

NGMDB-Lite – Database Design for the National Geologic Map Database's Data Portal

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Introduction

The National Geologic Map Database Project (NGMDB) has prototyped a Web-based Data Portal to evaluate a method for browsing geologic map data based on a standard collection of basic geoscience properties (<http://maps.ngmdb.us/dataviewer/>). This portal is a discovery application that allows users to view and query regional geologic data (1:100,000-scale or more generalized) through a single point of access using standard vocabularies and a uniform data schema. Data accessed through the portal is cross-referenced to more detailed content supplied by the data originators through their own delivery system (online or offline), and to the NGMDB's Geoscience Map Catalog (http://ngmdb.usgs.gov/ngmdb/ngm_catalog.ora.html) and the U.S. Geologic Names Lexicon (GEOLEX, <http://ngmdb.usgs.gov/Geolex/>).

One intention of the portal is to demonstrate the utility of presenting geologic map data using a uniform data schema and vocabulary in order to make data from different sources interoperable and more comprehensible to the user. Because of technological limitations, the current implementation is based on a data store that is simplified from previous NGMDB

prototype designs (for example, Richard and others, 2004; 2005) and centralized in the portal application in order to efficiently deliver information to users. The previous NGMDB designs were prototype implementations of the North American Data Model, and addressed the long-term goal of building an enterprise-level database. Because this current implementation is simpler and addresses a more limited objective, it is casually referred to as "NGMDB-Lite." We hope it will lead to similar implementations, as nodes in a more distributed system in which data providers expose geologic map data through standardized services like the Open Geospatial Consortium (OGC) Web Map Service (WMS) using a documented interoperability schema and vocabularies like the NGMDB-Lite database schema and vocabularies described here.

The focus of this paper is on documenting the content model developed for delivering data through the portal. The data schema for the portal is designed to be as simple as possible, while providing basic geologic information that will be useful to a broad spectrum of users. The schema includes specification of the geologic age, lithologic composition, genetic origin, stratigraphic correlation, and source citation information for each polygon in a geologic map dataset. Properties are specified in plain text using terms from

vocabularies developed upon the North American Geologic-Map Data Model Steering Committee Science Language Technical Team vocabularies (NADM-SLTT, 2004) and the IUGS Commission for the Management and Application of Geoscience Information's (CGI) Interoperability Working Group (see <https://www.seegrid.csiro.au/wiki/bin/view/CGIModel/ConceptDefinitionsTG>).

Portal Architecture

The NGMDB-Lite Data Schema

The Data Portal provides a simple flat (spreadsheet-like) data file that includes the mapped feature geometry along with basic geologic and other information that is most useful to users. The content model for this schema is based on that presented in Richard and Soller (2008b), and is based on informal surveys regarding the information content most commonly included in geologic map databases. Information in the data file is presented in a text format that is readily comprehensible. Use of standard syntax and controlled vocabularies for property attributes is intended to facilitate content searches. Because the data in the portal are managed using ESRI shapefiles, which include data in a dBase file, text was limited to 255 characters in any particular field.

Some terminology needs to be defined here, in order to minimize confusion. We use the terms 'geologic unit', 'map unit', and 'mapped feature' as follows. *Geologic units* represent particular (location situated) bodies of rock in the Earth (NADM-SC, 2004); they are the stratigraphic "building blocks" of the Earth. The names of geologic units in the United States are recorded in the U.S. Geologic Names Lexicon, or GEOLEX (<http://ngmdb.usgs.gov/Geolex/>). *Map units* are devised uniquely for each map product, to show the geology in a clear and concise fashion; map units may represent several geologic units (for example, several formations, undivided), or one or more material-type units for which a geologic unit name has not been assigned (for example, "till and stratified drift of the Erie and Miami Sublobes", "mafic volcanic rocks"). Material units are classifications of kinds of geologic material and do not represent particular (for example, location situated) bodies of rock. A *Mapped feature* is an individual line or polygon whose geometry and location has been determined by observation of the Earth in some area. The feature represents the outcrop of a rock body or geologic structure that has particular properties that are used to define and delineate the feature. This discussion is restricted to polygon features that represent the outcrop of a map unit. Each of these polygons represents a particular occurrence of the map unit. On a typical printed geologic map, all the polygons of a single unit share the same map unit description. In a geologic map database, polygons associated with the same map unit may have different descriptions, either provided by different sources, or perhaps

recording spatial variations in the character of the map unit. The properties associated with each polygon mapped feature are the map unit description for that polygon.

