The National Park Service Geology-GIS Geodatabase Data Model: A Story of Migration

By Stephanie A. O'Meara[1], Heather S. Stanton[1], James R. Chappell[1], Greg Mack[2], Anne R. Poole[3] and Georgia Hybels[4]

[1]Colorado State University/National Park Service Cooperator
1201 Oak Ridge Drive, Suite 200
Fort Collins, CO 80525
Telephone: (970) 225-3584
e-mail: Stephanie_O'Meara@partner.nps.gov; Heather_Stanton@partner.nps.gov; Jim_Chappell@partner.nps.gov

[2]National Park Service – Pacific West Region, Seattle Office
e-mail: Greg_Mack@nps.gov

[3]United States Forest Service – Chippewa National Forest
e-mail: apoole@fs.fed.us

[4]University of Denver/National Park Service Cooperator
e-mail: Georgia_Hybels@partner.nps.gov

INTRODUCTION

Geologic maps are an integral component of the physical science inventories stipulated by the National Park Service (NPS) in its Natural Resources Inventory and Monitoring (I&M) Guideline. The NPS has identified Geographic Information Systems (GIS) and digital cartographic products as fundamental resource management tools. There are few geologists employed at parks, thus these tools are particularly important to the NPS to aid resource managers in using geologic data for park management decisions (O'Meara et. al., 2003).

The NPS Geologic Resources Division (GRD) is currently developing a Geologic Resources Evaluation (GRE) that includes a geologic bibliography, a summary report of each park's geologic resources, and the development of a geology-GIS data model for implementation in the production of digital geologic-GIS data for each park. Colorado State University is a partner in the development and production of these products.

The present NPS Geology-GIS Data Model (O'Meara et. al., 2005a) for park digital geologic-GIS data is based upon Environment Systems Research Institute (ESRI) ArcInfo coverage and shapefile vector file formats and provides a robust method for storing geologic data. Recently, ESRI developed the geodatabase format for storing spatial data within a relational database management system (RDBMS). A geodatabase stores data in point, line or polygon data layers (feature classes) that can be grouped into a feature dataset, a logical groupings of vector feature classes that share the same spatial extent. The geodatabase has the added strength of allowing attribute validation rules, relationship classes, and topological rules that maintain data integrity within and between feature classes.

In order to take advantage of this new, enhanced functionality, migration from the coverage/shapefile-based geology-GIS data model to a geodatabase geology-GIS data model is underway. Using geologic data from Glacier National Park, Montana (GLAC), our poster presented at this meeting outlines 1) the present NPS Geology-GIS coverage/shapefile data model, and its benefits and drawbacks, 2) the ESRI geodatabase architecture and key components, and 3) the implementation of the NPS Geology-GIS Data Model within the geodatabase architecture, and its benefits and drawbacks. The Glacier National Park, Montana (GLAC) digital geologic-GIS map was produced from existing published USGS paper maps (Whipple, 1992 and Carrara, 1990). Of note, Figures 1 through 6 and 10 in this paper were produced using Microsoft Office Visio objects created from Geodatabase Diagrammer, an ArcScript created by ESRI.

THE NPS GEOLOGY-GIS COVERAGE/ SHAPEFILE DATA MODEL

The present data model defines how geologic features are captured, grouped and attributed in coverage and shapefile formats. In addition, relationships with ancillary source map and geologic unit information tables are also established in the data model. Acceptable data model data layer attribution values, or domain lists, are stored in separate table files.

Features Supported by NPS Coverage/ Shapefile Data Model

In the existing coverage/shapefile data model (O’Meara et. al., 2005a), geologic features are currently divided into 30 coverages and 38 shapefiles. The discordance in the corresponding number of files between coverages and shapefiles is the result of the capability of the coverage format to store multiple geometries within one coverage file. Shapefiles do not support multiple geometries and therefore multiple files are needed to represent some features. Table 1 lists coverage/shapefile data model data layers by geologic feature and spatial type (i.e. polygon, line and point).

Coverage/Shapefile Feature Attribute Tables

Coverage and shapefile feature attribute tables consist of descriptive attribute fields that contain information about geologic features in the data model. Attribute field parameters include field name, data type, field definition, and field width parameters. Figure 1 presents the attribute table for the Geologic Units (GLG) coverage/shapefile data layer.

Coverage/Shapefile Data Model Benefits

Several benefits exist for a coverage/shapefile-based data model. These include:

- Features are stored in discrete data files (E00 and SHP) with inherent topology.
- Relationships between data layers and/or tables can be established using joins and relates.
- Works well with ArcInfo, ArcView and related modules.

Coverage/Shapefile Data Model Drawbacks

Several drawbacks also exist for the coverage/ shapefile-based data model. These include:

- No efficient way to implement within a Relational Database Management System (RDBMS).
- Coverage format easy to corrupt as a coverage spatial component and attribute table are stored in separate folders. This also limits the portability of a coverage as export files are required to efficiently transfer a coverage.
- Relationships between data layers and/or related ancillary tables not stored with data files. These must be re-established for each project/map document.
- Difficult to maintain topological relationships across multiple data layers.
- Large datasets are difficult to manage.
- File size limitations.

THE NPS GEOLOGY-GIS GEODATABASE DATA MODEL

A geodatabase stores spatial and non-spatial data, including attributes, in tables, feature classes, and feature datasets. In addition, the geodatabase stores attribute validation rules, relationship classes, and topological rules for ensuring data integrity.

Two types of geodatabases exist: personal and multi-user (enterprise). Personal geodatabase support is implemented in ArcGIS using the Microsoft Jet Database Engine and is suitable for project-level GIS. Enterprise databases are deployed using ArcSDE and require a DBMS such as IBM DB2, Informix, Oracle, or Microsoft SQL Server. The NPS geodatabase data model presented here was constructed in a personal geodatabase.

Similar to the coverage/shapefile data model, the proposed NPS Geology-GIS Geodatabase Data Model (O’Meara et. al., 2005b) includes a list of feature classes, and feature attribute tables. More importantly the geodatabase data model also includes: 1) a geodatabase relational schema, 2) domains, 3) subtypes, 4) topological rules, and 5) relationship classes.

