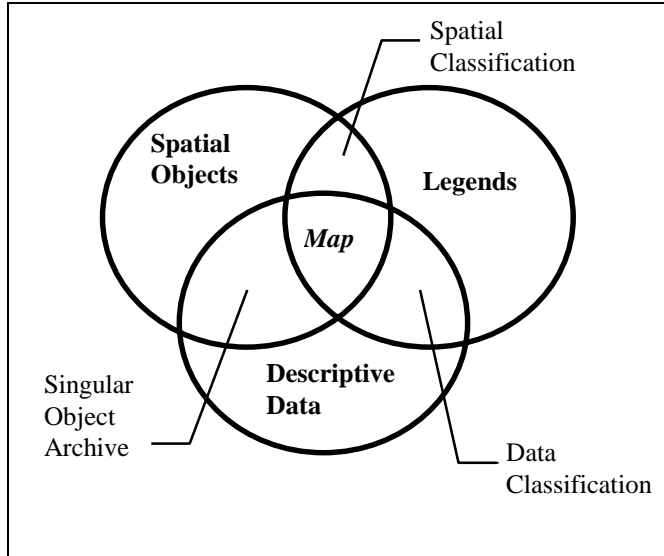


Figure 1-1: Diagram showing the three classes of objects in the geologic map data model. Each circle represents a class of objects and a portion of the model.

There are several different types of computer programs that can read and manipulate digital geologic maps. The most common types fall into three categories: Geographic Information Systems (GIS), Computer-Aided Drafting systems (CAD), and special purpose, geologic mapping programs.

There are also 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 analytical uses.

Overview

This report is composed for five chapters and one appendix: Introduction and Purpose, The Relational Model, Implementation Considerations, Background (not available 5/19/98), The Object Model (not available 5/19/98), and the appendix: Suggested future extensions and additional attributes. This report is intended for an audience with a wide diversity of GIS, database management, and geologic expertise. Consequently, the individual sections are not intended to 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 chapter 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 the second chapter, we then define a relational database model, which can be implemented on a modern GIS, and discuss some of the tools that will be necessary for a successful implementation of the relational model. The next chapter discusses some issues for implementing and evolving the relational database model. Chapters four and five (not available 5/19/98) present a discussion of background concepts in the design of a data model and present an object-oriented model, respectively. The object-oriented model cannot be implemented on any current GIS, but is clearly the direction that modern GIS and database

systems are evolving. The appendix tabulates suggestions for future extensions of the model and suggests how these extensions could be added.

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 the 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 this effort is to develop a digital data model (formal grammar) for geologic map information. A secondary objective is to develop as much of the vocabulary as possible, in the time available and as examples of the vocabulary that might be used. This vocabulary also helps communicate a better understanding of the model.

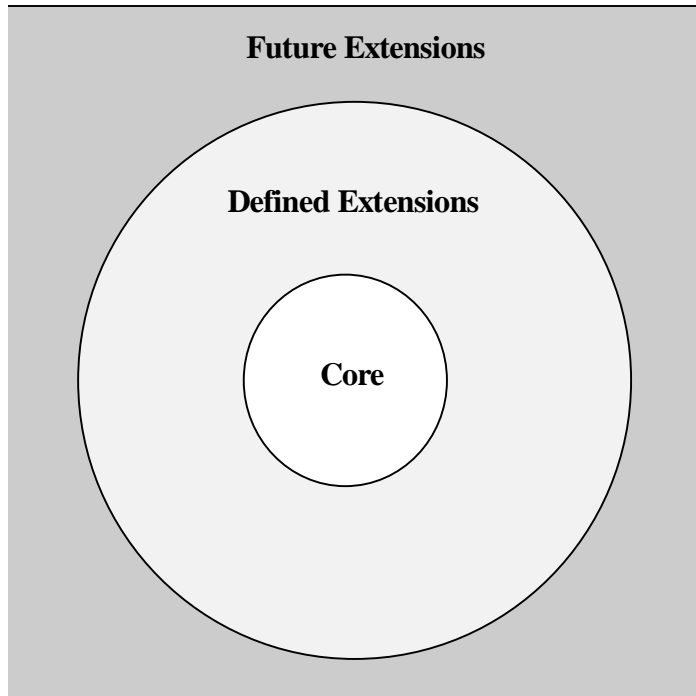
The data model is presented in two forms: an entity-relation model for relational databases, and an object model that is more conceptual in nature and future oriented. Both approaches attempt to be independent of any specific software/hardware configuration. Because technology is rapidly evolving, we are attempting to be forward looking in developing a conceptual data model using Object-Oriented notation. Some aspects of this conceptual model cannot be easily implemented in common relational database based GIS software. The entity-relation model is a translation of the more general conceptual model into a general relational database format that can be more easily implemented in current database software. The relational model is the stepping off point for implementing the data model in a GIS such as Arc/Info or Arcview. We intend to implement this model in Arc/Info and ArcView 3/Microsoft Access. The majority of the state geological surveys and the USGS National Cooperative Geologic Mapping Program plan to use the model in Arc/Info. Therefore, we feel it is incumbent upon us to implement the model in this GIS and to develop some first generation tools in Arc/Info to facilitate data entry, display, and use of geologic maps in this GIS. We will first present the relational model as the more specific and more familiar form. Then the conceptual model that provides the most general foundation of the data model will be presented.

Design Objectives

- The following design criteria have been identified to guide the development of the data model:
- 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 1-2), requirements that are necessary for all geologic maps. The core requirements are indicated in the model as required tables.
 - 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 1-2) 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 1-2) will evolve with time and definition of new uses. The objective of extensions is to enhance the information and maintain a connection with the ultimate source of the geologic data.
 - Mechanisms are needed within the model to document the source of each individual geologic object. The source would 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 can 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 extension as discussed above. We are attempting 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.
 - Geologic maps have, as a fundamental characteristic, attributes of geologic objects that are interrelated. Thus a fault may separate two polygons and continue internally into a third polygon. Spatial attributes

of such lines need to be stored with the polygon data in order to do structural analyses, for example, to select 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 1-2: 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.

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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 as 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.

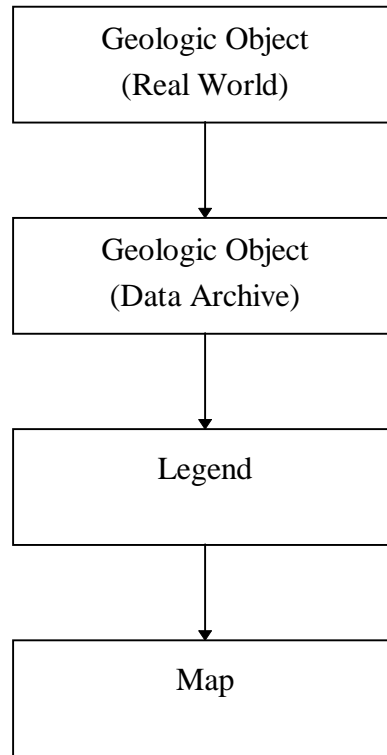


Figure 2-1. Fundamentals of the relational geologic map data model.

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 core of the relational geologic map data model is an archive of digital geologic objects from which one can create geologic maps (figure 2-1). 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.

The digital archive of geologic features is connected to a geologic map legend facility (figure 2-1). 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.

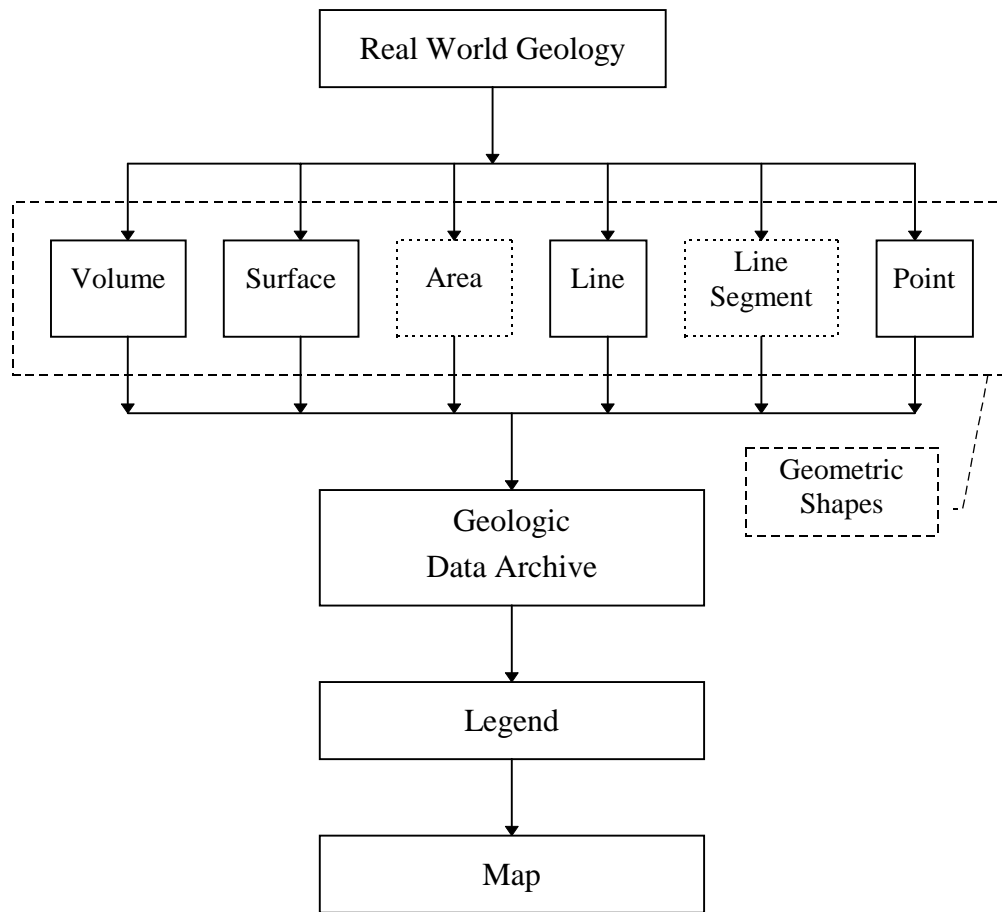


Figure 2-2. Geometric shapes of geologic objects.

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 previous discussion describes the model as shown on figure 2-1 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. User who wishes to retrieve a previously entered map for some sort of output simply retrieve the previously stored legend information and apply it to the archive to re-create the desired 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 2-2 - 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.