The NGMDB-Lite schema denormalizes several one-to-many relationships and chains together some important hierarchical relationships in order to deliver the desired information content in simple text strings in a standalone table. We thus define some delimiters for use in concatenating geologic content into data fields (for example, the lithology of each geologic unit that occurs in a map unit). This both assists visual interpretation of the strings by people and allows computer parsing of the strings to automate the extraction of particular values. The text delimiters are:

- Multiple values in a single field are separated by semicolons (;)
- If a value has multiple facets, each facet is separated by a colon (:)
- If a value is hierarchical, the most general term appears first, and parent-child links are separated by a slash (/)
- In the field definitions that follow, values in brackets ('[', ']') are optional. If the value is not included, but additional string contents are present following the position of the optional value, the necessary delimiters must still be included.

NGMDB-Lite Data Fields

MAP UNIT DESCRIPTION (Text, 255) – A free text description of the geologic unit that crops out in a particular mapped polygon. This may be verbatim from text on a published map unit description or may be compiled from publications referenced by the map.

MAP UNIT NAME (Text, 255) – Lexicon or informal name for unit that crops out in polygon mapped feature. For map units that represent geologic units included in GEOLEX, the "GenRemID" part of the Geolex URL is included with the unit name, in the format "Name[:GenRemID]" with colon delimiter. If the map unit specification for the polygon is an aggregation of more than one lexicon unit, the names of the component units are concatenated with semicolon delimiters, for example, name1:GenRemID1;name2:GenRemID2. The full geologic name will be included (for example, "Morrison Formation", not just "Morrison"). If the map unit is a geologic unit that is part of a higher rank unit, the hierarchy of units is reported with the most general unit first, with each unit separated by slashes (/). The GEOLEX database does not yet record hierarchical relationships of geologic units. Therefore, the database cannot be queried to directly determine the parent of a geologic unit (for example, a Formation is part of which Group?). As the result, when map data are imported into this field using these conventions, the user will need to consult GEOLEX in order to correlate the map units with geologic

unit names. Here are examples showing how various map unit names are parsed into this field:

- A. Map unit is a stratigraphic Group that includes several Formations that are not mapped separately – for example, “Group1, includes FormationA, FormationB, and FormationC undivided”. The name in NGMDB-Lite would include only the group name, “Group1:10394”.
- B. Map unit is a Formation that includes several Members that are not mapped separately – for example, “Redwall Limestone, undivided. Includes (in descending order) Horseshoe Mesa, Mooney Falls, Thunder Springs, and Whitmore Wash Members”. The composite entry for the map unit would aggregate the lithology constituents of the various parts, as “Redwall Limestone:10129”.
- C. Map unit consists of more than one related materials unit – “Till, includes basal and supraglacial undivided”. The name would be “Basal till;Supraglacial till”. In this example, there are no corresponding GEOLEX records.
- D. Map unit is a geologic unit that is part of a higher rank unit – for example, “Bright Angel Shale, of Tonto Group”. The name would be “Tonto Group/Bright Angel Shale:4814”. Here, only the GenRemID for the most specific unit is included. In this case, the parents are included with a slash delimiter.
- E. Map unit is a compound unit, where some of the constituent units have parent units and others do not – for example, “Columbia River Basalt Group/Grande Ronde Basalt:5441;Kittitas Drift:5793”.
- F. Map unit is a compound unit, consisting of geologic units that are not included in a higher rank unit – for example, “Everts Formation, Virgelle Sandstone, Telegraph Creek Formation, Cody Shale, Frontier Formation, and Mowry Shale, undivided”. The name would be “Everts Formation:8056;Virgelle Sandstone:11012;Telegraph Creek Formation:10805;Cody Shale:7568;Frontier Formation:8212;Mowry Shale:9436”.
- G. Map unit is a compound unit that includes some, but not all, parts of a higher rank unit. Here, the higher rank unit name is included with the part unit, other part units are listed subsequently, with the name prefixed with a ‘/’ to indicate it has the same parent units as the last entry – for example, for “Horseshoe Mesa and Mooney Falls members of Redwall Limestone”, the name would be “Redwall Limestone/Horseshoe Mesa Member:8547;/Mooney Falls Member:9367”.
- H. Map unit is an informal subdivision of a stratigraphic unit – for example, “Upper member of the Livingston Formation”. The name would be “Livingston Formation:9061/upper member”. The GenRemID for the most specific lexicon unit in the hierarchy is specified.