Feature Class List

Geologic features are currently divided into 44 geodatabase feature classes. Table 2 lists these feature classes by geologic feature type and spatial type (i.e. polygon, line and point).

Feature Datasets

In the NPS Geology-GIS Geodatabase Data Model, feature classes representing each of the geologic data layers on a single map are grouped into a feature dataset. All feature classes that participate in the feature dataset share the same spatial reference (i.e., projection and datum). Feature datasets store spatial data and relationships, but do not store tables. Tables are stored within the geodatabase, but outside the feature dataset. Feature datasets are

Table 1. List of coverage/shapefile data model data layers by geologic feature and spatial type (i.e., polygon, line, and point). Each data layer is assigned a three- or four-letter abbreviation (e.g., GLG for Geologic Units, GLGA for Geologic Contacts) that is indicated in the table. Data layers highlighted in gray are present in the Glacier National Park (GLAC) digital geologic-GIS map.

Geologic Features	Coverage Abbreviation (Spatial Type)	Shapefile Abbreviation (Spatial Type)
Geologic Units and Contacts	GLG (polygon and line)	GLG (polygon) and GLGA (line)
Linear Geologic Units	GLN (line)	GLN (line)
Point Geologic Units	GPT (point)	GPT (point)
Faults	FLT (line)	FLT (line)
Folds	FLD (line)	FLD (line)
Attitude Observation Localities	ATD (point)	ATD (point)
Age-Date Localities	DAT (point)	DAT (point)
Volcanic Line Features	VLN (line)	VLN (line)
Volcanic Point Features	VPT (point)	VPT (point)
Linear Dike Units	DKE (line)	DKE (line)
Area Dike Swarms and Contacts	DKS (polygon and line)	DKS (polygon) and DKSA (line)
Mine Point Features	MIN (point)	MIN (point)
Cross Section Lines	SEC (line)	SEC (line)
Area Volcanic Units and Contacts	ASH (polygon and line)	ASH (polygon) and ASHA (line)
Metamorphic/Alteration Boundaries	MET (line)	MET
Linear Glacial Features	MOR (line)	MOR (line)
Structure Contour Lines and Other Lines	LN# (line)	LN# (line)
Joints	JLN (line)	JLN (line)
Sensitive Geologic Point Features	SPF (point)	SPF (point)
Unique Geologic Point Features	UPF (point)	UPF (point)
Surficial Units and Contacts	SUR (polygon and line)	SUR (polygon) and SURA (line)
Measured Unit Thickness Localities	MUT (point)	MUT (point)
Mine Area Features	MAF (polygon and line)	MAF (polygon) and MAFA (line)
Seismic Data Localities	SMC (point)	SMC (point)
Sample Localities	SAM (point)	SAM (point)
Area Deformation Zones	DEF (polygon and line)	DEF (polygon) and DEFA (line)
Geologic Hazard Line Features	HZL (line)	HZL (line)
Geologic Hazard Point Features	HZP (point)	HZP (point)
Glacial Area Features	AGF (polygon and line)	AGF (polygon) and AGFA (line)
Geologic Hazard Area Features	HZA (polygon and line)	HZA (polygon) and HZAA (line)

necessary to the creation of topological rules, which will be discussed later. Figure 2 presents the geodatabase data model schematic for the Digital Geologic Map of Glacier National Park, Montana (GLAC), which includes the map's feature dataset and related ancillary tables.

Feature Attribute Tables

Feature attribute tables in the geodatabase consist of descriptive attribute fields that contain information about the features within a feature class. Attribute field parameters include field name, data type, whether or not to allow null values, field definition, domain type (coded value or range), and field width (precision, scale and length). Figure 3 presents the attribute table for the Geologic Units (GLG) feature class.

Attribute Domains

Attribute domains define acceptable values for fields in attribute tables that are contained in the geodatabase. Coded value domains are used in the NPS Geology-GIS Geodatabase Data Model to define acceptable values for various feature class type fields and their subtypes (see Subtypes section) including: Attitude Type (subtypes – planar measurements, linear measurements, etc.), geologic contact type, fault type, and fold type. Range domains are used to define ranges of acceptable values for attribute fields such as

Multiple-Geometry feature class

Geologic Units (glacglg)

Field Name	Data Type	Field Definition	Input Width	Output Width	Dec. Places
AREA	Binary	area of feature	8	18	5
PERIMETER	Binary	perimeter of feature	8	18	5
GLACGLG#	Binary	unique internal feature ID #	4	5	-
GLACGLG-ID	Binary	unique internal ID#	4	5	-
GLG_IDX	Integer	unqiue ID#	6	6	-
GLG_SYM	Character	unit age-lithology symbol	12	12	-
USGS_SYM	Character	source unit age-lithology symbol	12	12	-
GLG_AGE_NO	Number	unit age-sort number (young to old)	8	8	4
GMAP_ID	Integer	source map ID # (in MAP table)	6	6	-
HELP_ID	Character	unit (page) variable for Help File	12	12	-

Figure 1. Geologic Units (GLG) coverage/shapefile data layer attribute table. Attribute table fields highlighted in white store information about geologic unit polygons (areas) such as: geologic feature identification number (GLG_IDX); geologic unit symbol (GLG_SYM); source map geologic unit symbol (USGS_SYM); an age number sorting units from youngest to oldest (GLG_AGE_NO); a source map ID number (GMAP_ID); and a variable used to 'link' a geologic unit to a map help file containing geologic unit descriptions (HELP_ID). Standard ArcInfo polygon attribute fields are highlighted in medium gray. These are created automatically, and include area (AREA), perimeter (PERIMETER), a unique internal feature ID (GLACGLG#), and a unique internal ID (GLACGLG-ID).

Table 2. List of geodatabase feature classes by geologic feature and spatial type (i.e., polygon, line, and point). Each feature class is assigned a three- or four-letter abbreviation (e.g., FLT for faults, GLN for Linear Geologic Units) that is indicated in the table. Feature classes highlighted in medium gray are present in the Glacier National Park (GLAC) digital geologic-GIS map.

