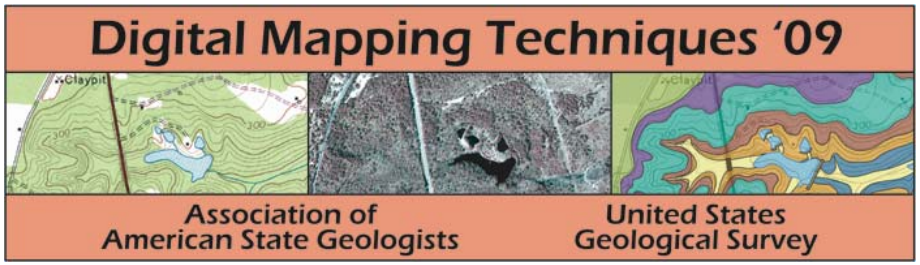

The following was presented at DMT'09 (May 10-13, 2009).

The contents are provisional and will be superseded by a paper in the DMT'09 Proceedings.

See also earlier Proceedings (1997-2008)
http://ngmdb.usgs.gov/info/dmt/

THE U.S. NATIONAL GEOLOGIC MAP DATABASE PROJECT

NCGMP09—a proposed standard format for digital publication of geologic maps

USGS National Geologic Map Database Project and Pacific Northwest Geologic Mapping Project
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This poster presents a proposed standard format for geologic map publications funded by the U.S. Geological Survey's National Cooperative Geologic Mapping Program.

The design is a logical database schema to **encode content analogous to that contained in a traditional geologic map** published by the USGS and state geological surveys.

We have implemented the database as an ESRI geodatabase in order to adhere to USGS policy and because this is a widely used GIS.

This design is intended to provide a stepping-stone toward development of multi-map databases, in particular the National Geologic Map Database (NGMDB)

Implementation in other database software format is straightforward

A version has been implemented in PostGIS to support GML-based GeoSciML web services.

Teal color indicates optional entity

Purple color indicates required entity

Entity type
Table name in database

	Primary Key
	OBJECTID--ESRI maintened
	Shape -- ESRI maintened
	required glossary terms in bold italic
	Required fields in bold
	Optional fields in plain black text
FK	**DataSourceID**

indicates that field is foreign key to another table

Explanation of diagrams

Point feature class
OrientationDataPoints

	OrientationPoints_ID
	OBJECTID
	Shape
	Type
FK	StationID
FK	MapUnit
	FgdcSymbol
	Label
	LocationConfidenceMeters
	PlotAtScale
	Notes
FK	**LocationSourceID**
FK	**DataSourceID**
	Azimuth
	Inclination
	IdentityConfidence
	OrientationconfidenceDegrees

Point feature class
GeochronPoints

	GeochronPoints_ID
	Shape
	OBJECTID
	Type
FK	StationID
FK	MapUnit
	FgdcSymbol
	Label
	LocationConfidenceMeters
	PlotAtScale
	Notes
FK	**LocationSourceID**
FK	**AnalysisSourceID**
	Age
	PlusErr
	MinusErr
	AgeUnits
	FieldSampleID
	MaterialAnalyzed
	AlternateSampleID

Points- Observation location features have geometry that records the location at which some data or sample was collected. Structural measurements, text notes, images, and samples may be associated with observation locations. A data production or management system would favor a normalized design in which a station (point) feature class is related to 0-to-many associated observations or samples. For the purposes of a single-map database, we decided that usability considerations favor a denormalized design with one feature class per point type. The most common of these would probably include: Samples, Structure measurement, Geochron-Data, Notes, and Photos. Data associated with station locations falls broadly into two categories: 1) data that are acquired at the location, e.g. orientation measurements, gravity data, magnetic measurements, etc; and 2) data derived from samples collected at the location, e.g. chemical analyses, thin section point counts, geochronologic data, etc. We provide Orientation-Data and Geochron point features as examples of these two categories. Other point feature class may be added as necessary according to the kinds of data included with the map product.