ROOT URL FOR GEOLEX (Text, 128) – The root URL for the GEOLEX record for a geologic unit (http://ngmdb.usgs.gov/Geolex/NewUnits/unit_). The GenRemID number and “.html” are appended to this root URL to obtain the URL to access the GEOLEX record for that unit. This design can be extended to use other HTTP URI (Uniform Resource Identifier) schemes that are constructed with a common root and a resource-instance specific suffix. Some modifications might be necessary if the URI scheme uses any of the special delimiters used in this NGMDB-Lite profile (‘/’, ‘:’, ‘;’, ‘,’).

LITHOLOGY COMPOSITION (Text, 255) – Composition of the mapped unit in terms of rock types from one of the NGMDB Data Portal lithology vocabularies, coupled with a proportion value for each constituent. Both lithology and proportion are controlled-term lists. Encoded as a set of {lithology:proportion} tuples. The format is “Lith1:prop1;Lith2:prop2”. The lithology vocabulary includes some hierarchy, and the lithology terms will encode the hierarchy from most general to most specific.

LITHOLOGY PROPERTIES (Text, 255) – Field containing the various properties that were used to describe the unit (for example, sorting, weathering, depth to rock, thickness, degree of interbedding and (or) heterogeneity, foliation, and so on). Properties are encoded as “Property:value:[qualifier]” tuples, separated by semicolons. Allowed properties are specified by controlled vocabularies. The optional qualifiers are terms such as ‘common’, ‘rare’, ‘average’, and will also be chosen from a controlled vocabulary (see table 1 for a draft list of properties).

Table 1. Geologic unit properties that may be associated with a geologic unit in the Lithology Properties fields using key-value pairs.

Bedding sequence pattern
Bedding style
Bedding thickness quantity
Bedding thickness term
Body morphology
Chemical character
Clast weathering style
Clast weathering degree
Color description
Contained geologic structures
Density
Depositional Environment
Event in history
Genetic environment
Genetic process
Geologic unit protolith
Metamorphic grade
not assigned
Outcrop character
Soil development
Surface armoring
Surface dissection
Surface morphology
Unit thickness
Varnish development
Weathering character
Depth to rock

GEOLOGIC AGE (Text, 255) – Text string for geologic age of event(s) in genesis of unit. Specified as “Age:Event[:Confidence]” tuples, with multiple values separated by semicolons. Ages are specified by terms from the USGS stratigraphic time scale (U.S. Geological Survey Geologic Names Committee, 2007). If a numeric age is known, it should be added after the corresponding stratigraphic age term in parenthesis. Numeric age values are in millions of years before 1950 (Ma). The confidence term is optional, defaulting to ‘std’, indicating that the age is considered reliable with a standard level of confidence. Other values allowed are ‘low’, used to indicate that the associated age assignment is uncertain, and ‘unk’ to indicate unknown reliability. Examples: “Jurassic:Deposition”, “Miocene(12.5):Eruption”, “Early Proterozoic(1750):Eruption; Middle Proterozoic(1420):Intrusion; Jurassic(165):Intrusion; Eocene:Metamorphism:Low; Miocene:Cooling”.

AGE ASSIGNMENT METADATA (Text, 255) – Syntax is “directOrIndirect; [Notes]”. The directOrIndirect value is either “direct” (that is, determined from within the study area) or “indirect” (that is, age determination extended by mapping into the study area). The ‘Notes’ text is for information that explains the basis for age assignments, for example, stratigraphic position, isotopic age date, fossil identification. This text should also identify any issues related to age assignments, and so on. For now, this field contains free text because the possible rationales for age assignment are too numerous and varied to presuppose a controlled vocabulary. Standard format citations to published information sources may be included in notes, for example, ‘Silver, 1966’.