Geologic Features	Feature Class Abbreviation	Spatial Type
Geologic Units	GLG	polygon
Geologic Contacts	GLGA	line
Linear Geologic Units	GLN	line
Point Geologic Units	GPT	point
Surficial Units	SUR	polygon
Surficial Contacts	SURA	line
Volcanic Ash Units	ASH	polygon
Volcanic Ash Contacts	ASHA	line
Linear Dike Units	DKE	line
Dike Swarm Units	DKS	polygon
Dike Swarm Contacts	DKSA	line
Deformation Zones	DEF	polygon
Deformation Zone Boundaries	DEFA	line
Faults	FLT	line
Folds	FLD	line
Linear Joints	JLN	line
Attitude Observation Localities	ATD	point

Geologic Sample Localities	GSL	point
Cross Section Lines	SEC	line
Structure Contour Lines and Other Value Lines	CN#	line
Observation, and Observed Extent and Trend Lines	LIN	line
Volcanic Linear Features	VLF	line
Volcanic Point Features	VPF	point
Geologic Linear Features	GLF	line
Geologic Point Features	GPF	point
Glacial Area Features	GAF	polygon
Glacial Area Feature Boundaries	GAFA	line
Glacial Linear Features	GFL	line
Glacial Point Features	GFP	point
Mine Area Features	MAF	polygon
Mine Area Feature Boundaries	MAFA	line
Mine Linear Features	MLF	line
Mine Point Features	MIN	point
Geologic Hazard Area Features	HZA	polygon
Geologic Hazard Area Feature Boundaries	HZAA	line
Geologic Hazard Linear Features	HZL	line
Geologic Hazard Point Features	HZP	point
Alteration and Metamorphic Areas	AMA	polygon
Alteration and Metamorphic Area Boundaries	AMAA	line
Alteration and Metamorphic Linear Features	AML	line
Alteration and Metamorphic Point Features	AMP	point
Geologic Measurements Localities	GML	point
Seismic Localities	SMC	point
Geologic Observation Localities	GOL	point
Map Symbology	SYM	point

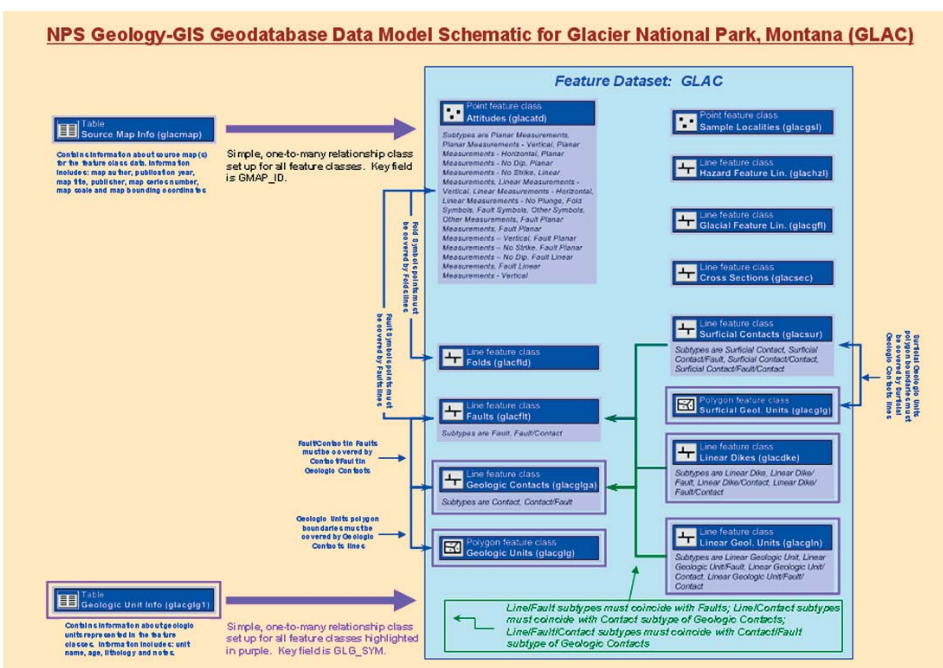


Figure 2. Geodatabase data model schematic for the Digital Geologic Map of Glacier National Park, Montana (GLAC) showing map feature dataset, feature classes, ancillary map tables, and implemented relationship classes.

Simple feature class

Geologic Units (glacglg)

Geometry *Polygon*
Contains M values *No*
Contains Z values *No*

Field Name	Data Type	Allow nulls	Field Definition	Domain	Pre	Scale	Length
OBJECTID	Object ID	-	feature object ID	-	-	-	-
SHAPE	Geometry	Yes	feature geometry	-	-	-	-
GLG_ID	Long integer	No	feature ID #	-	0	-	-
GLG_SYM	String	No	unit age-lithology symbol	-	-	-	12
SRC_SYM	String	No	source unit age-lithology symbol	-	-	-	12
NOTE	String	No	text notes and remarks	-	-	-	254
GMAP_ID	Long integer	No	source map ID # (in MAP table)	-	0	-	-
HELP_ID	String	No	unit (page) variable for Help File	-	-	-	12
SHAPE_Length	Double	Yes	feature perimeter	-	0	0	-
SHAPE_Area	Double	Yes	feature area	-	0	0	-

Figure 3. Geologic Units (GLG) feature class attribute table. Attribute table fields highlighted in white store information about geologic unit polygons (areas) such as: geologic unit symbol (GLG_SYM); source map geologic unit symbol (SRC_SYM); a notes and remarks field (NOTE); a source map ID number (GMAP_ID); and a variable (HELP_ID) used to 'link' a geologic unit to a map help file containing geologic unit descriptions. Attribute fields highlighted in medium gray are created automatically in a geodatabase, and include a unique feature ID (OBJECTID), as well as geometry type (SHAPE), length (SHAPE_Length), and area (SHAPE_Area).

strike, dip, and rotation in the Attitude Observation Localities (ATD) feature class. By placing limits and definitions on acceptable values, domains help to ensure consistency when attributing the features. Figure 4 presents the coded value domain used to define acceptable values for horizontal planar measurements (planar horizontal values subtype) in the Attitude Observation Localities (ATD) feature class. Figure 5 presents a range domain defining acceptable values for attitude strike/trend values for numerous subtypes in the Attitude Observation Localities (ATD) feature class.