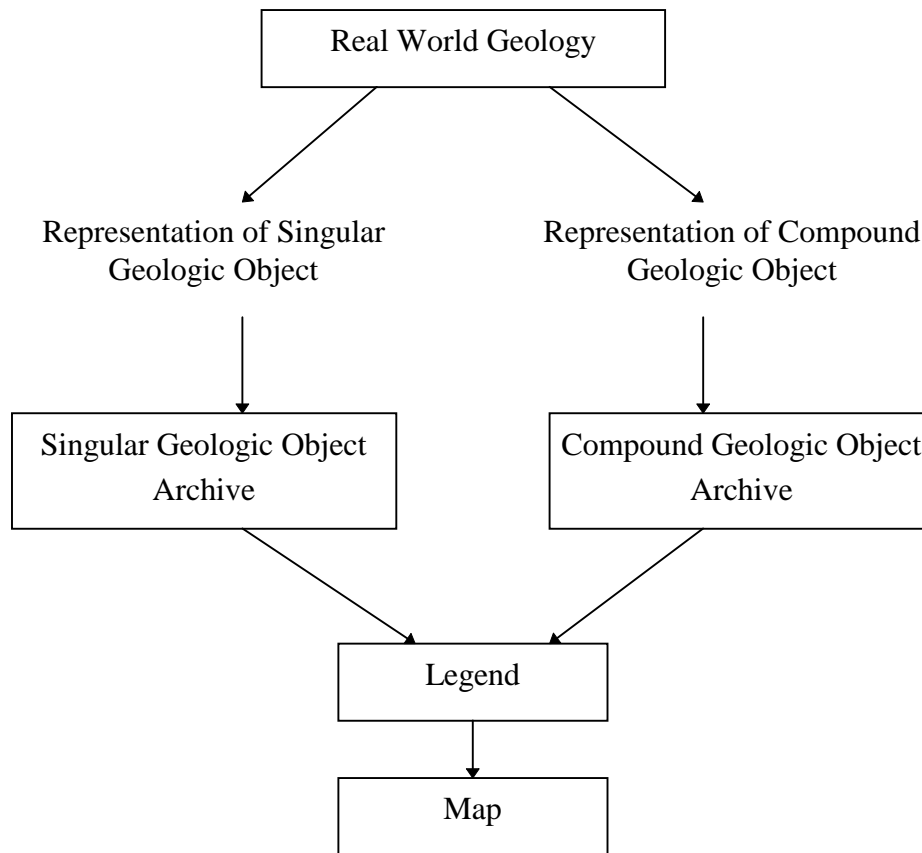


Figure 2-3. Two categories of geologic objects.

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 2-3). 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.

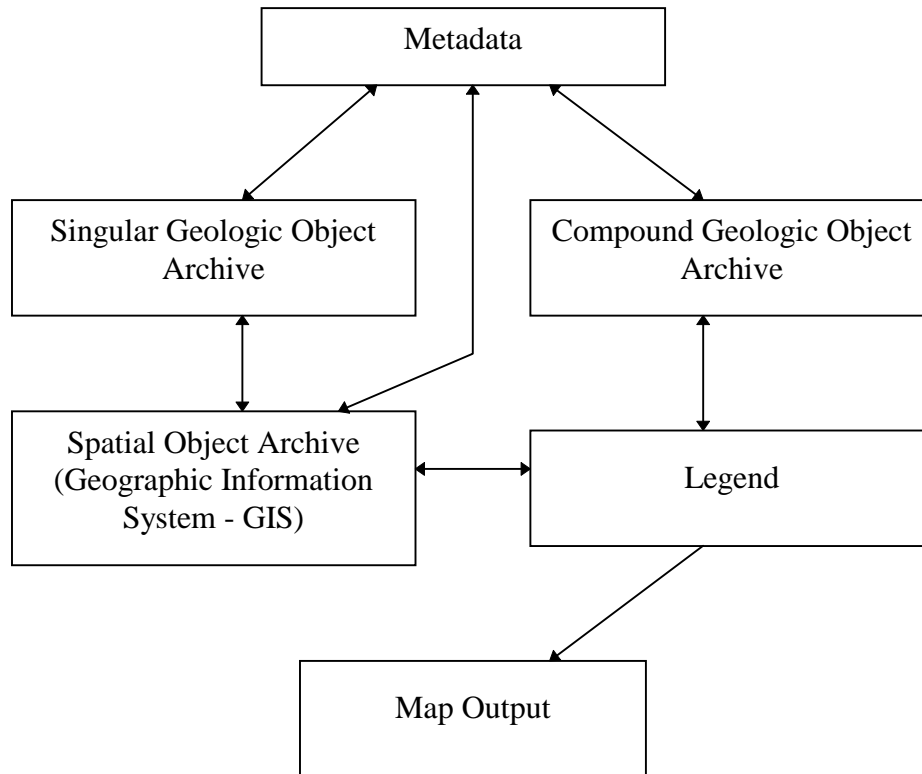


Figure 2-4. Generalized diagram of the relational geologic map data model.

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 2-4). 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.

Relational database table with the following information:

Lithology PAT 1/polygon	Table Name
* poly_id unit_name etc.	Single record occurrence frequency
	* key attribute(s) attribute list

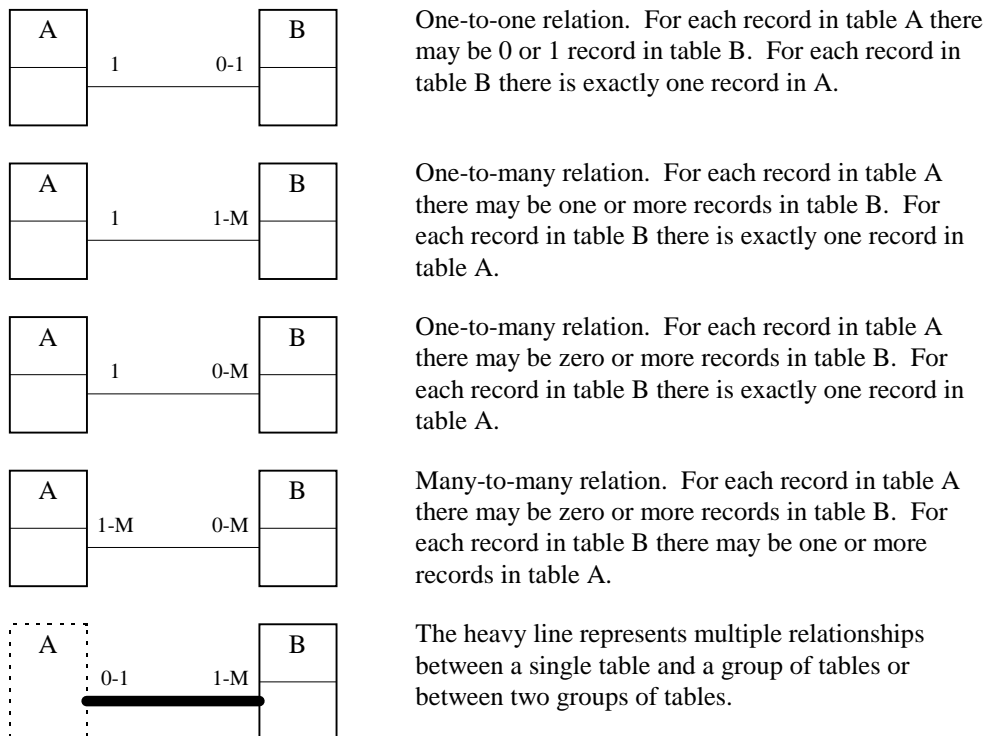


Figure 2-5. Diagram of relational notation used for entities (tables) and relations between entities.

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 strategy outlined in the previous text.

The notational shorthand that is used in all subsequent diagrams is given in figure 2-5. 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 2-5 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 the 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 figures 2-6 through 2-10. 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 the rest of this chapter, the names of attributes (columns, or fields in tables) are italicized, such as *map_title*. Key attributes that are used to link one table to another are in italicized bold, such as ***org_id***. In addition, the names of model tables are capitalized within the descriptive text.

Metadata, Legend and Related Tables

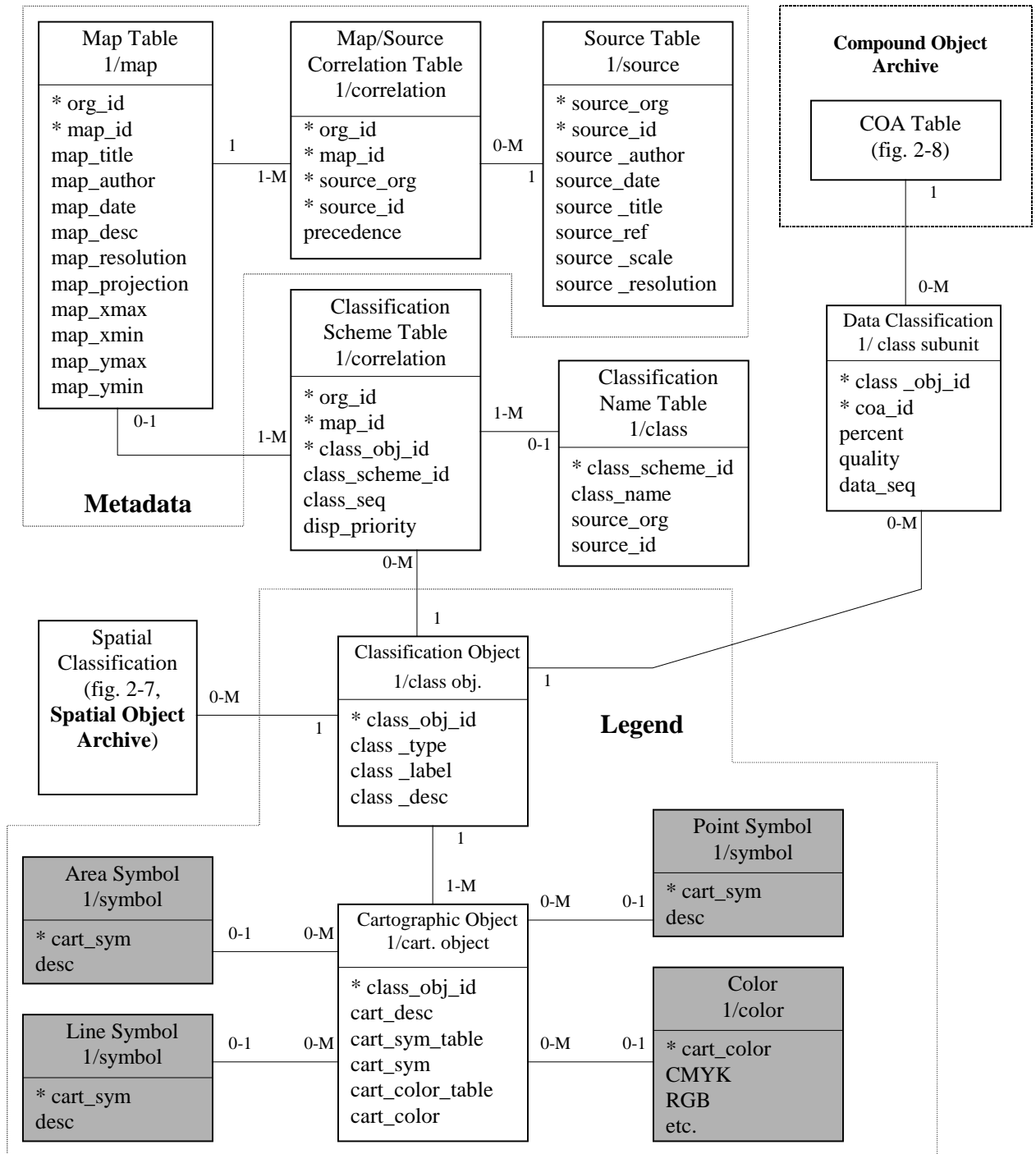


Figure 2-6. Legend and Metadata portions of the relational model.