GENETIC CATEGORY (Text, 255) – Terms to assign the unit to a genetic category that provides information on the geologic setting and processes related to the origin of the unit, for example lacustrine, mid-ocean ridge, plutonic, glacial. Terms from a controlled vocabulary should be used, for example, the CGI genetic category, Event Environment, and Event Process vocabularies (<https://www.seegrid.csiro.au/wiki/CGIModel/ConceptDefinitionsTG>). Concept hierarchy should be encoded from most general to most specific, separated by the delimiter ‘/’. Multiple values are separated by semicolons, for example “sedimentary/terrestrial;glacier related/glacial outwash plain”. The purpose of including the more general terms is to allow text searches on general terms to succeed when more specific terms are assigned in particular cases. To reduce the likelihood of exceeding the 255-character text string limit, general terms are not repeated on multiple values to which they might apply. For instance, in the example above, ‘glacier related’ is also a child concept of ‘sedimentary’, but the sedimentary parent concept is omitted because it is already specified. Examples: “igneous/extrusive/shield volcano; polar”, “igneous/intrusive/hypabyssal; oceanic/upper crust”, “sedimentary/shoreline/beach; clastic”, “sedimentary/marine/abyssal; basin plain; below carbonate compensation”, “composite/deformation dominated/cataclastic”, “composite/metamorphic/regional;

metasedimentary; crustal/continental crust/middle”, “composite/weathering; humid tropical”.

UNIT THICKNESS (Text, 255) – Unit thickness or depth to rock is encoded in a text string to allow representation of typical, minimum, and maximum values. The syntax is “typicalValue;Unit of Measure;[minimumValue];[maximumValue];[Notes];[Scope]”. All values are decimal numbers. Unit of Measure is either ‘ft’ or ‘m’ for feet or meters. The optional minimumValue and maximumValue may be included if known. The optional ‘Notes’ is for additional text and ideally would include information on how the thickness measure was obtained. The optional Scope field indicates the extent to which the thickness assignment applies. Since these attributes are applied at the feature (usually polygon) level, the thickness assignment might be based on data from the particular polygon or could be the reported regional thickness for the unit. Scope is thus either ‘here’ or ‘regional’. Default is ‘regional’ if no value is included. In order for the string to be parseable by computer program, all optional fields must be present up to the last one for which a value is to be specified. For example, if ‘Scope’ needs to be specified explicitly, then the ‘minimumValue’, ‘maximumValue’, and ‘Notes’ must be included as well. The fields for which there is no value may be left empty. Examples: “100; ft”, “50; m; 20; 75”, “50; m; ; ; here”, “230; ft; ; ;average of 6 boreholes in this area; here”, “540; ft; 300; 720; 6 measured sections in Tuscorora Mountains (Hewett, 1954)”.

FEATURE-LEVEL METADATA (Text, 255) – If any of the values specified in fields (including the mapped geometry) for this record have sources not specified by the dataset level metadata, this should be indicated in this field. This is particularly useful for maps compiled from various sources.

Vocabularies

As discussed in Richard and Soller (2008a), semantic interoperability is most easily achieved by the use of the same vocabularies to populate interchange format documents. For the portal implementation, the NGMDB Project developed vocabularies for specifying the genesis of geologic units and for specifying the lithologic constituents in a geologic unit. These were based on work done by the NADM Science Language Technical Teams (NADM-SLTT, 2004). Geologic age specifications in the NGMDB Portal use the USGS 2007 time scale definitions of geologic eras (U.S. Geological Survey Geologic Names Committee, 2007). With the exception of the map-unit-based lithology vocabulary shown in the Portal (Soller, 2008), these vocabularies were never formally published. However, they served as input for an international effort under the auspices of the IUGS Commission for the Management of Geoscience Information (CGI) to develop a collection of vocabularies designed for populating properties

in GeoSciML documents (GeoSciML, <http://www.geosciml.org/>, is an emerging standard Geographic Markup Language for the Geosciences). Moving forward, we recommend usage of the CGI vocabularies (<https://www.seegrid.csiro.au/wiki/bin/view/CGIModel/ConceptDefinitionsTG>).