Example point feature classes for observations and analyses

Polygons and Map Unit description

Polygons that represents the outcrop of a geologic unit. Topology rules: boundary must be covered by a ContactsOrFaultsLines feature on same map horizon. Must not overlap other GeolPolys features on same map horizon. Must not have gaps (map horizon must be covered over the extent of the map)

Polygon feature class
MapUnitPolys

	MapUnitPolys_ID
	OBJECTID
	Shape
FK	**MapUnit**
	Label
	IdentityConfidence
	AreaSymbol
	Notes
FK	**DataSourceID**

Table
DescriptionOfMapUnits

	DescriptionOfMapUnits_ID
	OBJECTID
FK	MapUnit
	Label
	Name
	FullName
	Age
	Description
	HierarchyKey
	ParagraphStyle
	AreaFillRGB
	AreaFillPatternDescription
FK	**DefinitionSourceID**

Polygon feature class
OverlayPolys

	OverlayPolys_ID
	OBJECTID
	Shape
FK	**MapUnit**
	IdentityConfidence
	Label
	AreaSymbol
	Notes
FK	**DataSourceID**

Optional polygon feature class to represent outcrops of units that do not participate in topologic relationships on the primary map horizon.

DescriptionOfMapUnits (DMU) (Required): Records structure and content of typical USGS description of map units included in the map collar of a geologic map. Includes headings, heading notes, unmapped units, and units that are commonly unlabeled (water, glaciers, overlays, unmapped area) as separate table rows. Text description may include html formatting tags, and hyperlinks to related information (e.g. additional text in associated publication.)

The MapUnit attribute is a unit abbreviation as typically used to label polygons on the map, unique for each map unit, and is used as an alternate primary key to join the DMU to polygons assigned to that unit, and to ExtendedAttributes and StandardLithology rows to specify additional queryable properties of the unit.

Several fields are used to record formatting an arrangement of unit descriptions in the map collar legend display. HierarchyKey is an outline-letter formatted string (A.A.B, A.A.C…) that sorts the DMU entries according to the order they should be displayed in the legend; AreaFill properties specify the color and pattern for the polygon fill symbol for polygons representing outcrops of the unit; ParagraphStyle indicates different styling for formatting text in the legend display.

Table
StandardLithology

	StandardLithology_ID
	OBJECTID
FK	MapUnit
	PartType
	Lithology
	ProportionTerm
	ProportionValue
	ScientificConfidence
FK	**DataSourceID**

StandardLithology (Required)**:** Analyzable breakdown of lithology constituents in a geologic unit defined in the DescriptionOfMapUnits table. MapUnit is the ForeignKey that links a standard lithology record to the DMU. Each associated rock type has a proportion (either a numeric value or a term like 'onlyPart', 'dominant', 'minor'…), a part type that specifies the relationship of the part to the whole (interbedded, layers, veins, stratigraphic part…). Scientific confidence is standard or low if there is some problem with assignment of the Lithology term from the vocabulary or with the proportion assignment.

Table
ExtendedAttributes

	ExtendedAttributes_ID
	OBJECTID
	OwnerTable
	OwnerID
	Property
	PropertyValue
FK	ValueLink
	Qualifier
	Notes
FK	**DataSourceID**

ExtendedAttributes (optional): allows association of a description (like DescriptionOfMapUnits) instance to include values for any property. The property is specified by the 'Property' attribute, which should be populated from a controlled vocabulary, the property value is a string that may be numeric or text; in addition, a property value may be a link to a row in another table (like GeologicEvent). Either PropertyValue or ValueLink must be present.

OwnerID identifies the row in the table specified by OwnerTable, to which the property is associated. This foreign key that may link to a data instance in one of several other tables: DMU, Glossary, some mapped feature for description of an individual outcrop polygon, or GeologicEvent to describe a displacement event or add additional process and environments associated with an event.