The model is in five parts; the Spatial and Singular Archive portions are shown on figure 2-7, the Compound Object Archive portion is shown on figures 2-8 and 2-9, and some standard look-up tables are shown on figure 2-10. Note that shaded boxes are standard tables that are used with many maps (figures 2-6 through 2-10). 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.

Spatial and Singular Object Archives and Related Tables

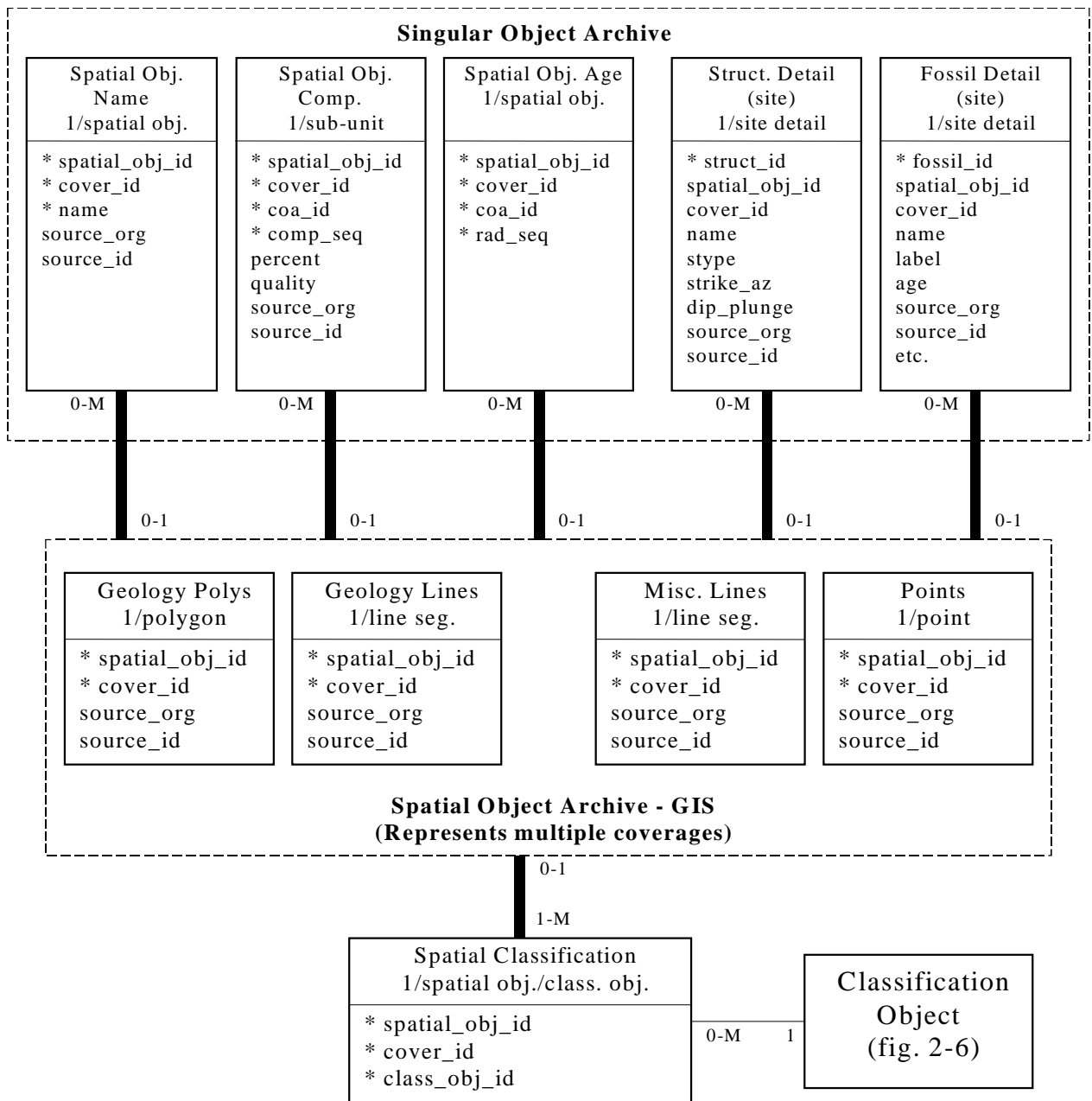


Figure 2-7. Singular Object Archive and the Spatial Object Archive (GIS) portions of the model.

Heavy lines represent a relationship between an individual table in the Singular Object Archive and *all* tables within the GIS. These relationships are portrayed in this manner because 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 or age 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.

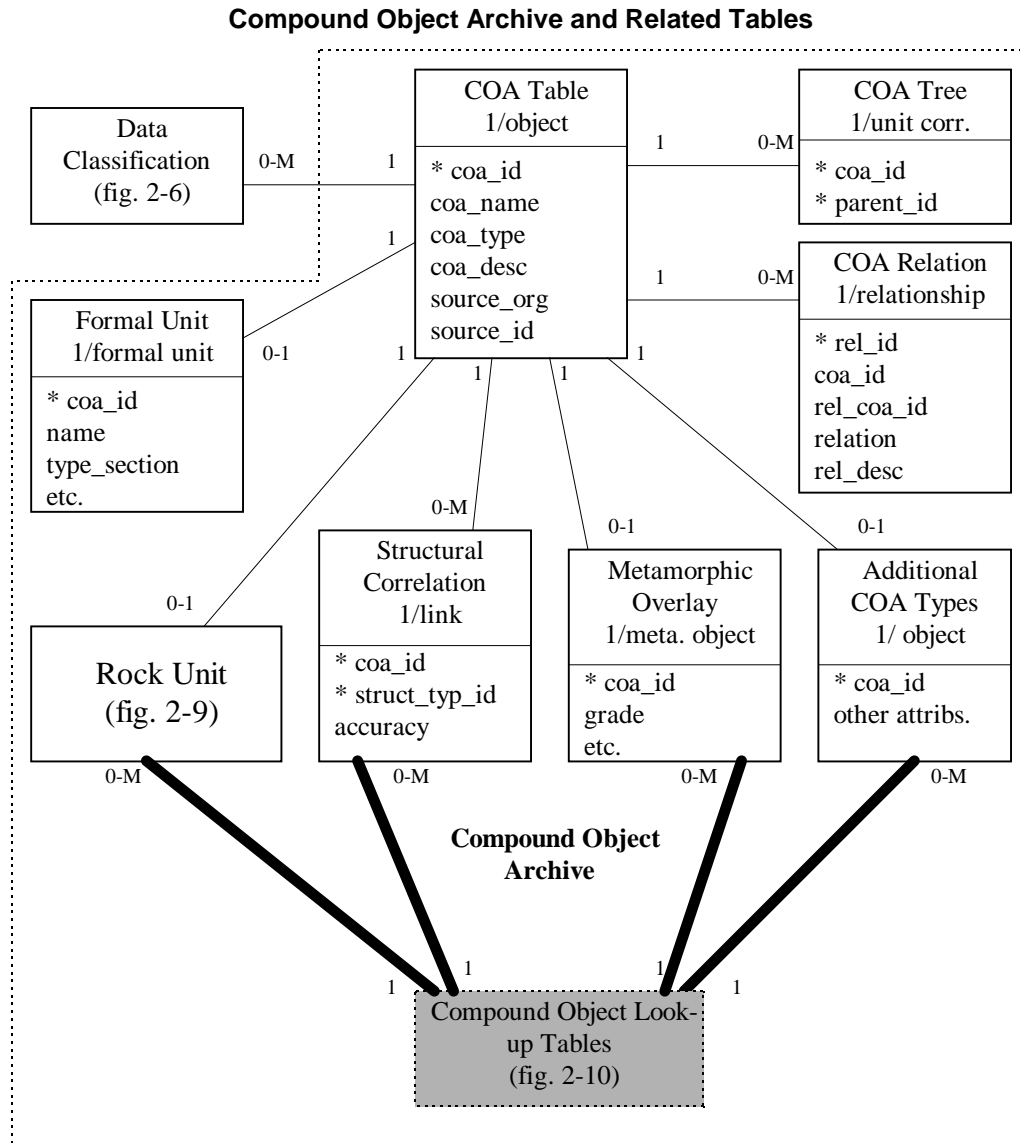


Figure 2-8. Compound Object Archive portion of the data model.

This 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.

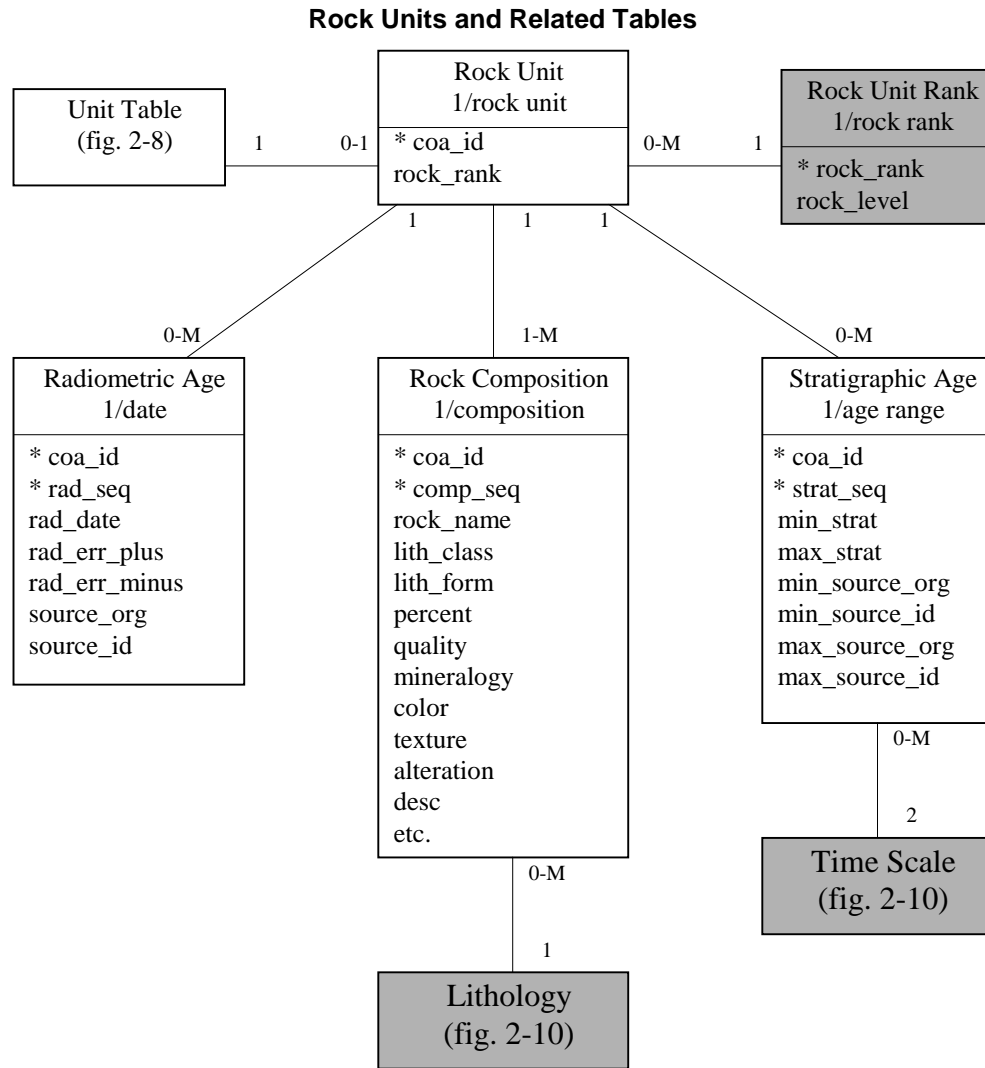


Figure 2-9. Rock Unit and related tables portion of the Compound Object Archive.