Subtypes

Geodatabase subtypes are used to subdivide data in feature classes into groups that share the same attribute or topological validation rules and/or default values. Subtypes are defined by integer values stored in a field in a feature class's attribute table.

The purpose of the contact and contact/fault subtypes in the Geologic Contacts (GLGA) feature class (Figure 6) is to enforce topological rules and attribute validation. For example, the "fault/contact" subtype in the Faults (FLT) feature class must spatially coincide with the "contact/fault" subtype in the Geologic Contacts (GLGA) feature class (see Topology section). Subtypes in the Geologic Contacts (GLGA) feature class share the same domain for positional accuracy (CNT_POS).

Nineteen subtypes were created for topological rule enforcement and to control attribution for attitude type, attitude strike/trend, and attitude dip/plunge in the Attitude Observation Locality (ATD) feature class. For instance, the planar measurements subtype consists of planar measurements that have an azimuth (strike) that as a range from 0 to 359 degrees and are inclined at an angle from 0 to 89 degrees. Both measurement values, strike and dip, are restricted by range domains. Another subtype, planar vertical measurements, shares the same strike domain, from 0 to 359 degrees, however, the dip value is restricted by a coded domain to 90 degrees. Figure 7 presents an example of the Attitude Observation Localities (ATD) feature class attribute table.

Topology

In a geodatabase, topological rules govern spatial relationships within and between different feature classes. In the NPS Geology-GIS Geodatabase Data Model, topological rules are used to ensure that: faults exactly coincide with geologic contacts where a fault is also a contact; geologic contacts coincide with the boundaries of geologic units; and fold symbols and fault symbols lie along folds and faults, respectively. Topological rules also stipulate that no gaps or overlaps and no self-intersections do not occur in the various polygon and line feature classes in the geodatabase. Figure 8 illustrates an example of a topology rule error caused by incorrect attribution. Figure 9 presents topology rules for the Glacier National Park, Montana digital geologic-GIS map.

Coded value domain
Attitudes–Planar Horizontal Values
Description
Field type *Short integer*
Split policy *Default value*
Merge policy *Default value*

Code	Description
4	horizontal beds
25	horizontal foliation
112	horizontal schistosity
125	horizontal cleavage
133	horizontal inclusion

Figure 4. Coded value domain used to define acceptable values for the planar horizontal measurements subtype in the Attitude Observation Localities (ATD) feature class. All acceptable coded domain values and their description are listed for the subtype.

Range domain
Attitudes–Strike Values
Description
Field type *Short integer*
Split policy *Default value*
Merge policy *Default value*

Minimum value	Maximum value
0	359

Figure 5. Range domain defining acceptable values for attitude strike for numerous subtypes in the Attitude Observation Localities (ATD) feature class. Acceptable strike/ trend values or azimuths are between 0 and 359 degrees, and are defined in a range domain by a minimum value (0) and maximum value (359).

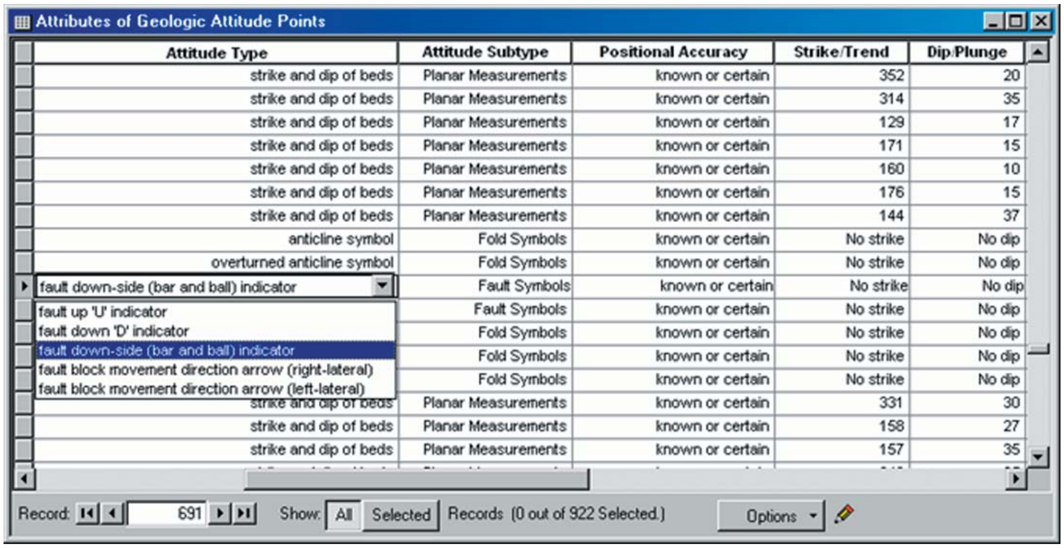
Simple feature class
Geologic Contacts (glacglga)
Geometry *Polyline*
Contains M values *No*
Contains Z values *No*

Field Name	Data Type	Allow nulls	Field Definition	Domain	Pre	Scale	Length
OBJECTID	Object ID	-	feature object ID	-	-	-	-
SHAPE	Geometry	Yes	feature geometry	-	-	-	-
GLGA_ID	Long integer	No	feature ID #	-	0	-	-
GLGA_SUB	Short integer	No	contact/faulted contact	Coded	0	-	-
POS	Short integer	No	contact position/concealment	Coded	0	-	-
NOTES	String	No	text notes and remarks	-	-	-	254
GMAP_ID	Long integer	No	source map ID # (in MAP table)	-	0	-	-
SHAPE_Length	Double	Yes	feature length	-	0	0	-

Subtypes of Geologic Contacts (glacglga) List of defined subtype definitions and domains in this class

Subtype Code	Subtype Description	Field name	Subtype Definition	Domains
0	Contact	GLGA_SUB	geologic contact	CNT_POS
1	Faulted Contact	GLGA_SUB	faulted geologic contact	CNT_POS

Figure 6. Geologic Contacts (GLGA) feature class subtypes. Note that the subtype field (GLGA_SUB) is defined as a short integer field. In the attribute table, the subtype description text, in this case "contact" and "faulted contact", appears in the actual attribute table, and not the actual coded value, 0 for contact and 1 for faulted contact. Subtype descriptions appear by default when viewing attribute data and aid in attribution during object creation.