Physical Implementation

A client Web map viewing application (accessed at <http://maps.ngmdb.us/dataviewer/>), referred to as the NGMDB Data Portal, has been implemented and deployed using Javascript in HTML, using OpenLayers and the MapFu framework (<http://www.arc.pdx.edu/arcprojects/completed/17>). The application allows the user to pan and zoom the geologic map, select layers to view, and click on polygons to obtain an on-screen window containing the geologic unit description. The application automatically configures the legend to include units visible in the current view frame. Three different map portrayals were designed – symbolizing the map units by age,

genesis, and geologic materials. At present, only the geologic materials are shown, according to the vocabulary described in Soller (2008). The portal site is currently hosted at Portland State University.

To improve performance, data for the NGMDB Data Portal are cached on the project Web server that hosts the application (fig. 1). Geologic unit descriptions are stored in a Postgres database. Spatial data for polygons are stored in shapefiles, with a foreign key to the geologic unit descriptions in the Postgres (<http://www.postgresql.org/>) database. MapServer (<http://mapserver.org/>) is used as the Web map serving application.

Cross reference between portal data and the NGMDB Geoscience Map Catalog and GEOLEX databases required additional steps in the work flow for loading data into the portal database. All geologic units were linked to their appropriate record(s) in GEOLEX. The portal application parses the geologic unit name field to extract the GEOLEX ‘GenRemID’, which is the primary key for the unit in GEOLEX, and uses that to construct the URL that will retrieve the GEOLEX page for that unit.

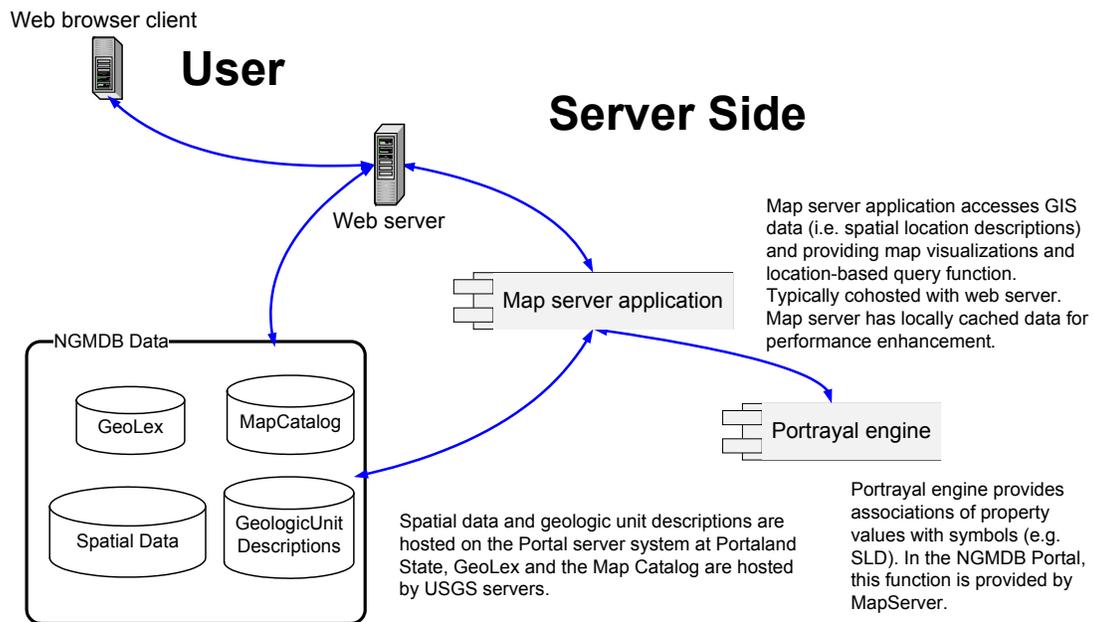


Figure 1. Diagram of basic system architecture. The portal client application runs in a Web browser on the client machine, accessing a Web server using standard HTTP protocol. The Web server sends map display requests to the Mapserver application, which retrieves the geometries for the spatial objects to display, assigns symbols (for example, colors for geologic map units), and generates a georeferenced image from the spatial data using the Portrayal engine. Requests for thematic data display are passed by MapServer to the portal database.

Loading Data for the Portal

The NGMDB project created an Import Tool to assist in the mapping of fields and vocabularies found in the various input shapefiles into the fields and controlled vocabularies used for the portal. This tool outputs shapefiles and tables for loading directly into the portal server. The Import Tool is a stand-alone Windows Desktop program.