Each rock unit as a whole can have associated one or more stratigraphic age ranges (each with a minimum and a maximum) as well as one or more radiometric 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.

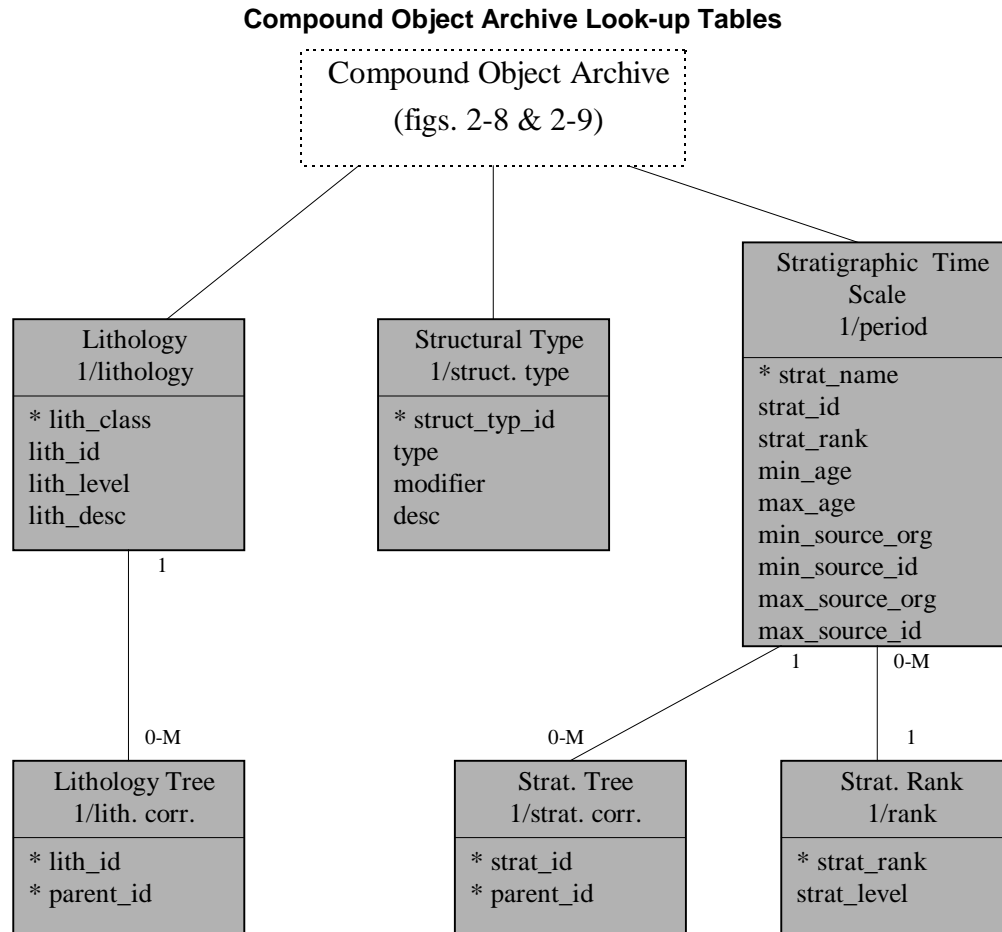


Figure 2-10. Standard look-up tables which are used with the Compound Object Archive.

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 (figures 2-6 through 2-10) along the same lines as the divisions made in the general overview of the data model as presented in figure 2-4. The first diagram (figure 2-6) includes the legend and metadata portions of the model along with some associated tables.

Metadata

The metadata portion of the model includes three tables, a Map Table, a Source Table, and a Map/Source Correlation Table. The Source Table contains reference information for published and unpublished sources of information that are contained in the digital library. 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 the formal metadata warehouse. There is one record in the Source Table for each individual source of information. The Source Table contains two key attributes, *source_org* (originating agency of source) and *source_id* (agency’s unique source identifier) which serve

to identify individual records; these same two attributes will be found throughout the model wherever it is necessary to preserve the source of a map feature or description.

The Map Table contains information pertaining to each map in the archive. It also has two key attributes, *org_id* (agency identifier) and *map_id* (map identifier) which identify individual records. Two key attributes are used within these two tables so that individual organizations can maintain their own map and source identification coding schemes and still share data sets. So, for each map or source record, there is an attribute that refers to the organization, *org_id* and *source_org*, and an attribute that distinguishes individual items within the organization, *map_id* and *source_id*. The remaining attributes in the Map Table are used to describe and to plot a particular map.

For a new map that is being added to the system, a record will be created in both the Source Table and the Map Table with some of the information duplicated between the tables. However, for a derivative map that is created from the archive, there will be one new record created in the Map Table which is related to one or more records in the Source Table, depending on how many maps are used as sources of features for the new map. A source map could potentially be used to create any number of derivative maps. Therefore, there is potentially a many-to-many relationship between the Map Table and the Source Table. To create that type of relation in a relational database model, one must insert a correlation table. The Map/Source Correlation Table is the first of several correlation tables in the model that will be discussed.

Correlation tables contain all of the key attributes from each of the tables being correlated, in this case, two key attributes from each table. For every record in the Map Table (each has a unique combination of *org_id* and *map_id*) there may be any number of records in the correlation table (each having the same *org_id* and *map_id*, but a different *source_org* and/or *source_id*), but for each record in the correlation table, there may be only one corresponding record in the Map Table. Similarly, for each record in the Source 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 Source Table. Therefore, the correlation table converts the many-to-many relation between the Map Table and the Source Table into two many-to-one relations between the correlation table and the other two tables. This technique is used throughout the relational model. An additional use of this correlation table is to allow a mechanism for assigning *precedence* to the sources of maps derived from multiple sources. Thus, the user may direct the system to use several overlapping sources for a derivative map, but specify the order in which the maps are to be used in areas of overlap.

Legend

The second major portion of the model that is diagrammed on figure 2-6 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_type*, 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 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 which symbol table is referenced. Point symbols are defined in standardized Point Symbol Tables, line patterns in Line Symbol Tables, etc. 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. These correlation tables interact with the adjacent portions of the model in the same way that the Map/Source Correlation Table interacts with the Map and Source Tables; they convert many-to-many relations to one-to-many relations. The Classification Scheme Table provides the correlation between the Map Table and the legend's Classification Object Table: i.e. it associates a set of classification objects with a particular map. It also allows the user to designate this set of classification objects as a particular classification scheme and save it for further use. In addition, the Classification Scheme Table includes a classification sequence number and a display priority. 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.

There is a Classification Name Table related to the Classification Scheme Table so that 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: *percent*, *quality*, and *data_seq*. The attributes, *percent* and *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 2-7) which connects the legend to the Spatial 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 2-7) 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, line 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. Often these layers are called coverages. Thus GIS maps typically consist of several coverages which are delineated by both theme and geometric type. The geologic map data model depicts the Spatial Object Archive (in figure 2-7) as a series of tables where each table is a geometrically delineated coverage. The geologic map data model does not impose or demand any particular organization of coverages within the GIS. It only requires that each spatial feature be uniquely identified and provides two attributes for this purpose, *spatial_obj_id* and *cover_id*. The attribute, *spatial_obj_id*, ensures that a spatial feature is uniquely identified within a coverage, while *cover_id* ensures the coverage is uniquely identified: no two coverages may contain the same *cover_id*. The data layers shown on the diagram are the minimum normally required for a geologic map. Certainly, if the map contains no point data or no linear features, those data layers would not be needed. But, most maps will have the data layers shown. 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 will be required. In that case, there would be more than one layer of polygon data. Each record in a coverage 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 *cover_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_org* and *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 2-7) has a heavy line drawn between the Spatial Object Archive and the Spatial Classification Table. 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, *cover_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 coverage 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. 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 2-7, 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 *cover_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 the *source_org* and *source_id* attributes 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 heavy line in figure 2-7, 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 heavy 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 2-8). 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*, *percent*, *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, *percent* and *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. The *source_org*, and *source_id* attributes refer 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 radiometric ages to individual spatial objects. Although many uses could be made of this table, its primary purpose is to relate radiometric age information which is stored in the Compound Object Archive (Radiometric Age Table, figure 2-9) 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 heavy line in figure 2-7, 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 heavy 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 *rad_seq*, are used to identify an individual radiometric age record in the Radiometric Age Table.

The Structural Detail and Fossil Detail 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 2-7.

Compound Object Archive

The Compound Object Archive is composed of a number of data tables and look-up tables (figures 2-8, 2-9, and 2-10) 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 which 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 Overlay Units will be described in the model not because they are particularly common in geologic maps, but 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 (fig. 2-8) 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 *source_org* and *source_id* attributes 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 overlay units, etc.

Connected to the COA Table by a one-to-one relation and sharing the same key attribute, *coa_id*, is the Formal Unit Table. This 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 the data model is adopted, 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* containing unit A, *rel_coa_id* containing 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 required.

A one-to-many relation also links a COA Tree Table to the COA Table. 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 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 Structural Correlation Table and outlines a Metamorphic Overlay 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 Structural Correlation 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 2-9) is the main entry point for descriptive information concerning rock units. For purposes of the model, 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, if any (attributes *coa_id* and *rock_rank*, respectively). 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 other 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 radiometric ages associated with it in the data model. These ages are stored in a separate table, the Radiometric 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 radiometric age dates for a single rock unit, the key attribute and sequence number, *rad_seq*, is used to assure that each record has a unique key. In addition to the key attributes, the Radiometric Age Table contains attributes for storing the measured radiometric age, errors on the age, and a source reference.

The stratigraphic age of the rock unit is stored in the same manner as the radiometric 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 only be one record for stratigraphic age 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 sequence number, *strat_seq*, is 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 difference between the two tables is that the Radiometric 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 2-10).

The Stratigraphic Time Scale Table (figure 2-10) 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, but the user or creator of each 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 a key 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 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 radiometric ages for the stratigraphic period and the sources of those ages.

Returning to the Rock Unit Table on figure 2-9, 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*, *color*, *texture*, and *alteration*, represent simple text descriptions of the rock type; additional descriptive attributes could be added. The attributes, *percent* and *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 2-10). 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, Intrusive, Extrusive, and Metamorphic. 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 rock type. 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 any rock name that they prefer. 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 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.

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 2-10) 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 2-8) 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 Structural Correlation Table.