A ValueLink foreign key would allow links to data elements in other tables as values for attributes. Having a pointer value to specify a property opens the door for use of the extended attributes table to represent any kind of semantic relationships between data in the database. Such relationships could include for example the association of a lineation and foliation in a compound fabric, or multiple bedding measurements associated with a derived fold hinge orientation. Property would become a generalized relation type.

Table
GeologicEvent

	GeologicEvents_ID
	OBJECTID
	Event
	AgeDisplay
	AgeYoungerTerm
	AgeOlderTerm
	TimeScale
	AgeYoungerValue
	AgeOlderValue
	Notes
	DataSourceID

GeologicEvent (optional): allows richer content to be included in geologic age assignment that provided by the age field of the DMU table. Associated with map units, faults, folds, etc. through ExtendedAttribute. Event ages could also be recorded in the description text in the DMT table, the text with the fault or fold name definition in the Glossary, or through a PropertyValue in an ExtendedAttribute record. Advantage of the event table is that data are in a more analyzable form. Use of this database will evolve best practices for age representation. (Optional). GeoSciML allows multiple process and environment terms to be associated with an Event; best way to capture this at present would appear to be ExtendedAttributes on the GeologicEvent. For GeoSciML services, also need to consider how to distinguish PreferredAge from events in a GeologicHistory; suggest applying 'preferred age' as qualifier on ExtendedAttribute with one of the events.

If age term is used, TimeScale is required.

Line feature classes

Line feature class
ContactsAndFaults

	ContactsAndFaults_ID
	OBJECTID
	Shape
	Type
	LocationConfidenceMeters
	ExistenceConfidence
	IdentityConfidence
	LocationMethod
	FGDCSymbol
	Label
	Notes
FK	**DataSourceID**

ContactsAndFaults- surface traces that participate in topologic relationships with MapUnitPolys. Contacts represent intersection of genetic boundary surface with a map horizon. Type term identifies different kinds of geologic body boundaries (intrusive contact, depositional contact, facies boundary, etc.) using terms from a controlled vocabulary.

Line feature class
ConcealedContactsAndFaults

	ConcealedContactsAndFaults_ID
	OBJECTID
	Shape
	Type
	LocationConfidenceMeters
	ExistenceConfidence
	IdentityConfidence
	LocationMethod
	FGDCSymbol
	Label
	Notes
FK	**DataSourceID**

ConcealedContactsAndFaults-mapped features that represent traces that do not participate in topologic relationship with MapUnitPolys on the represented map horizon. When merged with ContactsOrFaultsLines, no dangles are allowed unless marked as exceptions.

Line feature class
OtherLines

	OtherLines_ID
	OBJECTID
	Shape
	Type
	LocationConfidenceMeters
	ExistenceConfidence
	IdentityConfidence
	LocationMethod
	FGDCSymbol
	Label
	Notes
FK	**DataSourcesID**

OtherLines- mapped features that represent traces of dikes, marker beds, fold axes, cross-section lines, structure contours, Earth fissures. Concealed traces are depicted in the same feature class because lines do not participate in topology.

Table
ExtendedAttributes

	ExtendedAttributes_ID
	OBJECTID
	OwnerTable
FK	**OwnerID**
	Property
	PropertyValue
FK	ValueLink
	Qualifier
	Notes
FK	**DataSourceID**

Extended attributes assign age, displacement and other properties to lines. Either PropertyValue or ValueLink is required.

Table
GeologicEvent

	GeologicEvents_ID
	OBJECTID
	Event
	AgeDisplay
	AgeYoungerTerm
	AgeOlderTerm
	TimeScale
	AgeYoungerValue
	AgeOlderValue
	Notes
	DataSourceID

See description in Polygon section, above.