Figure 2 provides an overview of the schema and vocabulary mapping process implemented by the NGMDB Import Tool for geologic unit polygons. Two workflows are shown. In the first (left side, fig. 2), the starting dataset is not normalized, consisting of polygons that each have a collection

of geologic attributes such as age and lithology, which may vary from polygon to polygon and may not be in one-to-one correlation with the assigned map units from the source map. The second workflow (right side, fig. 2) is for a normalized database, in which each map unit is associated with exactly one description, typically in free text, analogous to what is typically presented on a printed geologic map.

Both workflows start with the user creating an 'Import Project' to serve as the workspace for processing a shapefile. Metadata for the imported shapefile can be established at this point, including a URL location that locates the source data, citations for published sources, and a text description of the source map.

Data import workflow

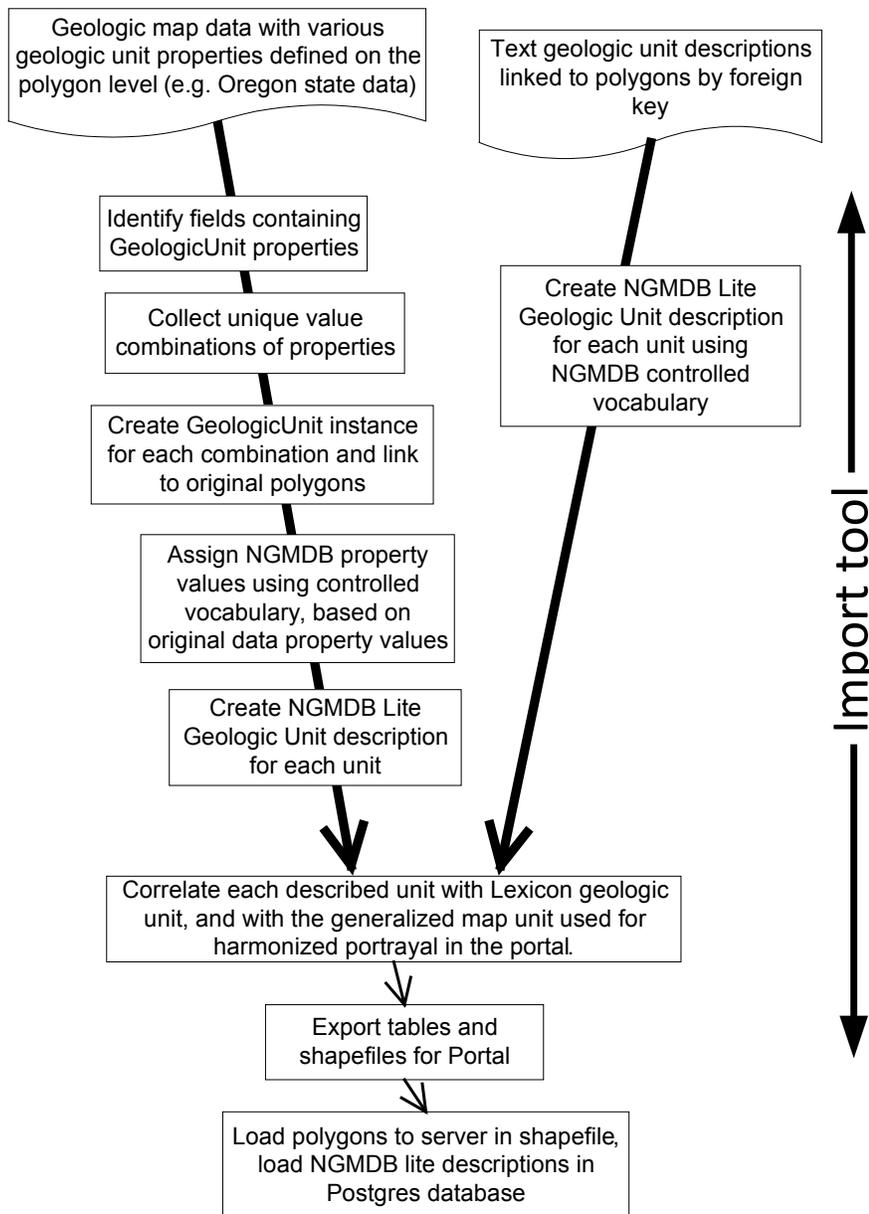


Figure 2. Two workflows, to process geologic information on maps or in databases that occurs in various formats with nonstandardized vocabulary, in order to produce standardized data in NGMDB-Lite. The workflow for nonnormalized data is shown in the left branch of this figure, and the workflow for normalized data is shown to the right.