The Structural Correlation 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 2-

10) into two one-to-many relations. The many-to-many relation between the two tables, and thus the Structural Correlation 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 Structural Correlation 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 Structural Correlation Table contains the attribute, *accuracy*, which is used to specify the degree of accuracy with which the structure has been mapped. It might contain words such as approximate, inferred, or concealed.

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, *desc*, 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 Overlay Units

Metamorphic overlay 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 overlay 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 solid color 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.

Each metamorphic overlay unit has a unique record in the COA Table where the record is identified as a metamorphic overlay unit by the *coa_type* attribute. There is a one-to-one relation between the Metamorphic Overlay Table to the COA Table. That is, if there is a metamorphic overlay object identified in the COA Table, it will have one and only one record in the Metamorphic Overlay Table. The Metamorphic Overlay 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 Overlay 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.

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 released on the Web site, <http://ncgmp.usgs.gov/ngmdbproject/>, for testing, as they become available.

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 and integer. 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. 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 three metadata tables, Map Table, Source Table, and Map/Source Correlation Table, include information that may be part of the requirements for FGDC standard metadata but are not intended to be complete formal metadata. 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 attributes, *org_id*, *map_id*, *source_org*, and *source_id* are carried throughout the archive so that any object within the archive can always be traced back to its original source.

Map Table

The Map Table (table 2-1) contains reference information for each map that is defined in the archive, whether it is an original map or a map derived from other maps. The information in this table is used to define the geographic extent and projection of the map as well as to provide descriptive text for the map layout. The Map Table can also be used to search the archive for specific maps.

Table 2-1: Definition of the attributes in the Map Table.

Attribute	Definition	Format
org_id	Organization identifier for a map	character
map_id	Individual map identifier	character
map_title	Title of the map	character
map_author	List of map authors	character
map_date	Publication date, if published	date
map_desc	Short description of map	character
map_resolution	Resolution of digital map, in meters	integer
map_projection	Description of map projection	character
map_xmax	Eastern limit of map in decimal degrees	float
map_xmin	Western limit of map in decimal degrees	float
map_ymax	Northern limit of map in decimal degrees	float
map_ymin	Southern limit of map in decimal degrees	float

Source Table

The Source Table (table 2-2) contains reference information for all maps that are original sources for geologic objects in the map archive. The two attributes, *source_org* and *source_id*, are 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, the bibliographic reference

information should be divided into several attributes. The author list, the year of publication, and the scale of the original should be placed in separate attributes. The remainder of the reference can be split into a title attribute and a publication attribute, or it can be left in a single attribute. Additional attributes could be added to contain information such as the projection of the original map, if needed. If formal metadata is available, this table could also be used as a link to the metadata database.

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

Attribute	Definition	Format
source_org	Identifier for the organization that created the map.	character
source_id	Source organization's identification of the source map	character
source_author	List of source map authors	character
source_date	Year of source map publication or creation	date
source_title	Title of source map	character
source_ref	Remainder of source reference citation (after title)	character
source_scale	Scale of source map (denominator of scale fraction)	integer
source_resolution	Resolution of digital source map, in meters	integer

Map/Source Correlation Table

The Map/Source Correlation Table (table 2-3) serves to connect the Map Table to the Source Table. Because multiple derivative maps can be created from the same source maps and multiple sources can be used to create a derivative map, the Map Table and Source Table must have a many-to-many relation. The Map/Source Correlation Table is used to convert that relation to two one-to-many relations. It is also used to define a precedence for selection of source materials where the source maps overlap in geographic coverage.

Table 2-3: Definition of the attributes in the Map/Source Correlation Table.

Attribute	Definition	Format
org_id	Organization identifier for a map	Character
map_id	Individual map identifier	Character
source_org	Identifier for the organization that created a source map.	Character
source_id	Source organization's identification of a source map	Character
precedence	Precedence of geologic entities where two source maps overlap geographically	Integer

Classification Scheme Table

The Classification Scheme Table (table 2-4) provides the correlation between the Map 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.

Table 2-4: Definition of the attributes in the Classification Scheme Table.

Attribute	Definition	Format
org_id	Organization identifier for a map	Character
map_id	Individual map identifier	Character
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 type (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	Integer

Classification Name Table

The Classification Name Table (table 2-5) 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 2-5: 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 a classification scheme with its name and source	Integer
class_name	Descriptive name for the classification scheme	Character
source_org	Identifier for the organization that created the map for which the classification scheme is used	Character
source_id	Source organization's identification of the source map	Character

Legend and Related Tables

The legend portion of the data model is used to record 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 2-6) 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, the labeling that is used for each object, and the display priority for each classification of the 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 labeling that is used for each object and the object's type. The attribute *class_type* is used to group similar objects on a map legend, for example all intrusive rock units or all structural symbols.

Table 2-6: 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_type	Categories of objects in the legend. Used to group 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 object. For a rock unit, this would be the unit label, such as TKgr	Character
class_desc	An English language description of the 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 2-7) contains examples of terms that might be entered into the *class_type* attribute. This list is not intended to be comprehensive, but to serve as an example only.

Table 2-7: Examples of words that could be used for the *class_type* attribute in the Classification Object Table.

class_type
sedimentary
intrusive
extrusive
volcanic
metamorphic
structural symbols
Proterozoic Rocks
Upper Plate Rocks

Cartographic Object Table

The Cartographic Object Table (table 2-8) 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 which symbol table is referenced. Point symbols are defined in standardized Point Symbol Tables, line patterns in Line Symbol Tables, etc. 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 includes a brief description of the symbol, the name of a symbol table where the definition of the symbol is to be found, the symbol number to use within that table, 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 2-8: 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 the map legend	Integer
cart_desc	Description of the pattern	Character
cart_sym_table	Name of a symbol table	Character
cart_sym	The symbol number from the table specified in <i>cart_sym_table</i>	Integer
cart_color_table	Name of the color table	Character
cart_color	The color number from the table specified in <i>cart_color_table</i>	Integer

Area Symbol Table

The Area Symbol Table (table 2-9) is a compilation of definitions of polygon fill patterns. There is one pattern defined by each record in the table. Multiple Area Symbol Tables can be used within a single map.

Table 2-9: Definition of the attributes in the Area Symbol Table.

Attribute	Definition	Format
cart_sym	The number of a specific fill pattern	Integer
desc	Description of the symbol and suggested uses	Character
Etc.	Additional attributes needed to actually define the symbol. These might be specific to the implementation system, but are optional in the data model.	

Line Symbol Table

The Line Symbol Table (Table 2-10) is a compilation of definitions of line patterns. There is one pattern defined by each record in the table. Multiple Line Symbol Tables can be used within a single map.

Table 2-10: Definition of the attributes in the Line Symbol Table.

Attribute	Definition	Format
cart_sym	The unique number for a specific symbol	Integer
desc	Description of the symbol and suggested uses	Character
Etc.	Additional attributes needed to actually define the symbol. These might be specific to the implementation system, but are optional within the data model.	

Point Symbol Table

The Point Symbol Table (table 2-11) is a compilation of point symbol definitions. There is one pattern defined by each record in the table. Multiple Point Symbol Tables can be used within a single map. These tables will include generic symbols such as circles, triangles, etc. as well as specific geologic symbols such as structural symbols.

Table 2-11: Definition of the attributes in the Point Symbol Table.

Attribute	Definition	Format
cart_sym	The unique number for a specific symbol	Integer
desc	Description of the symbol and suggested uses.	Character
Etc.	Additional attributes needed to actually define the symbol. These might be specific to the implementation system, but are optional within the data model.	

Color Table

The Color Table (table 2-12) 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 2-12: Definition of the attributes in the Color Table.

Attribute	Definition	Format
cart_color	The unique number for a specific color	Integer
CMYK	Definition of color in cyan-magenta-yellow-black coordinates	Character
RGB	Definition of color in red-green-blue coordinates	Character
Etc.	Additional attributes needed to define the color. These might be specific to the implementation system. But are optional within the data model.	

Data Classification Table

The Data Classification Table (table 2-13) 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 *percent* and *quality* attributes. The *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 *quality* attribute is used to specify the quality of the volume estimate. The *percent* and *quality* attributes are discussed more fully in the COA Tables from which they are derived.

Table 2-13: 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
percent	Estimated volume percent an individual unit in the Compound Object Archive comprises of the entire Classification Object	Integer
quality	Quality of the volume percent estimate (entered as: ± nn %)	Character
data_seq	Specifies the order in which individual units in the Compound Object Archive should appear in the map legend	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 layers, or coverages, within the GIS. Most digital maps will require several coverages for complete storage of all map objects. Each map object in a single coverage is assigned a unique *spatial_obj_id* attribute. The combination of the *spatial_obj_id* and the coverage identifier, which is stored in the *cover_id* attribute, are sufficient to uniquely identify any individual map object within the archive.

Geology Polygons Table: An Example GIS Polygon Coverage

A polygon type GIS coverage is normally used to store the geographic coordinates and topologic definitions which make up the spatial description of rock units and other areal data. The spatial data stored in the GIS is linked to the rest of the data model through a polygon feature attribute table (table 2-14). The combination of *spatial_obj_id* and *cover_id* provide a unique identifier for each polygonal object in the geology polygons coverage, while the attributes, *source_org*, and *source_id*, provide a link back to the original source for every polygonal map object.

Table 2-14: Definition of the attributes in the Geology Polygons Table.

Attribute	Definition	Format
spatial_obj_id	A unique identifier of each object in an individual data layer, or coverage.	Integer
cover_id	Coverage identification number	Integer
source_org	Identifier for the organization that created the source map.	Character
source_id	Source organization's identification of the source map	Character

Geology Lines: An Example GIS Line Coverage

A line type GIS coverage is normally used to store the geographic coordinates and topologic definitions that make up the spatial description of linear geologic features such as faults, contacts, folds, linear rock units, etc. The spatial data stored in the GIS is linked to the rest of the data model through a line (or arc) feature attribute table (table 2-15). The combination of *spatial_obj_id* and *cover_id* provide a unique identifier for each linear object in the geology lines coverage, while the attributes, *source_org*, and *source_id*, provide a link back to the original source for every map object.

Table 2-15: Definition of the attributes in the Geology Lines Table.

Attribute	Definition	Format
spatial_obj_id	A unique identifier of each object in an individual data layer, or coverage	Integer
cover_id	Coverage identification number	Integer
source_org	Identifier for the organization that created the source map.	Character
source_id	Source organization's identification of the source map	Character

Miscellaneous Lines: An Example GIS Line Coverage

A line type GIS coverage is normally used to store the geographic coordinates and topologic definitions which make up the spatial description of non-geologic linear features such as area outlines, shorelines, political boundaries, etc. The spatial data stored in the GIS is linked to the rest of the data model through a line (or arc) feature attribute table (table 2-16). The combination of *spatial_obj_id* and *cover_id* provide a unique identifier for each linear object in the miscellaneous lines coverage, while the attributes, *source_org*, and *source_id*, provide a link back to the original source for every map object.

Table 2-16: Definition of the attributes in the Miscellaneous Lines Table.