Attributes of Geologic Attitude Points

Attitude Type	Attitude Subtype	Positional Accuracy	Strike/Trend	Dip/Plunge
strike and dip of beds	Planar Measurements	known or certain	352	20
strike and dip of beds	Planar Measurements	known or certain	314	35
strike and dip of beds	Planar Measurements	known or certain	129	17
strike and dip of beds	Planar Measurements	known or certain	171	15
strike and dip of beds	Planar Measurements	known or certain	160	10
strike and dip of beds	Planar Measurements	known or certain	176	15
strike and dip of beds	Planar Measurements	known or certain	144	37
anticline symbol	Fold Symbols	known or certain	No strike	No dip
overturned anticline symbol	Fold Symbols	known or certain	No strike	No dip
fault down-side (bar and ball) indicator	Fault Symbols	known or certain	No strike	No dip
	Fault Symbols	known or certain	No strike	No dip
	Fold Symbols	known or certain	No strike	No dip
	Fold Symbols	known or certain	No strike	No dip
	Fold Symbols	known or certain	No strike	No dip
strike and dip of beds	Planar Measurements	known or certain	331	30
strike and dip of beds	Planar Measurements	known or certain	158	27
strike and dip of beds	Planar Measurements	known or certain	157	35

Figure 7. Attitude Observation Localities (ATD) feature class attribute table showing attribute fields with coded domains for attitude observation type, attitude subtype, and positional accuracy fields, and ranges domains for strike/trend and dip/plunge fields. The pull-down list displays attitude type values (ATD_TYPE field) dependent on the subtype field (ATD_SUB), in this case attitude type values that are fault symbols.

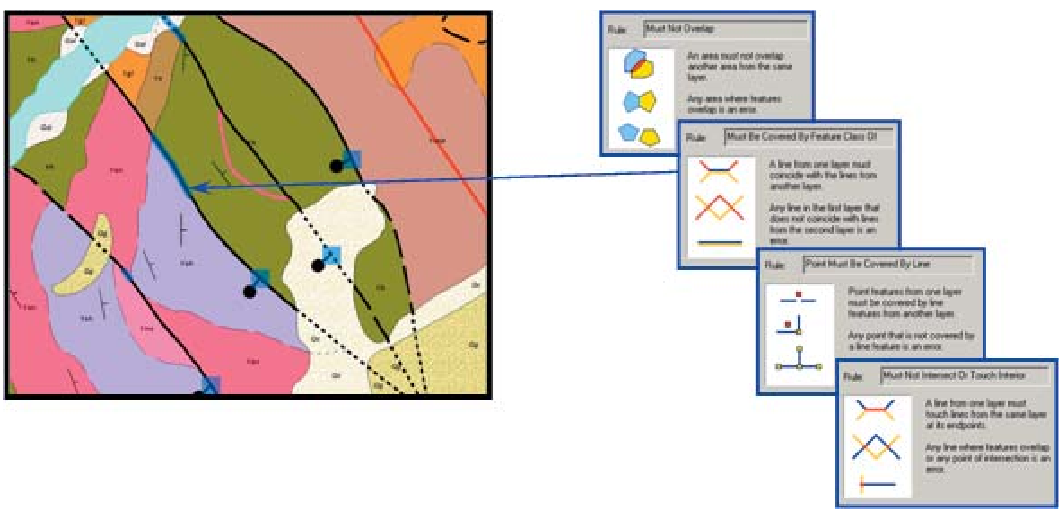


Figure 8. Snapshot of the Glacier National Park, Montana (GLAC) digital geologic-GIS map in ArcMap showing, in gray, a line segment where the rule “Must Be Covered By Feature Class Of” has been broken. Here, a fault/contact” in the Faults (FLT) is covered by a “contact” in the Geologic Contacts (GLGA). To correct the topological error, the contact should be attributed in the GLGA feature class as a “contact/fault”.

Rules between feature classes that are specific to the geodatabase

Rules that apply only within a single feature class; mimic coverage rules

Rules between feature classes that mimic coverage rules

	GLGA	FLT	SURA	DKE, GLN	FLD, GFL, HZL, SEC	GLG	SUR
GLGA	H	1-A-1, 0-B-0	-	-	-	C	-
FLT	1-A-1	G	-	-	-	-	-
SURA	0-B, 2-A-0, 3-A-1	0-B, 1-A-0	H	-	-	-	C
DKE, GLN	0-B, 2-A-0, 3-A-1	0-B, 1-A-0	-	G	-	-	-
FLD, GFL, HZL, SEC	-	-	-	-	G	-	-
GLG	D	-	-	-	-	F	-
SUR	-	-	D	-	-	-	F

A Must Be Covered By Feature Class Of

B Must Not Overlap With

C Must Be Covered By Boundary Of

D Boundary Must Be Covered By

E General Polygon Rules: Must Not Overlap

F General Polygon Rules 2: Must Not Overlap, Must Not Have Gaps

G General Line Rules: Must Not Intersect Or Touch Interior, Must Be Single Part, Must Not Self-Intersect