The user selects an ESRI shapefile to import into the workspace, and is prompted to select the fields from the source data that will be imported. The Map Unit Description field text in the portal output dataset may have its content populated by concatenating the content of one or more of the input fields or, if present and sufficient, the source map's descriptions are used. Next, the user is prompted to select from the imported fields those that will be used to define the geologic units (these are the units that are associated with unique descriptions in the original data). In the nonnormalized case (left branch in figure 2), this will be some combination of the fields that are present in the shapefile, and unique combinations of content in those fields will be used to define the geologic description units. In the normalized case, this will be one field containing a unit label or other unique identifier associated with each map unit. Likewise, unique values from combinations of one or more input fields may be mapped to controlled vocabulary terms for age, thickness, lithology, or other properties to be output in the NGMDB-Lite table for the portal.

When the combinations of input fields that will be mapped to output descriptions and description properties

have been defined, the tool user is ready to map unique combinations of input field values to corresponding terms from NGMDB controlled vocabularies. The tool presents a display of the unique combinations extracted on the left side (fig. 3). The center part of the window presents controls for searching the associated controlled vocabulary for the appropriate matching term (technically the term representing the most specific subsuming concept available in the controlled vocabulary), along with appropriate qualifiers (proportion for lithology). The selected matching term and qualifier is shown on the right side. Clicking the 'Done - Post Mapped Values' button on any of the 'Populate Attribute' forms adds the term or terms from the right side of the display to the underlying geologic unit description property for map units that include the corresponding distinct value (or combination of values) in the original shape file. For each property that can be attributed in the Import Tool, there is a pair of 'select distinct' and 'populate attribute' forms provided by the tool. These must be completed for all information available in the input data that is to be presented through the portal NGMDB-Lite format.