Attribute	Definition	Format
spatial_obj_id	A unique identifier of each object in an individual data layer, or coverage	Integer
cover_id	Coverage identification number	Integer
source_org	Identifier for the organization that created the source map.	Character
source_id	Source organization's identification of the source map	Character

Points: An Example GIS Point Coverage

A point type GIS coverage is normally used to store the geographic coordinates and topologic definitions which make up the spatial description of single point locations such as sample descriptions, structural measurements, fossil locations, mineral locations, etc. The spatial data stored in the GIS is linked to the rest of the data model through a point feature attribute table (table 2-17). The combination of *spatial_obj_id* and *cover_id* provide a unique identifier for each point object in the points coverage, while the attributes, *source_org*, and *source_id*, provide a link back to the original source for every map object.

Table 2-17: Definition of the attributes in the Points Table.

Attribute	Definition	Format
spatial_obj_id	A unique identifier of each object in an individual data layer, or coverage	Integer
cover_id	Coverage identification number	Integer
source_org	Identifier for the organization that created the source map.	Character
source_id	Source organization's identification of the source map	Character

Spatial Classification Table

The Spatial Classification Table (table 2-18) 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 2-18: 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 layer, or coverage	Integer
cover_id	Coverage identification number	Integer
class_obj_id	A unique identifier for each object or category of objects described and symbolized in the 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 *cover_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_org* and *source_id* attributes 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 2-19) 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 2-19: Definition of the attributes in the Spatial Object Name Table.

Attribute	Definition	Format
spatial_obj_id	A unique identifier of each object in an individual data layer, or coverage	Integer
cover_id	Coverage identification number	Integer
name	Name given to an individual point, line, or polygon. For example the name of a pluton or a fault	Character
source_org	Identifier for the organization that created the source map.	Character
source_id	Source organization's identification of the source map	Character

Spatial Object Composition Table

The Spatial Object Composition Table (table 2-20) 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 *percent* and *quality* attributes. The *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 *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 *percent* and *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 2-20: Definition of the attributes in the Spatial Object Composition Table.

Attribute	Definition	Form
spatial_obj_id	A unique identifier of a single object in an individual data layer, or coverage	Integer
cover_id	Coverage identification number	Integer
coa_id	Identification number of a unit in the Compound Object Archive (see 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
percent	Estimate volume percent of single map object that this composition comprises	Integer
quality	Quality of the volume percent estimate (entered as: ± nn %)	Character
source_org	Identifier for the organization that created the map.	Character
source_id	Source organization's Identification of the source map	Character

Spatial Object Age Table

The Spatial Object Age Table (table 2-21) is used to attach radiometric ages to individual spatial objects. Although many uses could be made of this table, its primary purpose is to relate radiometric age information which is stored in the Compound Object Archive (Radiometric Age Table, figure 2-9) 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 *rad_seq*, are used to identify an individual radiometric age record in the Radiometric Age Table (table 2-39).

Table 2-21: Definition of the attributes in the Spatial Object Age Table.

Attribute	Definition	Format
spatial_obj_id	A unique identifier of each object in an individual data layer, or coverage	Integer
cover_id	Coverage identification number	Integer
coa_id	Identification number of a unit in the Compound Object Archive (see COA Table)	Integer
rad_seq	Record identifier for a specific age determination within the Radiometric Age Table for the unit identified by the <i>coa_id</i> .	Integer

Structural Detail Table

The Structure Detail Table (table 2-22) 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: *stype*, *strike_az*, and *dip_plunge*, respectively. For maximum utility across organizations, the meaning of the values in *strike_az* 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, *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 detail records can be associated with each point location.

Many organizations are in the process of automating their field methods so that their 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 Detail 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 2-22: Definition of the attributes in the Structural Detail Table.

Attribute	Definition	Form
struct_id	A unique identifier for a record in the Structural Detail Table	Integer
spatial_obj_id	A unique identifier of a single point location in a point data layer, or coverage	Integer
cover_id	Coverage identification number	Integer
name	The field location number or name of the sample site.	Character
stype	The type of structural measurement.	Character
strike_az	The azimuth direction of the strike or bearing of the structural measurement	Integer
dip_plunge	The dip or plunge angle of the structural measurement.	Integer
source_org	Identifier for the organization that created the source map.	Character
source_id	Source organization's identification of the source map	Character

Fossil Detail Table

The Fossil Detail Table (table 2-23) 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 *name* (field location number or other text), a *label* if the text to label the map is different than the name, an *age*, 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 2-23: Definition of the attributes in the Fossil Detail Table.

Attribute	Definition	Form
fossil_id	A unique identifier for a single record in the Fossil Data Table	Integer
spatial_obj_id	A unique identifier of a single point location in a point data layer, or coverage	Integer
cover_id	Coverage identification number	Integer
name	The field location number or name of the sample site	Character
label	A label to associate with the map symbol, if it is different than the name	Character
age	The age of the fossil locality	Character
source_org	Identifier for the organization that created the source map	Character
source_id	Source organization's identification of the source map	Character
Etc.	Additional attributes as needed	

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 Overlay Units will be described, not because they are particularly common in geologic maps, but 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 2-8), 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 2-24) 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 attributes for linking each object in the archive back to its original source.

Table 2-24: 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	The name of the table containing the remaining descriptive information about the unit	Character
coa_desc	A text description of the object	Character
source_org	Identifier for the organization that created the source map	Character
source_id	Source organization's identification of the source map	Character

The following table (table 2-25) 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 2-25: Word list for the *coa_type* attribute in the COA Table.

coa_type	Definition
Structural	Descriptive information about structural features, such as contacts, faults, and folds
Rock	Descriptive information about rock units, such as composition and age.
Metamorphic Overlay	Descriptive information about metamorphic overlay units, such as overprinted, cross-cutting metamorphism.

Formal Unit Table

The Formal Unit Table (table 2-26) 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 2-26: 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 map unit	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 2-27) 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 2-11. 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 2-11. 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 2-28) 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.

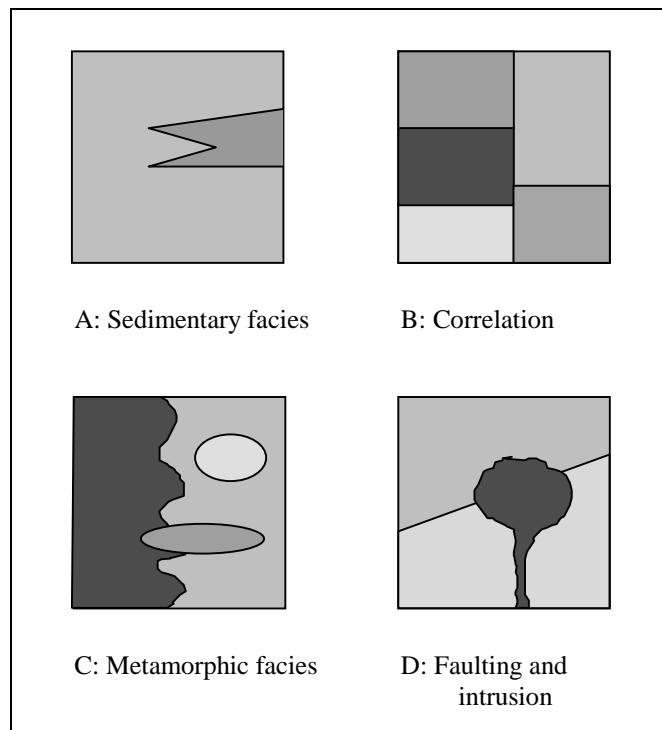


Figure 2-11: Examples of diagrams used on geologic maps to describe relationships between map objects.

Table 2-27: 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 relationships	Character
rel_desc	Text description of the relationship	Character

The following table (table 2-28) 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 2-28: 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 2-29) 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 return also 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.

Table 2-29: 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, 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 2-30) 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.

Table 2-30: 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

The following table (table 2-31) 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 2-31: 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 mapable 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
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 2-32) 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 2-32: 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 rank.	Number

The following table (table 2-33) contains an initial list of values for the attributes, *rock_rank* and *rock_level*, in the Rock Unit Rank Table.

Table 2-33: 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 2-34) 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*, *color*, *texture*, and *alteration* 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 *percent* contains information that is normally shown diagrammatically on maps by means of cross sections or columnar section diagrams. The *percent* attribute, containing an estimate of the volume percent of the 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 *quality* attribute is included to indicate how well the *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 *desc* 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 2-34: 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 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
percent	An estimate of the volume percent of the composition within the rock unit	Integer
quality	Quality of the volume percent estimate (entered as: \pm nn %)	Character
mineralogy	A mineral modifier associated with the rock name	Character
color	The color or colors of the composition	Character
texture	The texture of the composition	Character
alteration	A description of any alteration associated with the composition	Character
desc	A lithologic description defined by the map author which best describes this composition. This is intended to be read by people.	Character
Etc.	Additional attributes, as needed.	

Lithology Table

The Lithology Table (table 2-35) 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 2-35: Definition of the attributes in the Lithology Table.

Attribute	Definition	Format
lith_class	A lithologic term from a predefined list which best describes this composition	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 2-36) presents a sample lithologic classification as it would appear in the Lithology Table. The *lith_id* attribute is a unique integer which 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 2-36: 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 volcanoclastic 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 masse.
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 of 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 volcanoclastic 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 than 10. A group of monomineralic 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 2-37) 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 2-37: 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 2-38) shows some sample data as it would appear in the Lithology Tree Table (based on the example above).

Table 2-38: Example of the data in the Lithology Tree Table.

lith_id	parent_id
41	40
41	35
40	35

Radiometric Age Table

The Radiometric Age Table (table 2-39) is used for storing radiometric 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 single radiometric date for the unit with appropriate error values. In the simplest case, this table may be a real table in the database, which contains the appropriate radiometric date information for each rock unit. Alternatively, this table may be a correlation table that links the map archive to an external database of radiometric ages. The external database may be a complete database of all types of radiometric dates.

Table 2-39: Definition of the attributes in the Radiometric Age Table.

Attribute	Definition	Format
coa_id	Unique identification number of a unit in the Compound Object Archive	Integer
rad_seq	Record identifier for a specific age determination for the unit identified by the <i>coa_id</i> .	Integer
rad_date	Radiometric age date.	Number
rad_err_plus	The positive error for the radiometric age	Number
rad_err_minus	The negative error for the radiometric age	Number
source_org	Identifier for the organization that was the source of the date	Character
source_id	Source organization's identification of the date reference	Character

Stratigraphic Age Table

The Stratigraphic Age Table (table 2-40) is used for information about the time-stratigraphic age of the unit. The minimum and maximum stratigraphic ages (*min_strat* and *max_strat*) 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* and *max_strat* 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* and *max_strat* attributes are selected from the geologic time scale, which is encoded in the Time Scale Table (see below).

Table 2-40: 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 <i>coa_id</i> .	Integer
min_strat	The minimum time-stratigraphic age selected from the Stratigraphic Time Scale Table	Character
max_strat	The maximum time-stratigraphic age selected from the Stratigraphic Time Scale Table	Character
min_source_org	Identifier for the organization that was the source of the minimum age	Character
min_source_id	Source organization's identification of the minimum age reference	Character
max_source_org	Identifier for the organization that was the source of the maximum age	Character
max_source_id	Source organization's identification of the maximum age reference	Character

Stratigraphic Time Scale Table

The Stratigraphic Time Scale Table (table 2-41) 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 an 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 2-41: Definition of the attributes in the Stratigraphic Time Scale Table.