Metadata

Table
DataSources

	DataSources_ID
	OBJECTID
	Source
	Notes

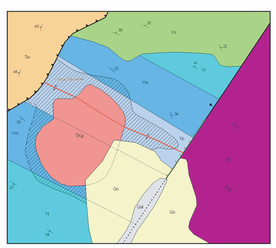
DataSources table provides feature level documentation that may be linked to any data instance through the DataSources_ID. The Notes provide information on the provenance of the linked data objects, including citations to published sources, mapping project, mapper, compiler, any discussion of interpretation of a particular feature, etc. (Required)

Table
ChangeLog

	ChangeLog_ID
	OBJECTID
	OwnerTable
	OwnerID
	ChangedWhen
	ChangedBy
	OldValue
	NewValue
	Notes

ChangeLog is an optional table to record updates to data after initial insertion into dataset. Item-level change tracking would mostly be used in an internal data maintenance environment. ChangeLog information would probably best be telescoped into DataSources records in a delivery dataset, providing the user with a summary of changes, or indicating that the data in a record have been updated on such and such a date.

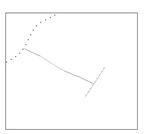
A Simple Map, showing feature classes



Example map of imaginary geology.

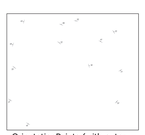
MapUnitPolygons (with auto-labeling)

ContactsAndFaults



OtherLines. Note that fault route is created by unsplitting segments of thrust fault to use for ornamentation (triangles) along fault trace. Fault scarp is represented as separate feature from fault

OverlyPolygons and Concealed-FaultsAndContacts



OrientationPoints (with auto-labelling for numbers)

Description of Map Units table example

Map Unit	Label	Name	FullName	Age	Description	HKey	Paragra. style	RGB	Pattern	Source
		Surficial deposits	Surficial deposits	Quaternary		01	Heading 1			DS0001
Qal	Qm	Younger Alluvium	Younger Alluvium	Late Holocene	Unconsolidated sandy gravel and sand	01-01	Map Unit	225,225,225	Solid fill	DS0001
Qo	Qo	Older Alluvium	Older Alluvium	Early to Middle Pleistocene	Unconsolidated to weakly consolidated gravel and sandy gravel	01-02	Map Unit	245,247,189	Solid fill	DS0001
aureole	<Font=symbol>m<Font> (m)	contact aureole of Schultze granite	contact aureole of Schultze granite	Paleocene	Zone of skarn and hornfels development; character varies rapidly with protolith rock type and distance from granite	02	Map Unit	0,0,0	black diagonal line hatch, 45, 0.2 mm, sp. 1 mm	DS0001
TKg	TKg	Schultze granite	Schultze granite	Paleocene	Fine grained equigranular biotite granitoid	03	Map Unit	244,126,127	Solid fill	DS0002
Ym	Ym	Mescal Formation	Mescal Formation of Apache Group	Middle Proterozoic	Very light gray, medium bedded limestone, locally laminated; reddish terra rosa zones common near top.	04	Map Unit	116,175,210	Solid fill	DS0003

StandardLithology table example

Standard-Lithology_ID	MapUnit	PartType	Lithology	ProportionTerm	ProportionValue
STL26	Tx	Interbedded	Sandstone	Dominant	
STL327	Tx	Stratigraphic part	Siltstone	Minor	
STL579	Tx	Stratigraphic part	Tuff	Minor	
STL264	Txt	Interbedded	Tuff	Dominant	
STL265	Kit	Only part	Tonalite	Dominant	
STL266	KJz	Interbedded	Limestone		.55
STL770	KJz	Interbedded	Mudstone		.45