H General Line Rules 2: General Line Rules Plus Must Not Have Dangles

Figure 9. Topological rules for the Glacier National Park, Montana (GLAC) digital geologic-GIS map are represented with the source or origin feature classes in rows and the destination feature classes in columns. Letters indicate the type of topology rule, as presented right of the principal table. A number before a letter (a topology rule) indicates the subtype in the origin feature class to which the topology rule is applicable. A number following a number (origin feature class) and letter (a topology rule) indicates the subtype of the destination feature class to which the topology rule is applicable. For instance, the Faults (FLT) feature class (source) is related to the Geologic Contacts (GLGA) feature class (destination) using the rule 1-A-1, where the first 1 is the "fault/contact" subtype (see line subtypes below figure) of the Faults (FLT) feature class, the A represents the topological rule (see list right of table), and the second 1 is the "contact/fault" subtype of the Geologic Contacts (GLGA) feature class. In other words, a "fault/contact" in FLT must coincide with a "contact/fault" in GLGA. If there is no number to represent a subtype for the source and/or destination feature class, the rule applies to the entire source and/or destination feature class. Note that one or more rules may apply to a given source and destination feature class.

Relationship Classes

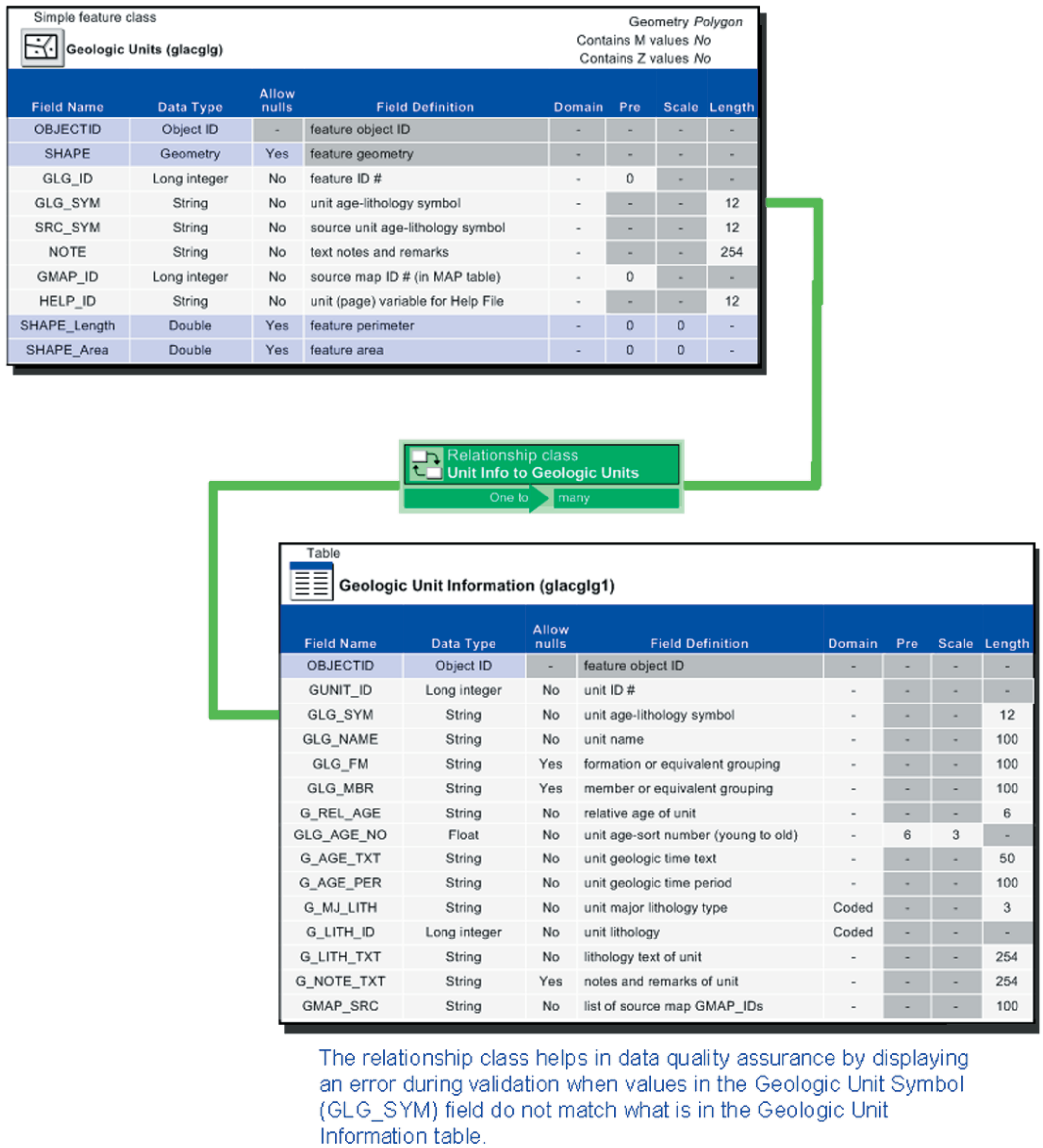
Relationship classes store information about how geodatabase objects such as tables and feature classes are interrelated. In the NPS Geology-GIS Geodatabase Data Model, they are used to relate the table of Geologic Unit Information (GLG1) to the Geologic Units (GLG) feature class, as well as to other feature classes containing geologic unit information. They are also used to relate the Source Map Information (MAP) table to all of the feature classes in the geodatabase. See Figure 2 for an example of implemented relationship classes for the Glacier National Park, Montana (GLAC) digital geologic-GIS map.

Relationships are implemented with simple, one-to-many relationship classes, where records in the tables exist independently from feature class objects, as opposed to composite relationship classes where the records in the source table control the deletion/addition of destination feature class objects. For instance, if a composite relationship existed between the Geologic Unit Information (GLG1) table and the Geologic Units (GLG) feature class, with the GLG1 table defined as the source, and the GLG feature class defined as the destination, if a record in GLG1 (source) table was deleted, all related records (in this case actual features) in the GLG (destination) feature class would automatically be deleted as well. Figure 10 displays a relationship between the Geologic Units (GLG) feature class and the Geologic Unit Information (GLG1) table.