Attribute	Definition	Format
strat_name	The time-stratigraphic name for the time interval	Character
strat_id	A unique identifier for the strat_name	Integer
strat_rank	A keyword representing the rank of the time-stratigraphic term. Must be defined in the Stratigraphic Rank Table	Character
min_age	Minimum numerical age, in millions of years	Number
max_age	Maximum numerical age, in millions of years	Number
min_source_org	Identifier for the organization that was the source of the minimum age	Character
min_source_id	Source organization's identification of the minimum age reference	Character
max_source_org	Identifier for the organization that was the source of the maximum age	Character
max_source_id	Source organization's identification of the maximum age reference	Character

The following table (table 2-42) 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 an 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. 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 2-42: 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	Aquitania	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	Precambrian	570	3800	era
98	Proterozoic	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 2-43) 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 a era and the era is further defined as a part of a 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 2-43: 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 2-44) shows some sample data as it would appear in the Stratigraphic Tree Table (based on the example above).

Table 2-44: 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 2-45) 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 2-45: 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 2-46) 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 2-46: 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

Structural Correlation Table

The Structural Correlation Table (table 2-47) 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 Structural Correlation Table is needed as a means of correlating the many-to-many relationship. Each record in the Structural Correlation Table contains the key attributes of the corresponding records in the COA Table and the Structural Type Table as well as the attribute, *accuracy*, which is used to record the positional accuracy of each structural type. It is expected that a limited set of pre-defined terms, such as definite, approximate, inferred, concealed, gradational, queried, etc. will be used within the *accuracy* attribute.

Table 2-47: Definition of the attributes in the Structural Correlation 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
accuracy	The positional accuracy of the structure type	Character

Structural Type Table

The Structural Type Table (table 2-48) contains the attributes of various types of structural features. It is linked to the Structural Correlation 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 Structural Correlation 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 need 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 2-48: 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 2-49) 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 2-49: 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 Overlay Table

The Metamorphic Overlay Table (table 2-50), used to store information about metamorphic overlay 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 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 units. 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 2-50: Definition of the attributes in the Metamorphic Overlay Table.

Attribute	Definition	Format
coa_id	Unique identification number of a unit in the Compound Object Archive	Integer
grade	The metamorphic grade of the metamorphic overlay, which should be selected from a defined list of terms	Character
Etc.	As yet undefined additional attributes needed for this table	

References Cited

- Bally, A. W. and Palmer, A. R., 1989, Decade of North American Geology Geologic Time Scale: Geologic Society of America, The Geology of North America, vol. A, p. 601.
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- Williams, H., Turner, f. J., and Gilbert, C. M., 1954, Petrography: an introduction to the study of rocks in thin sections: Freeman, San Francisco, 406 pp.

Appendix A: A Common GIS Data Model

Many GIS users are now creating digital version of geologic maps, both for cartographic reproduction of original maps and for use in natural systems analysis and decision support. As an example of the entity-relation notation presented in this chapter, the implementation in a GIS such as Arc/Info of a typical model currently used for digital geologic maps is represented in figure 2-11 using the notation presented in figure 2-5. Each box in the diagram 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.

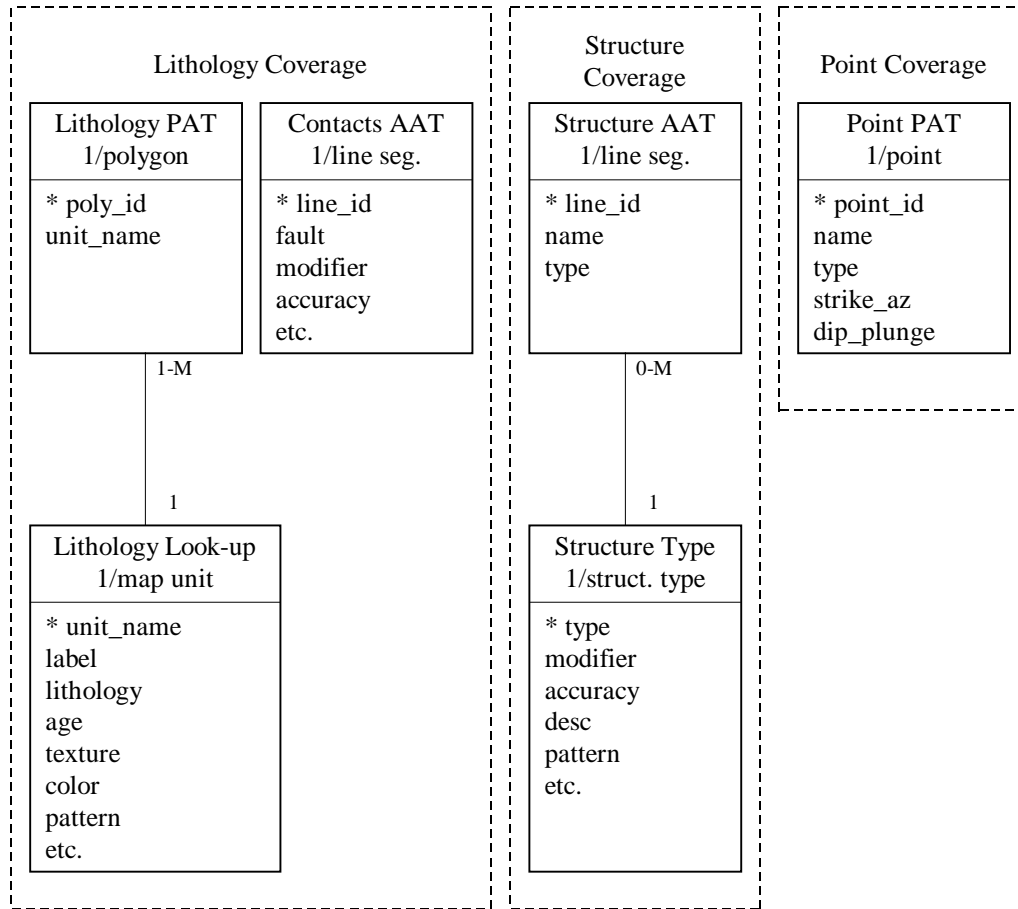


Figure 2-12. The implementation in a GIS of a typical digital geologic map model.

A typical model currently used for digital geologic maps is represented here using the entity-relation notation presented in figure 2-5. The model used is simply a series of GIS coverages directly linked to look-up tables, as needed.

The model shown in figure 2-12 represents a series of GIS coverages directly linked to look-up tables, as needed. Each type of information (rock units, linear structures, point structural orientations, etc.) is stored in a separate data layer (coverage). In addition, the contacts (linear features between rock units) are separated into a different data layer from the rock units. In some GIS, one can store linear features and polygonal features in the same data layer; in others, it is not permitted. In an effort to normalize the data structure, attribute information for the rock units and linear structures is stored in separate look-up tables. This reduces the storage needs for the digital map and also prevents the errors produced by storing the same information in several portions of the same database. In addition to the feature tables and look-up tables shown here, the complete digital geologic map would also include the spatial description of each feature stored in the GIS proper and a set of symbolization tables which would be used

to convert pattern and symbol names in the feature attribute tables to actual display symbolization. The simple model, although extensively used, has serious drawbacks when attempting to combine maps or to develop derivative maps. To achieve these goals, more information must be included in the model.

Of the many possible examples of data required for spatial analysis of digital geologic maps not provided by the simple model, only a few will be noted here. It is often desirable to be able to select areas that are underlain by rocks within a certain age span or to select all areas with rocks that fit a general lithologic class. For example, suppose the user needs to separate all areas underlain by Tertiary rocks from all areas underlain by older rocks. Although the simple model (figure 2-11) includes an age attribute for all polygons, the system doesn't include any information about which age categories are within the Tertiary. To select all polygons representing Tertiary rocks, the user would have to select all polygons with any of the possible Tertiary age attributes (Pliocene, Cenozoic, etc.) plus all possible abbreviations. More importantly, the user would have to know of all of the possibilities ahead of time. It is more efficient and less error prone to include the geologic time hierarchy in the data model.

If the user needed to separate all areas underlain by volcanic rock, a similar problem would occur. Without a lithologic hierarchy built into the model, the user would have to know all of the possible lithologic terms that could be used for volcanic rock units. If the user was interested in all areas underlain by Tertiary volcanic rocks, then the complexity of the search would increase. Similar examples could be used to demonstrate the need for additional model complexity for all polygon data as well as for lines and points. The trade-off for additional model complexity is the increased time required to build the model and to enter data for each individual map. In the sections above which describe a relational data model for digital geologic maps, a compromise has been attempted which balances the information commonly needed for modeling and analysis with the need for flexibility and efficiency.

There is an additional attribute, not shown in the simple model in figure 2-11, which should be attached to every feature on every data layer. That is the source of the feature. At the time that a geologic map is first created in a digital format, it often seems wasteful to attach a source attribute to every feature on every data layer. In all probability, every feature on the map will have the same source, the original map (whether published or not). However, as the original digital geologic map is used it will be periodically updated and modified. Each time a change is made to the digital version of the map, the new source of the changes should be attached to every feature that is changed. As the map is then used in analytical procedures, the source of each feature will be carried along with the feature. At any subsequent stage of any analysis, it will then be possible to identify any individual feature and trace it back to its original source. The same is true of any derivative map that is created from features from several original maps. This is the only way that the chain of responsibility for a particular analytical result can be traced back to its origins.

Appendix B: 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 discussion above on the use of look-up tables demonstrates one method of achieving similar storage space savings without adding the burden of looking up codes to the user.

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 were 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. It can also be extended by allowing fractional codes. These can 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.

Appendix C: Implementation Issues

Point features

A restriction of many GIS's (including ARC/INFO) is that point data and polygon data can not be stored in the same data layer. The reason for this restriction is that polygons use label points to link the graphic description of the polygon with the polygon attribute table. The polygon attribute data is stored in the same format as point attribute data. To avoid confusing the topological structure of the data layer, data points and polygon label points must be stored in separate attribute tables. Therefore, points and polygons are stored in separate data layers. Points and arcs can be stored on the same layer, but it is not recommended for digital geologic maps. When combining digital geology with other types of data, the point data is often not needed. It is much more common to use the line or polygon data, or both, than it is to use the point data. Point data is more commonly used for cartographic purposes to create a hard copy of the digital map than in analytical work.

Linear features

Linear features are in many ways more complicated than point features. There are more types of linear features that are likely to be found on typical geologic maps and they interact in complicated patterns. The first question that arises in implementing the linear features portion of the Spatial Object Archive is whether the linear features should be combined with the polygon features. The lines that make up the borders of polygons are also linear features; they are nearly all contacts, faults, or area boundaries. If the linear features are placed on a separate data layer, nearly all of the lines on the polygon data layer will also appear on the linear features data layers. This duplication of data increases both the storage space required for the digital map and the potential for creating problems by modifying one data layer without making identical changes to the other data layer. In addition, all lines on the map are generally entered into the GIS at the same time. Thus, to make two data layers out of the original raw data, the lines have to be separated, or copied from one layer to the other.