ExtendedAttributes table example

Extended-Attribute_ID	OwnerTable	Owner ID	Property	Property Value	Value-Link	Qualifier	Notes	Data-SourceID
EA306096	Description OfMapUnits	DMU3	Permeability	Low		Typical	Rock is full of alteration clays	DS2140
EA308062	Description OfMapUnits	DMU3	Permeability	High		Rare		DS0001
EA338396	Description OfMapUnits	DMU27	MetamorphicGrade	Low		Uncommon		DS0364
EA306358	Description OfMapUnits	DMU27	MetamorphicGrade	Medium		Typical		DS2069
EA306066	Description OfMapUnits	DMU27	MetamorphicAge	Early Proterozoic		Probable		DS2106
EA306906	Description OfMapUnits	DMU27	MetamorphicAge	Middle Cretaceous		Possible		DS045
EA375796	Geologic-Events	Slip-Event1	Displacement	4 km				DS1045
EA352796	Geologic-Events	Slip-Event1	DisplacementType	Right- lateral strike slip				DS1130
EA306334	Geologic-Events	Slip-Event1	Successor		GE2466			DS1205
EA302476	Geologic-Events	GE2466	Displacement	200 km				DS1135
EA304996	Geologic-Events	GE2466	DisplacementType	Right- lateral strike slip				DS0980
EA306461	Contacts-AndFaults	COF22	HasPhotograph	Photo2008-11-12b				DS2640
EA306765	Contacts-AndFaults	COF22	ContactCharacter	Gradational				DS3656

Vocabulary

Table
Glossary

	Glossary_ID
	OBJECTID
	Term
	Definition
	DefinitionSourceID

Glossary: definitions of terms used in the database. Terms used in the database must be defined in this Glossary, unless those terms are from a published vocabulary referenced in the dataset metadata.

Fields that contain terms that require definition are shown *in this font, colored purple* in the diagrams, and include:

- Type term used to classify features
- all non-numeric ScientificConfidence values
- Property names,
- non-numeric PropertyValue terms,
- Qualifiers for ExtendedAttributes;
- Lithology in StandardLithology. Lithology terms used in StandardLithology must not be redefined from the NCGMP standard.
- ProportionTerm If there are no intellectual property restrictions, it is permissible to replicate all or part of an external glossary here. Be sure to provide appropriate credit via the DefinitionSourceID. Values of Term must be unique within the database because they are used in fields in other tables where they function as foreign keys to the Glossary table.

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

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

Scientific confidence terms

std	The attribute assignment is considered reliable with a standard level of confidence
low	The associated attribute assignment is uncertain.
unk	Unknown reliability, generally for use with legacy data.

Property Value qualifier vocabulary

Some example values that might be used to qualify property values in ExtendedAttributes.

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

Property vocabulary

The following table lists a variety of other properties that might be associated with a map unit through the ExtendedAttributes table. These have been extracted from the GeoSciML version 2 model, and from NGMDB vocabulary compilations. Vocabularies for populating these properties have been compiled but are not included with this package. The NGMDB vocabularies are available at http://ngmdb.usgs.gov/Info/standards/NGMDBvocabs/; please note – these are draft unpublished documents, offered to the community in order to provide terminology lists and definitions that may be found useful by projects and agencies, and to improve the vocabulary content.