Geodatabase Data Model Benefits

Several benefits exist for a geodatabase-based data model. These include:

- All geographic data is centrally stored and managed in one database.
- The availability of subtypes, domains, relationship classes, and topological rules help maintain database integrity and reduce database maintenance by making data entry and editing more efficient and accurate.
- Previous data formats (i.e., coverage and shapefile) can be created via data export from a geodatabase.
- Geodatabase specifications or schema can be replicated and reused for production purposes using Microsoft Visio, Extensible Mark-up Language (XML) and/or Computer-Aided Software Engineering (CASE) tools.
- Geodatabase annotation can be linked to respective features. When annotated features are altered, the



Field Name	Data Type	Allow nulls	Field Definition	Domain	Pre	Scale	Length
OBJECTID	Object ID	-	feature object ID	-	-	-	-
SHAPE	Geometry	Yes	feature geometry	-	-	-	-
GLG_ID	Long integer	No	feature ID #	-	0	-	-
GLG_SYM	String	No	unit age-lithology symbol	-	-	-	12
SRC_SYM	String	No	source unit age-lithology symbol	-	-	-	12
NOTE	String	No	text notes and remarks	-	-	-	254
GMAP_ID	Long integer	No	source map ID # (in MAP table)	-	0	-	-
HELP_ID	String	No	unit (page) variable for Help File	-	-	-	12
SHAPE_Length	Double	Yes	feature perimeter	-	0	0	-
SHAPE_Area	Double	Yes	feature area	-	0	0	-

Field Name	Data Type	Allow nulls	Field Definition	Domain	Pre	Scale	Length
OBJECTID	Object ID	-	feature object ID	-	-	-	-
GUNIT_ID	Long integer	No	unit ID #	-	-	-	-
GLG_SYM	String	No	unit age-lithology symbol	-	-	-	12
GLG_NAME	String	No	unit name	-	-	-	100
GLG_FM	String	Yes	formation or equivalent grouping	-	-	-	100
GLG_MBR	String	Yes	member or equivalent grouping	-	-	-	100
G_REL_AGE	String	No	relative age of unit	-	-	-	6
GLG_AGE_NO	Float	No	unit age-sort number (young to old)	-	6	3	-
G_AGE_TXT	String	No	unit geologic time text	-	-	-	50
G_AGE_PER	String	No	unit geologic time period	-	-	-	100
G_MJ_LITH	String	No	unit major lithology type	Coded	-	-	3
G_LITH_ID	Long integer	No	unit lithology	Coded	-	-	-
G_LITH_TXT	String	No	lithology text of unit	-	-	-	254
G_NOTE_TXT	String	Yes	notes and remarks of unit	-	-	-	254
GMAP_SRC	String	No	list of source map GMAP_IDs	-	-	-	100

Figure 10. A relationship class relating the Geologic Unit Information (GLG1) table to the Geologic Units (GLG) feature class. The field relating the Geologic Unit Information (GLG1) table to the Geologic Units (GLG) feature class is the geologic unit symbol (GLG_SYM) field. Through the relationship, data from all other fields in the Geologic Unit Information (GLG1) table can be accessed, preventing duplication and data redundancy throughout the database.

feature-linked annotation also is altered.

- Provides more intuitive data objects instead of generic points, lines, and polygons.
- Geodatabases can accommodate very large datasets without the need for tiling or spatial partitions.
- More portable than coverages and shapefiles as data layers and tables can be stored in one geodatabase file, and not as multiple files.
- Enterprise geodatabases allow for multiple users to access data at the same time via versioning, and they can leverage additional functionality from additional connected robust databases.

Geodatabase Data Model Drawbacks

A few drawbacks also exist for the geodatabase-based data model. These include:

- Significant learning curve when migrating from coverage or shapefile format to a geodatabase format and data model.

- Requires duplication of data where polygon boundaries overlap and where bounding lines carry attribution.
- Geodatabases have not yet been universally adopted by GIS users, requiring those who use them to import from, and export to, other data types (shapefiles and coverages, for example).
- At its current version, ArcGIS still has many functionality problems (bugs).

IMPLEMENTATION USING XML SCHEMA

Because geologic features present on a geologic map frequently vary, a flexible approach to data model implementation using XML files for each feature class or two interdependent feature classes (i.e., Geologic Contacts (GLG) and Geologic Units (GLGA)) has been adopted. For example, not all geologic maps have faults. Having the functionality to implement a feature class to store faults only if these features are present decreases time spent creating the data layer if needed; including specifying attribute field parameters, domains, and participating relationship classes, and eliminates the need to delete components of a geodatabase that only pertain to a faults data layer should these not be desired in the final digital map.

Methods for implementing topological rules and relationship classes are currently under development. XML files are in the format accepted by Geodatabase Designer version 2, an ArcScript created by ESRI. Figure 11 shows a screen capture of Geodatabase Designer in ArcCatalog.

CONCLUSIONS

The current NPS Geology-GIS Coverage/Shapefile Data Model provides a robust method for storing geologic map data in a GIS. ESRI's new geodatabase model offers features and functionality that enhance the quality, portability, and scalability of digital geologic map data.