Unfortunately, there are some problems with combining all linear features with all polygons on the same data layer. Most of these problems have to do with the way the GIS stores data and structures the data topologically. Lines are broken into segments at every line intersection. The same is true of polygons. Every line that crosses an area divides that area into two polygons. Even though the two resulting polygons may represent the same geologic unit and may have identical attributes, if a line separates them, they are topologically two distinct polygons. Ordinarily, this does not cause any problems; the GIS keeps track of all the polygons and their attributes so that whenever a user queries polygons with the appropriate attribute, both polygons would appear. A problem does appear, however, if the polygons are plotted with some types of area-filling patterns. Some area-filling patterns use the edge of the polygon as the beginning of the pattern for each line of the pattern. If an area representing a single rock unit is crossed by a linear feature (a fault, for example), the GIS stores the area as two polygons with the fault making up part of the boundary of each polygon. If the map is plotted with an area-filling pattern, the patterns will be mis-aligned between the two polygons, even if the fault is not plotted. If area-filling patterns are not used, or the cartographic display of the map is not important, this problem may not affect the design of the digital map.

There is another aspect of the multiple polygon problem which may not be initially recognized. If users of the digital map will be doing any analysis using areas of polygonal features, the multiple polygon per area problem caused by storing the linear features with the polygons will give erroneous results that are often overlooked. For each digital map design, the choice must be made whether it's more important to reduce the size of the data files and improve the ease of updating by leaving all linear feature and polygons in a single data layer or to achieve maximum flexibility of the digital map for unknown future uses by separating the two data types. For presentation of the data model, the two data types are shown as separate coverages. They may, however, be combined into a single coverage if the user prefers.

Polygonal features

Polygonal features form the most basic information supplied on a geologic map and the background for most of the remaining features. There are two different types of polygonal features. The first type includes all

geologic units that are large enough to be shown in two dimensions at the original map scale and other features such as water and ice through which the rock units have not been mapped. The second type of polygonal feature includes all types of overlays that are large enough to be depicted in two dimensions on the original map. The difference between these two classes of features is that the first set always forms a complete, non-overlapping, data layer while the second set overlaps the first, is usually not complete, and occasionally has internal overlaps. The current state of GIS technology makes it difficult to work with a topological structure of overlapping polygonal areas. Most GIS's require overlapping polygons to be kept on separate data layers. Until this restriction is relaxed for most common GIS's, multiple polygon data layers will be required in any map area that contains overlays. All geologic units which do not overlap, such as rock units and water bodies can be stored on one data layer, and overlays will be stored on additional data layers, as necessary.

CHAPTER 3: Implementation Considerations

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Tables

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Implementation Considerations

There are many important issues that have to be addressed when implementing this model within a specific database software. The first consideration might be: is the model going to be too expensive to use ? Aspects of this critical question were considered throughout the design of the data model and are further discussed in the following sections. Another critical question is: what is the intended purpose of creating digital geologic maps ? If the answer is more wide-spread use of geologic maps, then the complexity and resulting costs associated with this data model are, we postulate, the minimum needed.

Summary of Tables and Attributes

The large number of tables and attributes might give the impression that implementation and use of the data model is overwhelming. Table 3- 1 and Table 3- 2 summarize the tables and attributes. Inspection of the list of attributes quickly leads to the conclusion that only minimal information is used by the model. With the proper computer tools, the complexity of the tables will be transparent to the user: i.e. the user should not need to know which table contains which attribute as the tools should manage these issues. As discussed in the Tools section, the complexity of the tables is required to address the complex relationships inherent in geologic maps, to allow for extension as new features are added, and to normalize the data for rapid use.

Table 3- 1: Summary of the Geologic Map Data Model tables. Group indicates the greater conceptual component to which the table belongs. Type indicates the function served by the table. Category describes the table according to its function within the model: tables required of all maps (Core), required tables to deal with many-to-many relationships (Junction), proposed additional tables not necessarily required of all maps (Defined Extensions), and lookup tables that contain standard, hierarchial word lists that could be implemented to allow for computer analysis (Standard Lookup).

Table	Group	Type	Category
COA	Compound object archive	Descriptive data	Core
COA Relation	Compound object archive	Descriptive data	Defined Extension
COA Tree	Compound object archive	Descriptive data	Core
Formal Unit	Compound object archive	Descriptive data	Defined Extension
Lithology	Compound object archive	Standard Lookup	Defined Extension
Lithology Tree	Compound object archive	Standard Lookup	Defined Extension
Metamorphic Overlay	Compound object archive	Descriptive data	Future Extension
Radiometric Age	Compound object archive	Descriptive data	Defined Extension
Rock Composition	Compound object archive	Descriptive data	Core
Rock Unit	Compound object archive	Descriptive data	Core
Rock Unit Rank	Compound object archive	Standard Lookup	Core

Stratigraphic Age	Compound object archive	Descriptive data	Core
Stratigraphic Rank	Compound object archive	Standard Lookup	Core
Stratigraphic Time Scale	Compound object archive	Standard Lookup	Core
Stratigraphic Tree	Compound object archive	Standard Lookup	Core
Structural Correlation	Compound object archive	Descriptive data	Core
Structural Type	Compound object archive	Standard Lookup	Core
Area Symbol	Legend object	Standard Lookup	Defined Extension
Cartographic Object	Legend object	Descriptive data	Core
Classification Object	Legend object	Descriptive data	Core
Color	Legend object	Standard Lookup	Defined Extension
Line Symbol	Legend object	Standard Lookup	Defined Extension
Point Symbol	Legend object	Standard Lookup	Defined Extension
Data Classification	Legend/Compound object archive	Junction	Core
Map	Metadata object	Descriptive data	Core
Map/Source Correlation	Metadata object	Descriptive data	Core
Source	Metadata object	Descriptive data	Core
Classification Name	Metadata object/Legend object	Descriptive data	Core
Classification Scheme	Metadata object/Legend object	Descriptive data	Core
Fossil Detail	Singular object archive	Descriptive data	Future Extension
Spatial Object	Singular object archive	Descriptive data	Defined Extension
Composition			
Spatial Object Name	Singular object archive	Descriptive data	Defined Extension
Structural Detail	Singular object archive	Descriptive data	Defined Extension
Geology Lines	Spatial object archive	Spatial data	Core
Geology Polygons	Spatial object archive	Spatial data	Core
Miscellaneous Lines	Spatial object archive	Spatial data	Defined Extension
Overlay Polygons	Spatial object archive	Spatial Data	Future Extension
Points	Spatial object archive	Spatial data	Core
Spatial Classification	Spatial object archive/Legend Object	Junction	Core

Table 3- 2: Unique attributes that the creator of a geologic map will need to specify. The cartography column deals with symbolization of objects and the creation of a map legend. The metadata column contains attributes to designate the source reference for a geologic object, a map, or spatial feature. It is assumed that these attributes would link to a more complete set of metadata. The simple map and complex map columns are subdivided into various types of geologic object types: sites, linear features, and map units. For each of these types of objects the simple map and complex map attributes may require multiple entries for some objects, such the various lithologies in one map unit. The complex map column includes attributes that may not occur on most geologic maps.

Cartography	Metadata	Objects	Simple Map	Complex Map
class_type	source_id	Sites	name	
class_label	source_org		stype	
class_description	spatial_obj_id		strike_az	
cart_desc	source_author		dip_plunge	
cart_sym_table	source_date	Linear Features	structural_typ_id	
cart_sym	source_title	Map Units	name	
cart_color_table	source_ref		relationship	relationship description
cart_color	source_scale		stratigraphic age	age reference
class_scheme_id	source_resolution		stratigraphic minimum age	
class_seq	org_id		stratigraphic maximum age	

disp_priority	map_id	color	
class_name	map_title	texture	radiometric age
	map_author	structure	radiometric minimum age
	map_date	mineralogy	radiometric maximum age
	map_desc	rock name	radiometric age reference
	map_projection	lithology	
		mineralogy	
		description	
		alteration	
		volume %	metamorphic grade
		quality	
	Polygon		object name
			rock_type, etc.
	Line		object name
	Point	structural	object name
		measurements	

Word Lists

Probably the single most controversial aspect of the data model is 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 the 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, memo-type attributes are included to allow for English-language descriptions. These descriptions are meant to be read by people, not computers. These word lists are critical to meeting one of the goals identified in the Design Objectives 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 list provided here be seen only as examples. Once a set of word lists is agreed upon by the geologic community, it will be necessary to establish a process to evolve these lists. 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 a 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 list 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.

Future Extensions

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 things called 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, that is 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 will be needed to deal with this evolution. Extensions and additional attributes have already been proposed and are listed in Appendix A.

Metadata

The implementation of metadata standards are rapidly evolving. We have identified several attributes of geologic maps, Map and Source tables that are needed by the data model. Some of this metadata needs to be computer accessible for the implementation of the data model. However, broader metadata issues for geologic maps are the subject of another committee. Eventually the standards for metadata and geologic maps must come together.

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.

Appendix A: Suggested future extensions and additional attributes.

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 include 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 A-1: 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
Accuracy or confidence in the structural object type or type modifier.	Additional attribute in the Structural Type Table
Minimum thickness of a lithology in a rock unit.	Additional attribute in the Rock Unit Table
Maximum thickness of a lithology in a rock unit.	Additional attribute in the Rock Unit Table
When digitizing a geologic map, the vocabulary may need to be translated to conform to the data model vocabulary. Some record is need of the individual or organization translating the map vocabulary.	Additional attributes or tables to the Source Table.

Table A-2: Suggested extensions to the model. These are new types of objects requiring new tables.

Extensions	Location in Data Model
Geomorphologic Objects	These objects could be attributed in the COA Table with additional tables below similar to the Rock Unit Table
Cross Sections	These could be treated as a new map object in the GIS. Related tables in the data model could contain relevant attributes.
Aquifer Objects	These objects could be attributed in the COA Table with additional tables similar to the Rock Unit and related tables, associated with it.
Topographic base - the geology is often distorted to fit existing topographic base maps. There may be a need to record the original base map used for compilation of the geology.	This is typically considered a separate entity or coverage in the GIS. The primary data of interest is the hypsography. This would be placed as a new object in the GIS . It is not clear what additional tables might be included.
Measured Sections	These would probably require an additional table attached to the COA Table, similar to the Rock Unit Table.
Drill or well logs	Because drill logs are have their own extensive set of characteristics, these should probably exist in their own data base with their own data model. A link to these logs could be made by using the table similar to the Structure or Fossil Detail Tables diagrammed in the Observed Object Archive.
Contour maps such as	These types of data are typically shown as contours, but are analyzed in

structure contours, thickness maps, or depth to a unit.	computers as grids. Either could be handled by complete GIS; so they could be included as a data set in the GIS portion of the Map Archive and then an additional set of tables attached to IOA Table in the Interpreted Object Archive. Alternatively, they could be treated as a totally separate spatial object with their own data model; and then they would be joined spatially in a GIS as an additional theme or coverage.
Underground maps or extent of mine maps	These should probably be considered as a separate theme or coverage in a GIS with their own data model.