Property	Scope notes
Bedding Pattern	Term(s) specifying patterns of bedding thickness or relationships between bedding packages, Examples: thinning upward, thickening upward
Bedding Style	Term(s) specifying the style of bedding in a stratified geologic unit, e.g. lenticular, irregular, planar, vague, massive
Bedding Thickness	Term(s) or numeric values characterizing the thickness of bedding in the unit.
Body Morphology	The geometry or form of a Geologic Unit. Examples include: dike (dyke), cone, fan, sheet, etc. Morphology is independent of the substance (Earth Material) that composes the Geologic Unit.
Clast weathering degree	The degree of weathering intensity of clasts in sedimentary surficial deposits. Classification is based on degree of weathering of clasts that were originally indurated material.
Clast weathering style	The weathering style of clasts on a surface. Examples: pitted, etched, weathering rinds.
Composition Category	Term to specify the gross chemical character of geologic unit. Examples: siliceate, carbonate, ferromagnesian, oxide. Chemical classification terms for igneous rocks also go here. Examples: alkalic, subaluminous, peraluminous, mafic, felsic, intermediate.
Contained Structure	Geologic structures that are present in a geologic unit.
Exposure Color	Typical color at the outcrop of a geologic unit.
Genetic Category	A term that represents a summary geologic history of a geologic unit. (ie, a genetic process classifier term) Examples include igneous, sedimentary, metamorphic, shock metamorphic, volcanic, pyroclastic.
Magnetic Susceptibility	Material magnetic susceptibility, customarily measured in SI units. The ratio of induced magnetization to the strength of the magnetic field causing the magnetization. Note that volume magnetic susceptibility is dimensionless, being magnetization (magnetic dipole moment) in amperes per meter (SI) divided by the applied field, also in amperes per meter. However, many tables of magnetic susceptibility and some instruments give cgs values that rely on different definitions of the permeability of free space than SI values. The cgs value of susceptibility is multiplied by 4pi to give the SI susceptibility value. For example, the cgs volume magnetic susceptibility of water at 20°C is -7.19x10-7 which is -9.04x10-6 in SI. The xml encoding should specify whether the uom is SI or cgs, and if in cgs provide a
Metamorphic Facies	A description of characteristic mineral assemblages indicative of certain metamorphic P-T conditions. Examples include Barrovian metasedimentary zones (e.g.: biotite facies, kyanite facies) or assemblages developed in rocks of more mafic composition (e.g.: greenschist facies, amphibolite facies).
Metamorphic Grade	A term to indicate the intensity or rank of metamorphism applied to an EarthMaterial (eg: high metamorphic grade, low metamorphic grade). Indicates in a general way the P-T environment in which the metamorphism took place. Determination of metamorphic grade is based on mineral assemblages (ie, facies) present in a rock that are interpreted
Outcrop Character	Describes the nature of outcrops formed by a geologic unit. Examples: boudlery, cliff-forming, ledge-forming, slope-forming, poorly exposed
Permeability	The measure of the capacity of a porous material to transmit a fluid under unequal pressure. Customary unit of measure: millidarcy
Porosity	The percentage of the bulk volume of a material that is occupied by interstices, whether isolated or connected.
Protolith	An interpretation of the EarthMaterial that constituted the pre-metamorphic lithology for this metamorphosed CompoundMaterial.
Stratigraphic Rank	Term that classifies the geologic unit in a generalization hierarchy from most local/smallest volume to most regional. Scoped name because classification is asserted, not based on observational data. Examples: group, subgroup, formation, member, bed, intrusion, complex, batholith
Soil Development	Characterization of soil in a surficial deposit.
Surface morphology	Characterization of the form of the surface developed on a unit.
Surface dissection	The degree to which the upper surface of unconsolidated sedimentary material has been degraded and incised by erosion after the unit has been abandoned by the geologic processes that formed it
Surface armoring	Characterization of the development of pavement or other surface armor on a surficial deposit.
Surface varnish	The degree of development of rock varnish on clasts on an outcrop surface.
Weathering Degree	term to specify degree of modification from original material, e.g. slightly weathered, strongly weathered, weathered rock grade III
Unit Thickness	Typical thickness of the geologic unit.
Weathering product	material result of weathering processes, e.g. saprolite, ferricrete, clay, calcrete. Materials observed in a soil profile could be identified using this property, but EarthMaterial content model does not allow representation of relationships between materials in a soil profile. A full soil profile description would have to use GeologicUnitParts and Composition part?
Weathering Environment	Terms to specify the environmental context of the weathering description. Typically would be specified by terms for climate (tropical, arid, temperate, humid, polar..)
Peak metamorphic temperature	A numerical value to indicate the estimated temperature at peak metamorphic conditions.
Peak metamorphic pressure	A numerical value to indicate the estimated pressure at peak metamorphic conditions.
Density	Material mass per unit volume
Weathering Process	Characteristic weathering process, e.g. leaching, accumulation

SMR 05/19/2009