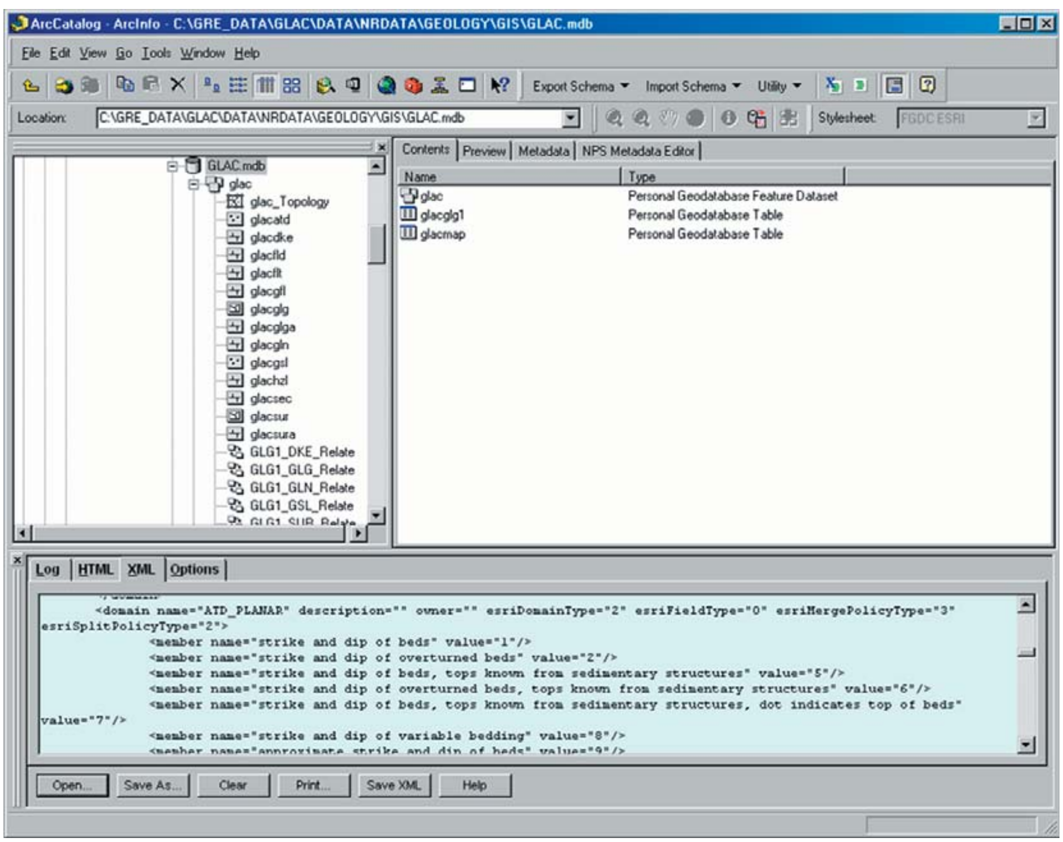


Figure 11. Screen capture of the Geodatabase Designer in ArcCatalog. The Geodatabase Designer is used to implement geodatabase feature class schema stored in XML files. A feature class XML schema file includes name and alias of the feature class(es), as well as field parameters, subtypes, and associated domains. XML schema for the Attitude Observation Localities (ATD) feature class is visible in the lower window of the figure. The schema is implemented in the Glacier National Park, Montana (GLAC) digital geologic-GIS map.

The decision to migrate to a geodatabase-based data model was influenced by the potential value that these new features and functionality could bring to the Geologic Resources Evaluation’s (GRE) digital geologic map data program. The new NPS Geology-GIS Geodatabase Data Model incorporates the functionality of a geodatabase and enhances attribution and data integrity through the use of domains, subtypes, topology, and relationship classes. Current data formats (i.e., coverage and shapefile) also can be supported through export functionality included with ArcGIS.

FUTURE PLANS

The GRE program has identified several ideas to further develop, implement, and integrate a geodatabase-based data model into the production of digital geologic-GIS maps. These include:

- Further develop procedures for creating and presenting digital geologic-GIS map data in a geodatabase.
- Continue to refine database design, including information stored in ancillary tables (e.g., geologic unit information and source map).
- Develop improved methodology for storing map symbology (i.e., fault and fold symbols).
- Continue to refine current Geodatabase Designer XML file implementation of data model, including incorporation of topological rules and relationship classes.
- Further investigate other methods of data model implementation, including XML functionality included with ArcGIS 9.x and CASE tools.
- Reproduce existing coverage-based procedures for Quality Control and feature class digitizing using ArcObjects programming. Create new schema implementation, data loading, and export routines using ArcObjects.
- Develop methodology for efficiently producing FGDC metadata for feature datasets and object classes (i.e., feature classes and tables) within a geodatabase.

REFERENCES

O’Meara, Stephanie, Joe Gregson, Anne Poole, Greg Mack, Heather Stanton and Jim Chappell, 2005a, National Park Service Geologic Resources Evaluation Geology-GIS Coverage/Shapefile Data Model, http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.htm.

O’Meara, Stephanie A., Heather I. Stanton, James Chappell, Greg Mack, Anne R. Poole and Georgia Hybels, 2005b, National Park Service Geologic Resources Evaluation Geology-GIS Geodatabase Data Model (Draft v. 1.2), http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.htm.

O’Meara, Stephanie A., Trista L. Thornberry, Anne R. Poole, and Victor deWolfe, 2003, The National Park Service Geologic Resources Inventory “From Paper to Digital: Exploring a Geologic-GIS Map”, in D.R. Soller, ed., Digital Mapping Techniques ’03—Workshop Proceedings: U.S. Geological Survey Open-File Report 03-471, p. 247-254, available at http://pubs.usgs.gov/of/2003/of03 471/omeara/index.html.

Environmental Systems Research Institute (ESRI) Inc, 2002, Building a Geodatabase: ESRI Inc., 380 New York St., Redlands, CA 92373, http://www.esri.com.

Whipple, James W., 1992, Geologic Map of Glacier National Park, Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I-1508-F, scale 1:100,000.

Carrara, Paul E., 1990, Surficial Geologic Map of Glacier National Park, Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I-1508-D, scale 1:100,000.

SOFTWARE REFERENCES

ArcGIS 8.3 and 9.0 (ArcCatalog and ArcMap) - Environmental Systems Research Institute (ESRI) Inc., 380 New York St., Redlands, CA92373, http://www.esri.com.

Geodatabase Diagrammer – Developed by Michael Zeiler, Environmental Systems Research Institute (ESRI) Inc., 380 New York St., Redlands, CA 92373, http://arcscripts.esri.com.

Geodatabase Designer v2 – Developed by Richie Carmichael, Environmental Systems Research Institute (ESRI) Inc., 380 New York St., Redlands, CA 92373, http://arcscripts.esri.com.

Microsoft Office Visio Professional 2003, Microsoft Corporation, http://www.microsoft.com.