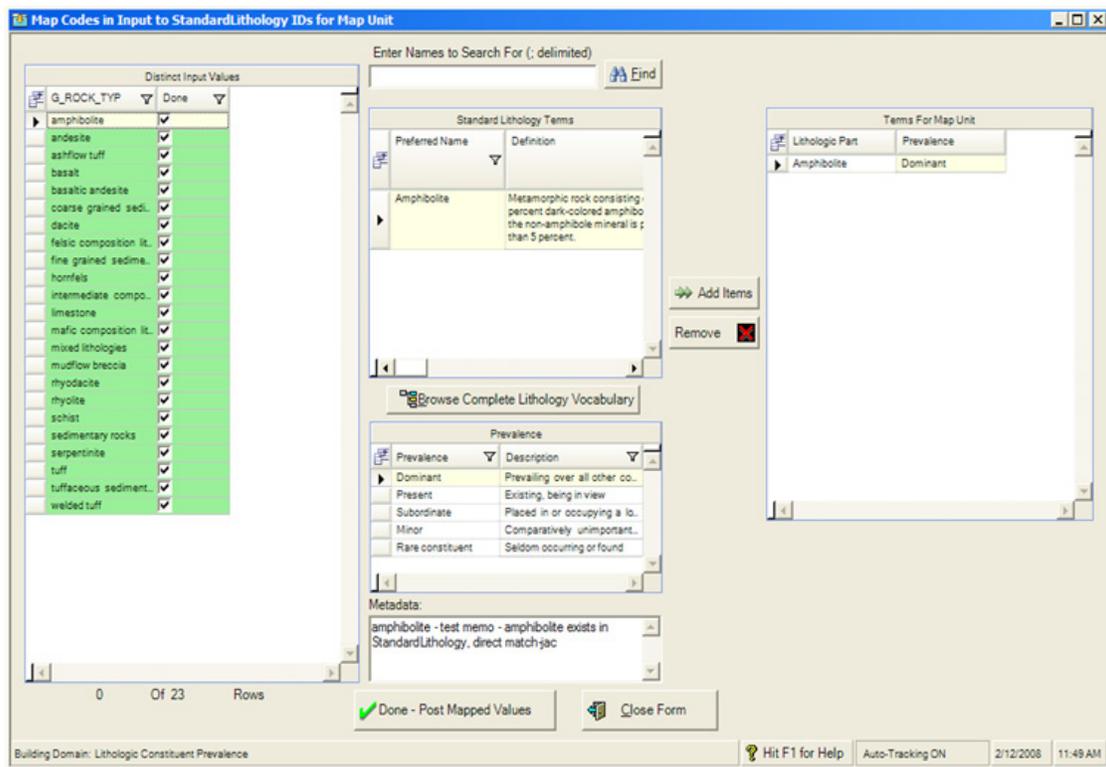


Figure 3. Screen shot of NGMDB data entry tool window, opened to the form used for mapping from a unique value or combination of values in the source data into the lithology category scheme for the NGMDB Data Portal. In this example, the source is derived from only one field in the source dataset. The center part of the form provides for searching the controlled vocabulary, or opening a separate window to browse the tree hierarchy for the vocabulary. The lower part of the center panel allows selection of a proportion term to specify the abundance of the lithology type in the geologic unit, again based on a controlled vocabulary. Source notes on the lithology or proportion assignment can be recorded in the bottom text box of the center panel. The right panel shows the selected controlled-vocabulary terms.

The next step before exporting data for loading on the portal server was to map the defined geologic units into the map units for display. The portal was designed to offer 'Geologic Materials', 'Genesis', and 'Geologic Age' views, although only Geologic Materials is currently provided. The Geologic Materials view is based on a generalized lithogenetic unit map legend (see Soller, 2008). The Genesis legend symbolized map units based on the geologic processes that formed the unit (igneous, sedimentary, volcanic...). The Geologic Age view symbolized based on the geologic age during which the unit originated. All of these symbolization schemes are determined by the properties of the unit, but in the course of finalizing the data for the portal, we discovered that in many cases, there is not a unique mapping between the properties of the unit and the symbol scheme. Lithologically heterogeneous, or genetically complex units, may have characteristics of more than one of the Geologic Materials categories. For example, complex igneous and metamorphic units can have genetic histories that include a variety of genetic processes occurring during different geologic time intervals. Final decisions on the symbolization required adding explicit symbol fields for each of the schemes to the polygon feature class. A new window added to the Import Tool used the same pattern used in the 'Populate Attribute' window to match each map unit with a legend item.

The final step performed by the Import Tool was to export the data and values tagged in the Tool. An ESRI shapefile was exported that includes a geologic unit identifier field that links to the NGMDB-Lite description for rocks cropping out in that polygon, a text label field used by the Web map server to place labels on the map images, symbol fields for each of the three portrayal views (Geologic Materials, Genesis, and Geologic Age), and a source identifier field that links the polygon to metadata describing the original source map. A separate NGMDB-Lite table, using the schema outlined above, was exported as a .dbf file for loading into Postgres.

Future Development

The portal was developed to demonstrate the utility of data integration on the server side using a single schema and specific vocabularies for key properties (genesis, lithology). In the long run, we envision the NGMDB Data Portal functioning as one of perhaps many aggregating portals that would provide content supplied by the various State geologic surveys and other data providers through standard Open Geospatial Consortium Web Mapping and Web Feature Services (WMS and WFS). Participation in development of international standards for data interchange format (GeoSciML) and vocabularies through the IUGS Commission for the Management and Application of Geoscience Information (CGI) Interoperability Working Group (http://www.cgi-iugs.org/tech_collaboration/

<http://www.onegeology.org/>) is laying the foundation for definition and implementation of such services. The OneGeology project (<http://www.onegeology.org/>) has been spearheading a similar effort on an international scale.

The NGMDB Data Portal Web application offers some additional utility by parsing the input data content to provide direct user access to GEOLEX records for named geologic units represented by map units in the map view, definitions for vocabulary terms used in the unit descriptions, and linkage to the NGMDB Map Catalog records for maps with extents that intersect the viewer's current window extent. The Data Portal application interface could be adopted to operate with data services provided through OGC WMS and WFS services as a basic data browsing and discovery tool. This application could provide a web-browser based gateway for searching the NGMDB Map Catalog, and for previewing data discovered through the Catalog.

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